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AN EVALUATION OF STANDARD 214

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16. Abstract

Federal Motor Vehicle Safety Standard 214 sets crush resistance requirements for the side doors of passenger cars. Its goals are to reduce the frequency and depth of intrusion in side impact crashes, thereby reducing the number of deaths and the severity of injuries. The objectives of this preliminary evaluation are to determine the effectiveness of Standard 214 in preventing intrusion and occupant casualties in side impacts, to measure the actual cost of the Standard and to assess its cost-effectiveness. The evaluation is based on statistical analyses of National Crash Severity Study accident data and teardown analyses for cost estimation. It was found that Standard 214

- o prevents a substantial proportion of the deaths and severe injuries in single vehicle sidedoor impact crashes.
- o reduces the likelihood of intrusion in nonlateral sidedoor impact crashes.
- o is significantly less effective in multivehicle than in single vehicle crashes.
- o adds $56 to the cost of purchasing and operating a car over its lifetime.

The principal conclusions of this preliminary evaluation are that

- o the performance requirements of the Standard are accomplishing their goal of reducing intrusion, in nonlateral crashes.
- o the Standard is cost-effective because it prevents many deaths and injuries in single vehicle sidedoor impact crashes.

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U.S. DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION
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THE ADMINISTRATOR

PREFACE

Since the dawn of motorized transportation and man's inventive spirit that spawned the automobile, engineers and researchers have wrestled with the problem of protecting vehicle occupants in side impact crashes. So far, their efforts, for the most part, have yielded limited benefits. Car builders and safety experts alike acknowledge that side impact crashes are a major cause of fatalities and injuries in passenger cars.

Despite technological advancements achieved over the last two decades, progress toward reaching effective solutions has been painstakingly slow. Even today, approximately 30 percent of all passenger car occupant fatalities and serious injuries still occur in side impacts. Accident investigation data tell us that the primary cause of death and injury in the side impact crash involves intrusion into the occupant compartment and ejection from the vehicle. Statistics show that ejection increases the chances of a person being killed or seriously injured by 40-fold.

Years of hard work by the auto industry, researchers, suppliers and the National Highway Traffic Safety Administration have resulted in giant strides toward resolving the serious problem of frontal crashes with the introduction of air bags and automatic belts beginning with 1982 model cars. One of the highest priorities of the Agency, therefore, is to concentrate on providing better protection for occupants in side impact collisions, and the problem of ejection.

The first real breakthrough in devising improved protection for vehicle occupants in this type of accident came in the 1956 model year with the voluntary adoption by the automobile industry of interlocking door latches, an engineering advance pioneered by American carmakers. Although this improvement reduced side impact deaths to some degree, it did not, by any means, eliminate the problem. Indeed, our recent findings from the National Crash Severity Study demonstrate the seriousness of occupant ejection, which often occurs in side impact crashes.

The NCSS file, a collection of data from detailed investigations of vehicle-disabling accidents, also shows that more than 90 percent of the fatalities and serious injuries in side crashes occur where the vehicle damage is caused by intrusion into the occupant compartment.

A major advance in the search for remedies to reduce intrusion or penetration into the impacted vehicle were side door beams developed at General Motors and incorporated in all full-sized GM cars in the 1969 model year. Placed in the outer door panels, the side door beam strengthened the door structure considerably and provided increased crush resistance against a penetrating vehicle or object. Carl Hedeen and David D. Campbell, working at the GM's Fisher Body Division, managed the program that led to the design of this safety innovation. These engineers must have a unique pride in their craftsmanship which produced a vehicle system that has saved thousands of lives.

GM's design subsequently was adopted industrywide in 1973 to meet the performance levels required under Federal Motor Vehicle Safety Standard 214, Side Door Strength.

This report shows that this standard has helped considerably in reducing the likelihood of intrusion in side door impact crashes, and that when all cars on the road are in compliance, an estimated 2,800 deaths will be averted annually. The report, however, also shows that the standard does not solve the problem of side impact crashes involving two vehicles. These findings are critical to the actions now underway to upgrade the standard under our five-year rulemaking plan.

The Agency has been pursuing various alternative solutions to this problem. Our research activities and the Research Safety Vehicle program, as well as new developments by manufacturers, show promising new designs that could meet the requirements of an upgraded side impact protection standard. Volvo, for example, is developing an advanced system that incorporates the vehicle seats as an essential component. General Motors' past accomplishments in this field portend the capability for fresh accomplishments. Perhaps Alfred North Whitehead put it with characteristic wisdom when he said: "Duty arises from the power to alter the course of events."

Another illustration of innovative engineering can be seen in the unique design of the RSV developed for us by Minicars. This vehicle is designed to provide occupant protection when it is struck in the side by another car at a relative speed of up to 50 miles per hour. This protection is provided by two basic components. First, the design of the side structure, with its foam-filled door and high door sill, transmits crash forces to the entire RSV structure, thereby reducing intrusion into the occupant compartment. Second, the interior of the door is equipped with contoured padding which provides a cushion for the occupant's head, chest, and pelvis during impact.

This study reports on our evaluation of the performance of vehicles that meet the existing standard in reducing occupant fatalities and injuries in side impacts. Its principal findings show that the standard is cost-effective and helps prevent deaths and injuries, particularly in single-vehicle accidents.

We welcome public review and comments on this evaluation.

Joan Claybrook

Administrator

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ACKNOWLEDGEMENTS

I would like to acknowledge the National Center for Statistics and Analysis for their persistent effort in assuring that the National Crash Severity Study satisfies the specific data needs of the Office of Program Evaluation. We look forward to continuing this relationship with the National Center, as they implement the National Accident Sampling System, because accurate, representative and timely accident data are essential to our evaluation activity.

Sue Partyka and Jim Hedlund of the National Center provided detailed suggestions for analyses. David Gitterman instructed me in the use of data files and analysis software.

Maryanne Fletcher and Robert Lemmer, my colleagues in the Office of Program Evaluation, made substantial contributions to the study.

EXECUTIVE SUMMARY

Side impact crashes caused the deaths of more than 9000 passenger car occupants in 1970. Occupants were often crushed, trapped or lacerated by deformed side structures intruding into the passenger compartment.

The National Highway Traffic Safety Administration responded in 1970 by proposing Federal Motor Vehicle Safety Standard 214, a static crush resistance requirement for side doors of passenger cars, in the hope that the frequency and depth of intrusion, and resultant deaths and injuries, would be reduced. The Standard became effective on January 1, 1973.

Executive Order 12044 (March 1978) called for a review and evaluation of existing major regulations. This study is an evaluation of Standard 214, based on the actual operating experience of passenger cars that meet the requirements of the Standard. The evaluation objectives were

(1) To determine if Standard 214 is performing as intended - reducing intrusion in side impacts.

(2) Measuring the actual cost of the Standard.

(3) Calculating the benefits of the Standard - life savings and injury severity reduction.

(4) Assessing the cost-effectiveness of Standard 214, in order to determine whether the Standard meets the need for motor vehicle safety without inflationary impact.

Statistical analyses of National Crash Severity Study (NCSS) data - 5557 accident cases were on file as of October 1978 - were performed to determine the number of deaths and injuries that occur in sidedoor impact crashes, the Standard's effectiveness in reducing fatalities, injury severity, and the likelihood of intrusion. Fatal Accident Reporting System (FARS) data were also analyzed as a backup for the NCSS results on fatality reduction. The cost of Standard 214 was calculated on the basis of detailed teardown analyses of post-Standard and pre-Standard vehicles.
Cost-effectiveness was assessed with the use of two alternative statistical approaches.

This preliminary report is based on accident and cost data that were available through October 1978. The NCSS data were sufficient, in terms of sample size and information quality, for statistically significant results on many of the analyses. They were adequate to support a preliminary and tentative conclusion that the standard is effective and noninflationary. The FARS data also support this conclusion. But the results are not, at this point, sufficiently precise or consistent that this evaluation can be considered definitive or final. Follow-up reports are needed and are, in fact, planned annually for the next two years. (The accident data file will be nearly three times its current size two years from now; the cost data base will also be refined.)

A few words of caution are in order before the presentation of the principal findings and conclusions. First, the specific point estimates of effectiveness may change considerably in follow-up reports - but the underlying trends and conclusions are likely to stay the same. Secondly, more prominence is given in this report to statistically significant findings than to nonsignificant ones, in accordance with the accepted procedure of statistical report writing. Since, specifically, nearly all of the significant findings were of a positive nature, the report may create the unintended impression that the positive was emphasized at the expense of the negative. In fact, the strongly positive results on some analyses must be tempered by the lack of a significant finding on some important analyses. At the same time, however, the nonsignificant results in this report must not be interpreted to mean that the standard is not effective in those crash modes. The accident data sample size is currently too small to give any meaningful indication of the Standard's true effectiveness in multivehicle and lateral sidedoor impact crashes.

Third, this evaluation suffers from the inherent shortcoming of a "before-after" design - i.e., the post-Standard cars are generally newer than the pre-Standard cars. A considerable effort was made to search for and remove any difference in the injury rates of the pre- and post-Standard cars that is not due to the standard itself. Nevertheless, it is possible that an effect has been overlooked and erroneously attributed to the standard.

Fourth, the accident data base currently contains information only on whether there was some intrusion versus no intrusion. Detailed measurement of the depth of intrusion will not be available until the follow-up reports. Until the depth measurements become available, any discussion of how effectively the standard reduces intrusion must be viewed with caution. Any attempt to compare intrusion reduction and casualty reduction by crash mode or to explain why the standard is more effective in certain crash modes must await the follow-up reports.

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

Principal findings

The Problem

- Sidedoor impacts - crashes in which a car suffered damage in the door area and where an occupant was seated adjacent to the struck door - accounted for an estimated 26 percent of all passenger car occupant fatalities and 19 percent of all severe or life-threatening injuries prior to the promulgation of Standard 214.
- Single vehicle sidedoor impact crashes alone accounted for an estimated 14 percent of all passenger car fatalities, and 7 percent of severe and life-threatening injuries.

Casualty Reduction in Single Vehicle Crashes

- Standard 214 provides significant occupant protection in single vehicle sidedoor impact crashes - eliminating an estimated 74 percent of the fatalities and 66 percent of the severe or life-threatening injuries. These are point estimates based on the National Crash Severity Study (NCSS) data. The Fatal Accident Reporting System (FARS) data corroborate that Standard 214 is highly effective in these crashes, but suggest a somewhat lower point estimate of effectiveness - in the range of 35 to 60 percent.

- When all cars on the road will be in compliance (by the mid 1980's), Standard 214 will be preventing nearly 2800 deaths, 4000 severe or life-threatening injuries and 3000 moderate injuries per year in single vehicle sidedoor impact crashes. These estimates are derived directly from the NCSS sample and may change in follow-up reports.

Casualty Reduction in Multivehicle Crashes

- The NCSS sample of accidents investigated was not large enough to establish whether or not Standard 214 reduces casualties at all in multivehicle sidedoor impact crashes. The observed effectiveness, which was slightly less than zero, was statistically compatible with a wide range of positive and negative values. But the sample was large enough to establish that the Standard is less effective in multivehicle crashes than in single vehicle crashes. The FARS data suggest that Standard 214 may have a modest positive effect (e.g., 10 to 15 percent) in multivehicle crashes.

Overall Casualty Reduction (Single plus Multivehicle)

- In all types of sidedoor impacts (single vehicle plus multivehicle), Standard 214 was observed to reduce fatalities by 31 percent and severe or life-threatening injuries by 17 percent. The observed reductions, however, are based on too small an accident sample to be statistically significant.

Intrusion Reduction

- Standard 214 reduced the likelihood of occupant compartment intrusion by 25 percent in multivehicle sidedoor impacts with primarily nonlateral force. The reduction is statistically significant.
- Standard 214 reduced the likelihood of intrusion by just 3 percent in multivehicle sidedoor impacts with primarily lateral force. The reduction is not statistically significant.
- The sample size of the accident data was not large enough to determine whether the Standard reduces intrusion in single vehicle sidedoor impacts or to compare the intrusion reduction in single and multi-vehicle crashes.

Cost of Standard 214

- Standard 214 increased the cost of owning and operating an automobile for two reasons: equipment installed to comply with the Standard increased the purchase price of cars; the equipment added to the weight of the car and increased its fuel consumption.
- An average of $30 (in 1977 dollars) was added to the price the consumer paid for 1973 model cars as a result of the Standard.
- An average of 36.1 pounds was added to the weight of the 1973 model cars, thereby requiring an incremental expenditure of $26 for fuel over the life of the cars.
- The total lifetime consumer cost averaged $56 (in 1977 dollars) per car, for 1973 model cars.
- The cost of Standard 214, in real dollars, may have decreased by as much as 25 percent since model year 1973, as a result of downsizing and more efficient design.

Cost Effectiveness

- Standard 214 costs about $198,000 (in 1977 dollars) for every Equivalent Fatality Unit that it eliminates. One Equivalent Fatality Unit corresponds to one life saved or a number of injuries prevented -- the number depending on the severity of the injuries.

Casualty Reduction Classified by Direction of Crash Force

- The Standard is significantly more effective in preventing deaths and non-minor injuries in sidedoor impacts with primarily frontal, rear or non-horizontal direction of force than in sidedoor impacts with a primarily lateral direction of force. This trend is consistent with the findings on intrusion reduction.

Conclusions

- Standard 214 appears to provide cost-effective occupant protection because it greatly reduces the likelihood of death or severe injury in single vehicle sidedoor impact crashes. The Standard meets the need for motor vehicle safety without inflationary impact.

- The significant intrusion and casualty reduction in nonlateral sidedoor impact crashes shows that the performance requirements of Standard 214 are accomplishing their purpose in these crashes.

- "Sidedoor impacts" are usually envisioned as vehicle-to-vehicle collisions, primarily with lateral forces acting on the struck vehicle. In fact, many deaths and severe injuries occurred in single vehicle crashes and/or primarily involved nonlateral forces.

- The Standard is most effective in preventing deaths and injuries in single vehicle crashes, and in crashes with a primarily nonlateral direction of force. The most plausible speculation is that these crashes involve contact with stronger structural members (sills and pillars) as well as the door. The improved door structure in the post-Standard cars acts in tandem with the sills or pillars, possibly enabling the vehicle to "slide by" impacting objects, preventing more serious structural engagement and smoothing out the peak forces on the vehicle. Also, in the nonlateral crashes, the lateral force component (against which the beam offers least resistance) is relatively small.

- The significantly lower effectiveness of Standard 214 in primarily lateral vehicle-to-vehicle sidedoor impacts suggests that there remains considerable potential for improving occupant protection in these crashes.

CHAPTER I

INTRODUCTION

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

The National Traffic and Motor Vehicle Safety Act of 1966 [23], 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 specifications mean that

(1) The standards must incorporate performance tests that can be objectively carried out under controlled conditions. The test conditions are relevant to some aspect of actual highway performance.

(2) There is a specific motor vehicle safety problem to which the standard addresses itself.

(3) The vehicle modifications required for compliance with the standard must be within the financial capability of manufacturers.

In 1975, the NHTSA Administrator directed the Office of Program Evaluation to evaluate existing Motor Vehicle Safety Standards [19]. The specific objectives of each evaluation were:

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

(2) To determine benefits and costs and to evaluate cost-effectiveness.

Executive Order 12044, dated March 23, 1978 and titled "Improving Government Regulations," called for a Government-wide review of existing regulations. If the review shows that a regulation fails to achieve its intended purposes, or imposes unreasonable burdens on these directly or indirectly affected or has an inflationary impact, it should be amended or revoked. The Secretary of Transportation responded to Executive Order 12044 by issuing, on May 22, 1978, a Department Regulations Review List that reaffirms the schedule and specific evaluation objectives of the 1975 evaluation plan.

Standard 214 - Side Door Strength - was given high priority because it adds more than most other Standards to the cost and weight of passenger cars. The Standard requires a static strength test for sidedoors of passenger cars. The objective is to reduce intrusion in sidedoor impacts and, thereby, to prevent deaths and reduce injury severity. Side impact fatalities are exceeded only by those in frontal crashes and pedestrian impacts.

This preliminary report is based on accident and cost data that were available through October 1978. The data were sufficient, in terms of sample size and information quality, for statistically significant results on many of the analyses. They were adequate to support a preliminary and tentative conclusion that the standard is effective and noninflationary. But the results are not, at this point, sufficiently precise or consistent that this evaluation can be considered definitive or final. Follow-up reports are needed and are, in fact, planned annually for the next two years. (The accident data file will be nearly three times its current size two years from now; the cost data base will also be refined.)

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Third, this evaluation suffers from the inherent shortcoming of a "before-after" design - i.e. the post-Standard cars are generally newer than the pre-Standard cars. Every effort has been made, within the available time constraints, to search for and remove any difference in the injury rates of the pre- and post-Standard cars that is not due to the Standard itself. Nevertheless, it is possible that an effect has been overlooked and erroneously attributed to the standard.

Fourth, the accident data base currently contains information only on whether there was some intrusion versus no intrusion. Detailed measurement of the depth of intrusion will not be available until the follow-up reports. Until the depth measurements become available, any discussion of how effectively the standard reduces intrusion must be viewed with caution. Any attempt to compare intrusion reduction and casualty reduction by crash mode or to explain why the standard is more effective in certain crash modes await the follow-up reports.

The remainder of the report is organized as follows: Chapter II summarizes the findings and conclusions. Chapter III consists of a review of Standard 214 and an assessment of the problem - deaths and injuries in sidedoor impacts. Costs of Standard 214 are analyzed in Chapter IV; benefits and cost-effectiveness are evaluated in Chapters V and VI. Appendices A to F contain auxiliary material in support of the analyses of Chapters III-VI. The preliminary analyses of Fatal Accident Reporting System data, which serve as a backup for the main analyses of this report, may be found in Appendix G. Appendix H briefly examines the broader question of long-term trends in side impact casualty risk.

CHAPTER II

FINDINGS AND CONCLUSIONS

The results from the evaluation of Standard 214 - Side Door Strength - are presented in this Chapter. The findings are based on an analysis of 5557 National Crash Severity Study (NCSS) accident cases and a component cost analysis of a representative sample of vehicles. Fatal Accident Reporting System (FARS) data were analyzed as a backup for the NCSS results. The FARS results are discussed in a separate section near the end of this chapter.

Principal Findings

The Problem

- Sidedoor impacts - crashes in which a car suffered damage in the door area and where an occupant was seated adjacent to the struck door - accounted for an estimated 26 percent of all passenger car occupant fatalities and 19 percent of all severe or life-threatening injuries prior to the promulgation of Standard 214

- Single vehicle sidedoor impact crashes alone accounted for an estimated 14 percent of all passenger car fatalities, and 7 percent of severe and life-threatening injuries.

Casualty Reduction in Single Vehicle Crashes

- Standard 214 provides significant occupant protection in single vehicle sidedoor impact crashes - eliminating an estimated 74 percent of the fatalities and 66 percent of the severe or life-threatening injuries. These are point estimates based on the National Crash Severity Study (NCSS) data. The Fatal Accident Reporting System (FARS) data corroborate that Standard 214 is highly effective in these crashes, but suggest a somewhat lower point estimate of effectiveness - in the range of 35 to 60 percent.
- When all cars on the road will be in compliance (by the mid 1980's) Standard 214 will be preventing nearly 2800 deaths, 4000 severe or life-threatening injuries and 3000 moderate injuries per year in single vehicle sidedoor impact crashes. These estimates are derived directly from the NCSS data and may change in follow-up reports.

Casualty Reduction in Multivehicle Crashes

- The NCSS sample of accidents investigated was not large enough to establish whether or not Standard 214 reduces casualties at all in multivehicle sidedoor impact crashes. The observed effectiveness, which was slightly less than zero, was statistically compatible with a wide range of positive and negative values. But the sample was large enough to establish that the Standard is less effective in multivehicle crashes than in single vehicle crashes. The FARS data suggest that Standard 214 may have a modest positive effect (e.g., 10 to 15 percent) in multivehicle crashes.

Overall Casualty Reduction (Single plus Multivehicle)

- In all types of sidedoor impacts (single vehicle plus multivehicle), Standard 214 was observed to reduce fatalities by 31 percent and severe or life-threatening injuries by 17 percent. The observed reductions, however, are based on too small an accident sample to be statistically significant.

Intrusion Reduction

- Standard 214 reduced the likelihood of occupant compartment intrusion by 25 percent in multivehicle sidedoor impacts with primarily nonlateral force. The reduction is statistically significant.
- Standard 214 reduced the likelihood of intrusion by just 3 percent in multivehicle sidedoor impacts with primarily lateral force. The reduction is not statistically significant.
- The sample size of the accident data was not large enough to determine whether the Standard reduces intrusion in single vehicle sidedoor impacts or to compare the intrusion reduction in single and multivehicle crashes.

Cost of Standard 214

- Standard 214 increased the cost of owning and operating an automobile for two reasons: equipment installed to comply with the standard increased the purchase price of cars; the equipment added to the weight of the car and increased its fuel consumption.
- An average of $30 (in 1977 dollars) was added to the price the consumer paid for 1973 model cars as a result of the Standard.
- An average of 36.1 lbs were added to the weight of the 1973 model cars, thereby requiring an incremental expenditure of $26 for fuel over the life of the cars.

- The total lifetime consumer cost averaged $56 (in 1977 dollars) per car, for 1973 model cars.
- The cost of Standard 214, in real dollars, may have decreased by as much as 25 percent since model year 1973.

Cost Effectiveness

- Standard 214 costs about $198,000 (in 1977 dollars) for every Equivalent Fatality Unit that it eliminates. (Equivalent Fatality Units are defined in the Discussion of Findings and in Chapter V.)

Casualty Reduction Classified by Direction of Crash Force

- The Standard is significantly more effective in preventing deaths and non-minor injuries in sidedoor impacts with primarily frontal, rear or non-horizontal direction of force, than in sidedoor impacts with a primarily lateral direction of force. This trend is consistent with the findings on intrusion reduction.

Discussion of Findings

The Problem

Standard 214 was intended to protect passenger car occupants involved in sidedoor impacts - i.e. crashes in which the car was damaged in the door area and the occupant was seated adjacent to the struck door. The starting point for the evaluation is to determine how many deaths and injuries would result from sidedoor impacts if there were no Standard. These numbers, the baseline casualties, were obtained by analyzing the National Crash Severity Study (NCSS) data file.

Prior to the promulgation of the Standard, nearly 26 percent of all passenger car occupant fatalities occurred in sidedoor impacts. If the Standard had not been promulgated, there would have been a total of approximately 7000 sidedoor impact deaths in 1977. Sidedoor impacts are also to blame for a large percentage of the more serious types of injuries, as summarized in Table II-1.

TABLE II-1

CASUALTIES DUE TO SIDEDOOR IMPACTS

	Deaths and Injuries in 1977 If Standard 214 Had Not Been Promulgated	
	Number of Sidedoor Casualties	Percent of Passenger Car Occupant Casualties
Deaths	7060	26
Severe or life-threatening injuries	15,700	19
Moderate injuries	16,200	12
Minor injuries	157,000	8

Sidedoor impacts are the result of collisions between two vehicles, as well as single vehicle accidents such as hitting fixed objects, rollovers, and off-road excursions. Single vehicle crashes are less common, but much more severe. They would account for approximately 3750 sidedoor impact deaths in the absence of the standard and about 6000 severe or serious injuries, as shown in Table II-2.

TABLE II-2

SINGLE VEHICLE VERSUS MULTIVEHICLE SIDEDOOR IMPACT CRASHES

	1977 Deaths and Injuries If Standard 214 Had Not Been Promulgated	
	Single Vehicle Crashes	Multivehicle Crashes
Deaths	3,750	3,310
Severe or life-threatening injuries	6,000	9,700
Moderate injuries	5,200	11,000
Minor injuries	27,000	130,000

Casualty Reduction in Single Vehicle Crashes

Single-vehicle sidedoor impacts were a serious safety problem. They were comparable to the total number of fatalities in light trucks and vans; the total number of motorcyclist deaths; and they exceeded the number of fatalities resulting from crashes between cars and heavy trucks.

Standard 214 is very effective in preventing deaths and non-minor injuries in single vehicle sidedoor impacts. Based on NCSS data, the sidedoor beams installed in response to the Standard eliminated approximately 74 percent of the deaths, 66 percent of the AIS $\geq$ 3 (severe to fatal) injuries and 60 percent of the AIS ≥ 2 (moderate to fatal) injuries in single vehicle crashes. Enough data have been collected to establish that the effectiveness is statistically significant[2] and to supply rather small confidence bounds, as shown in Table II-3(a).

TABLE II-3

EFFECTIVENESS OF STANDARD 214 IN
SINGLE VEHICLE AND IN MULTIVEHICLE SIDEDOOR IMPACTS

	Observed Effectiveness (percent)	Confidence Bounds[3] for Effectiveness (percent) Lower	Upper	Is Effectiveness Significantly[3] Different from Zero?
(a) In Single Vehicle Sidedoor Impact Crashes				
Fatalities	74	56	92	Yes
AIS ≥ 3	66	48	84	Yes
AIS ≥ 2	60	41	79	Yes
Any Injury	18	- 4	39	No
(b) In Multivehicle Sidedoor Impact Crashes				
Fatalities	-20	-83	+43	No
AIS ≥ 3	-20	-62	+22	No
AIS ≥ 2	- 4	-35	+27	No
Any Injury	+ 2	-13	+17	No

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[2] i.e. one must reject the hypothesis that there is no difference in the casualty rates of occupants of beam-equipped and unequipped cars.

[3] One-sided $\alpha = .05$

When all passenger cars on the highway will be equipped with side protection structures,i.e., by the mid 1980's, the Standard will be responsible for saving approximately 2780 lives per year (i.e. 74 percent of the 3750 fatalities if the Standard had not been promulgated). Seatbelts, by comparison, are now saving only a little over 2000 lives per year, because their usage has fallen so low. The confidence bounds on the number of lives saved per year are calculated in Appendix E and are 1400 (lower bound) and 4800 (upper bound).

Casualty Reduction in Multivehicle Crashes

The sample of accidents investigated was not large enough to establish whether Standard 214 is effective in multivehicle sidedoor impact crashes. In fact, a slightly negative effectiveness was observed in NCSS (See Table II-3(b)); because of the small sample size, the observed negative result is of no significance, being statistically compatible even with fairly large positive values of hypothesized effectiveness. The sample was sufficiently large, however, to establish that the Standard is significantly less effective in multivehicle crashes than in single vehicle crashes.

Overall Casualty Reduction (Single Plus Multivehicle)

The observed effectiveness of the Standard in all types of sidedoor impacts, single vehicle and multivehicle combined, is substantially lower than that for single vehicle crashes alone. The observed effectiveness of beams was 31 percent in preventing fatalities, 17 percent in preventing AIS ≥ 3. These levels of effectiveness are not statistically significant and, as Table II-4 shows, the confidence bounds are too large to provide a definitive measurement of benefits.

TABLE II-4

EFFECTIVENESS OF STANDARD 214 IN
ALL TYPES OF SIDEDOOR IMPACTS

	Observed Effectiveness (Percent)	Confidence Bounds[4] for Effectiveness (percent) Lower	Upper	Is Effectiveness Significantly[4] Different from Zero?
Fatalities	31	4	58	No
AIS ≥ 3	17	- 7	40	No
AIS ≥ 2	18	- 2	38	No
Any injury	1	-13	14	No

Even though the observed effectiveness in preventing fatalities (31 percent) and non-minor injuries (18 percent) is not quite statistically significant, it is definitely in the right direction. If the observed effectiveness were to persist over one additional year of National Crash Severity Study data collection, the results would be statistically significant and would corroborate the findings based on single vehicle crashes only.

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[4] one-sided $\alpha = .05$

Intrusion Reduction

The goal of Standard 214 is to prevent deaths and injuries in sidedoor impacts by reducing the frequency or severity of intrusion of side structures into the occupant compartment as a result of crash damage. Of the pre-Standard cars with sidedoor impacts severe enough to require their towaway, 69 percent suffered at least some intrusion as compared to only 59 percent of the post-Standard cars. This is a statistically significant (14 percent) reduction of intrusion frequency.

In many of the crashes where Standard 214 failed to eliminate intrusion entirely, it may well have reduced its severity. Thus, the 14 percent reduction in the frequency of any intrusion, although significant, is probably an understatement of the Standard's beneficial effect. This is supported by comparing the frequency of intrusion in low-speed and higher-speed crashes, as shown in Table II-5.

TABLE II-5

FREQUENCY OF SIDE INTRUSION IN
TOWAWAY SIDEDOOR IMPACTS

	Percent of Cars with Intrusion		
	Without Standard 214	With Standard 214	Are Frequencies Significantly Different?
All impacts	69	59	Yes
Low-speed impacts (velocity change < 10 mph)	66	50	Yes
Higher-speed impacts (velocity change ≥ 10 mph)	80	73	No

In the low-speed crashes (velocity change < 10 mph), Standard 214 reduces the frequency of intrusion by a substantial 24 percent: 66 percent of the pre-Standard cars had some intrusion, but only 50 percent of the post-Standard cars had any. In the higher speed crashes, however, some intrusion was nearly unavoidable even with Standard 214. Thus, the frequencies of intrusion in beam-equipped and unequipped cars were not significantly different, at these higher speeds.

In the National Crash Severity Study accident cases currently on file, severity of intrusion was not coded. But it will be coded on the cases investigated after April 1, 1978.

The most important finding on intrusion, however, is the substantial and statistically significant benefit of beams in <u>multivehicle nonlateral</u> sidedoor impact crashes. Standard 214 reduced the likelihood of intrusion from 59 percent to 44 percent (See Table II-6). It means that beams are about 25 percent effective in preventing intrusion in nonlateral vehicle-to-vehicle collisions. It appears, then, that the Standard is accomplishing its purpose in these crashes. By contrast, no substantial reduction of intrusion was observed in the lateral multivehicle crashes.

The sample of accidents was not large enough to establish whether Standard 214 reduces intrusion in single vehicle sidedoor impact crashes or to allow a meaningful comparison of intrusion reduction in single and multivehicle crashes.

TABLE II-6

FREQUENCY OF SIDE INTRUSION IN SIDEDOOR IMPACTS, BY CRASH TYPE AND PRINCIPAL DIRECTION OF FORCE

Percent of Cars with Intrusion

	Without Standard 214	With Standard 214	Are Frequencies Significantly Different?
Multivehicle nonlateral	59	44	Yes
Multivehicle lateral	75	73	No
Single vehicle nonlateral	47	43	No
Single vehicle lateral	65	72	No

Cost of Standard 214

Standard 214 increased the cost of owning and operating an automobile for two reasons: equipment installed to comply with the Standard increased the purchase price of cars; the equipment added to the weight of the car and increased its fuel consumption.

Component cost analyses were performed by inspection of a representative sample of model year 1973 cars - the year in which the Standard took effect - to determine the average cost and weight of equipment.[5]

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[5] See Chapter IV.

It was found that the equipment installed in response to the Standard added an average of $30 (in 1977 dollars) to the price consumers paid for a car. It added an average of 36.1 pounds of weight to a car. Since each additional pound of weight requires approximately 1.1 gallons of fuel over the life of a car, the cost to consumers for added fuel is $26 over the life of the car. (Fuel cost an average of 65¢ a gallon in 1977.)

Thus, the total lifetime consumer cost averaged $56 (in 1977 dollars) per car, for the 1973 models.

There have been major changes in the vehicle fleet since 1973. Some new nameplates, built on new body designs, have been introduced. Some nameplates that existed in 1973 have had their body design substantially altered (e.g. downsized). In order to measure the effect of these changes on the cost of Standard 214, teardown analyses were performed on 9 cars that represented most of the new or substantially redesigned models. The average cost of the Standard was found to be roughly 40 percent lower in these cars than in the 1973 models they replaced. The remaining models, which account for less than half the vehicle fleet, generally did not change substantially since 1973, so it was assumed the cost of Standard 214 (in 1977 dollars) remained the same. Under this assumption, it appears that the average cost of the Standard for the entire 1977 model year production may be close to 25 percent lower than for 1973 model cars. A more precise estimate of the current cost would require a larger teardown analysis sample. But $56 can be considered an upper bound for the current cost.

Cost Effectiveness

The findings on casualty reduction and cost of Standard 214 were analyzed to determine whether the costs per life saved and injury prevented are low enough to avoid inflationary impact. Based on the Standard's benefits in single vehicle crashes (and assuming that the Standard's effectiveness in multivehicle crashes is zero at worst) and based on a cost of $56 per car (the cost in model year 1973) it was found that Standard 214 costs about $198,000 (in 1977 dollars) per Equivalent Fatality Unit (EFU) that it eliminates. The EFU is a single quantity that measures the number of lives saved <u>and</u> injuries prevented by a standard: each life saved is 1 EFU; each injury prevented is assigned a fraction of an EFU, the exact amount depending on the severity of the injury.[6] The upper confidence bound [7] for cost per EFU eliminated is $390,000; the lower bound is $133,000 (calculated using the confidence bounds for AIS $\geq$ 3 casualty reduction given in Appendix E).

These figures were calculated using $56 as the cost of the Standard for model year 1973 cars. The benefits of the Standard, on the other hand, were calculated from accident data involving cars as recent as the 1977 model year. Since the cost of Standard 214 may have been as much as 25 percent lower in model year 1977 than in model year 1973, the calculated cost of $198,000 per EFU eliminated may similarly be an overstatement of the current cost.

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[6] See Chapter V, Definition 9.
[7] One-sided α = .05

The above calculations are based on the observed effectiveness of Standard 214 in single-vehicle sidedoor impact crashes and the assumption that effectiveness in multi-vehicle crashes is zero at worst. When, however, the observed effectiveness in both types of crashes (single and multivehicle combined) is used to calculate cost-effectiveness, the sample size of the accident data is too small to produce a meaningful result. The observed cost per EFU eliminated is $361,000, but the confidence bounds are very wide. The analysis in Chapter VI suggests that 2 more years of National Crash Severity Study data would be needed for the results based on both types of crashes to be as meaningful, statistically, as the ones already available, based on single-vehicle crashes.

Since the assumption of zero effectiveness in multivehicle crashes is probably conservative (especially in view of the significant intrusion reduction attributable to the Standard in those crashes), the positive result based on single vehicle crashes alone is fairly strong evidence that the standard is cost-effective. But, the presence of an ambiguous result based on all types of sidedoor impacts suggests that the data should be reevaluated annually for the next 2 years before a final conclusion on cost-effectiveness is reached.

Casualty Reduction Classified by Direction of Force

The criterion for a sidedoor impact in this study is the location of the vehicle damage (i.e. whether or not a sidedoor sustained crash damage), not the direction of impact force. Sidedoor impacts may involve primarily lateral forces (the force vector is within 45° of perpendicular to the car) primarily frontal or rear forces (the vector is within 45° of parallel to the car) or non-horizontal forces (as in rollovers).

It was found that 41 percent of the sidedoor impacts had primarily non-lateral principal direction of force (PDOF). The PDOF was frontal in 29 percent of the impacts, from the rear in 7 percent and non-horizontal in 6 percent. Twenty-eight percent of the fatalities and 22 percent of the severe injuries in sidedoor impacts primarily involved frontal, rear or non-horizontal PDOF.

Standard 214 was very effective in these types of impacts - reducing fatalities by 65 percent, severe injuries by 71 percent and moderate injuries by 51 percent. By contrast, the Standard had no statistically significant benefit in crashes with a side PDOF (i.e., force within 45° of lateral).

Since Standard 214 is highly effective in non-lateral impacts and in single vehicle crashes, it is natural to question the extent to which these crash modes overlap. Single vehicle crashes are more frequently nonlateral (57%) than multivehicle crashes (38%). But, because multivehicle crashes are much more common overall, the majority (74%) of nonlateral impacts are multivehicle. Thus, the overlap of the crash modes is limited. While the sample sizes are not large enough to attach much statistical significance to the numbers, the standard was observed to be nearly as effective in nonlateral multivehicle crashes (32% AIS$\geq$3 reduction) and in lateral single vehicle crashes (59%) as it was in nonlateral single vehicle crashes (70%).

The observed difference in effectiveness in nonlateral and lateral crashes may be exaggerated because of a possible action by the side beam to change the direction of force - this is discussed in Chapter VI.

The results on casualty reduction by direction of force are consistent with the results on intrusion reduction, especially so for multivehicle crashes.

Findings Based on the Fatal Accident Reporting System

The analyses of Fatal Accident Reporting System data, which are presented in Appendix G,

(1) confirm the findings based on NCSS data, that Standard 214 is substantially more effective in single vehicle than in multivehicle crashes.

(2) suggest that the effectiveness of Standard 214 in multivehicle crashes is not negative (as was observed in NCSS) but rather has a relatively small positive value, on the order of 10-15 percent (a value which is statistically compatible with the NCSS results).

(3) suggest that the fatality-reducing effectiveness of Standard 214 in single vehicle crashes might not be quite as high as what was observed in NCSS (74 percent) but is nevertheless quite substantial, on the order of 35 to 60 percent (depending on the interpretation of the analysis results discussed in Appendix G).

Conclusions

- Standard 214 appears to provide cost-effective occupant protection because it greatly reduces the likelihood of death or severe injury in single vehicle sidedoor impact crashes.

- The significant intrusion and casualty reduction in nonlateral sidedoor impact crashes shows that the performance requirements of Standard 214 are accomplishing their purpose in these crashes.

- "Sidedoor impacts" are usually envisioned as vehicle-to-vehicle collisions, primarily with lateral forces acting on the struck vehicle. In fact, most of the deaths and many of the severe injuries occurred in single vehicle crashes and/or primarily involved nonlateral forces.

- The Standard is most effective in preventing deaths and injuries in single vehicle crashes and in crashes with a primarily nonlateral direction of force. The most plausible speculation is that these crashes involve contact with stronger structural members (sills and pillars) as well as the door. The improved door structure in the post-Standard cars acts in tandem with the sills or pillars, possibly enabling the vehicle to "slide by" impacting objects, preventing more serious structural engagement and smoothing out the peak forces on the vehicle. Also, in the nonlateral crashes, the lateral force component (against which the beam offers least resistance) is relatively small.

- The significantly lower effectiveness of Standard 214 in vehicle-to-vehicle sidedoor impacts suggests that there remains considerable potential for improving occupant protection in these crashes.

CHAPTER III

A REVIEW OF THE SIDEDOOR IMPACT PROBLEM AND STANDARD 214

Introduction

Side impact crashes caused the deaths of more than 9000 passenger car occupants in 1970. Only frontal crashes caused more occupant fatalities. Results from accident investigation revealed that occupants were often crushed, trapped or lacerated by deformed side structures intruding into the passenger compartment.

The NHTSA responded in 1970 by proposing Standard 214, a static crush resistance requirement for side doors of passenger cars, in the hope that the frequency and depth of intrusion, and resultant injuries, would be reduced. The Standard became effective on January 1, 1973.

Definition of "Sidedoor Impact"

In this study, passenger cars are considered involved in sidedoor impacts if the crash damage they sustained overlaps partially or completely with their side door areas. Occupants of passenger cars are considered involved in sidedoor impacts only if they were sitting on the struck side of the car. Occupants sitting on the opposite side of the car or in the middle are excluded from the tabulations on sidedoor impact casualties.

The purpose of the definitions is to include situations where Standard 214 has the potential to protect occupants and to exclude situations where the potential seems to be limited. Since the Standard set requirements for sidedoor strength, any impact resulting in sidedoor damage falls within the scope of the Standard.

The criterion for a sidedoor impact in this study is the location of the vehicle damage (i.e. if a sidedoor sustained crash damage); not the principal direction of impact force (PDOF). Sidedoor impacts need not involve primarily lateral PDOF (the force vector is within 45° of perpendicular to the car). Some sidedoor impacts involve primarily frontal or rear PDOF (the vector is within 45° of parallel to the car) or non-horizontal PDOF (as in rollovers). Conversely, impacts with lateral PDOF need not be sidedoor impacts. An impact with lateral PDOF that resulted only in damage away from the sidedoor areas was not defined as a sidedoor impact.

The Sidedoor Impact Problem

The National Crash Severity Study (NCSS)[1] data provide information on the current distribution, by crash mode, of automobile accidents and on the likelihood of death or injury in pre-Standard and post-Standard cars. The data can be used to infer[2] the number of casualties that would now be occurring in sidedoor impacts if Standard 214 had not been promulgated.

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[1] The National Crash Severity Study is discussed in detail at the beginning of Chapter VI.

[2] The computations are shown in Appendices A and B.

The casualties consist of deaths and non-fatal injuries; the latter are classified according to the Abbreviated Injury Scale (AIS) [1].

As Table III-1 shows, in the absence of Standard 214, nearly 38 percent of the passenger car fatalities would have occurred in vehicles damaged primarily in the side area.[3] The majority of these deaths, 25.8 percent of all fatalities, would be sidedoor impacts. At least 13.7 percent of all occupant fatalities would have occurred in single-vehicle sidedoor impacts. This means that there would have been about 7000 sidedoor impact fatalities in 1977, with about 3750 of them being single vehicle crashes. Even though only 7.4 percent of towaways involve sidedoor impacts, these accidents are far more severe than other crash modes and result in much larger proportions of fatalities and AIS $\geq$ 3 injuries (22.3 percent). Sidedoor impacts, before Standard 214, ranked second only to frontal impacts as a cause of motor vehicle occupant fatalities. Single-vehicle sidedoor impacts alone were also a serious safety problem, resulting in a number of automobile occupant fatalities comparable to the <u>total</u> number of deaths in light trucks and vans, or the <u>total</u> number of motorcyclist deaths, and they exceeded the number of fatalities resulting from crashes between cars and heavy trucks.

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[3] By contrast, only 27% of fatalities involved side PDOF. Many crashes with frontal or non-horizontal PDOF result primarily in side damage.

TABLE III-1

DISTRIBUTION OF CASUALTIES AND TOWAWAY INVOLVED OCCUPANTS BY POINT OF PRINCIPAL IMPACT

	Deaths	AIS $\geq$ 3 Injuries	AIS $\geq$ 2 Injuries	All Injuries	Towaway Involved Occupants
N of NCSS cases	300	1053	2173	13,103	35,002
Front of car	50.3%	55.8%	61.0%	61.3%	61.7%
Back of car	0.6%	0.8%	1.1%	6.2%	5.5%
Top or Bottom	11.1%	8.8%	7.5%	5.5%	5.0%
SIDE	37.9%	34.6%	30.4%	27.0%	27.9%
Opposite side from occupant	11.1%	10.1%	11.4%	13.1%	14.6%
Same side as occupant, non-door	1.0%	2.1%	2.2%	4.2%	5.9%
SIDEDOOR IMPACT	25.8%	22.3%	16.9%	9.7%	7.4%
Multivehicle	12.1%	12.7%	10.3%	7.4%	6.0%
Single vehicle	13.7%	9.6%	6.6%	2.3%	1.4%

Since single vehicle sidedoor impacts have received little attention as a class of accidents, the high number of deaths and severe injuries they cause may come as a surprise. The accidents comprising this class have typically been lumped with other categories (usually by Principal Direction of Force), thereby obscuring their common features and drawing attention away from their exceptional severity.

Single vehicle sidedoor impacts appear to fall into 4 broad subclasses:

(1) Arrested sideswipe - Crashes that resemble sideswipes (frontal direction of force) except that a substantial engagement of structural members occurs in the sidedoor area. That part of the car is highly vulnerable to frontal forces, and serious intrusion may occur.

(2) Sideway skid into fixed object - Crashes with a frontal or lateral principal direction of force, depending on the yaw angle. Yawing and loss of control is common before impact and exposes a vulnerable part of the car.

(3) Rollover - where the principal impact is in the sidedoor area, and where an occupant contacts the door, or is ejected through it.

(4) Offroad excursion into rough terrain - causing several light impacts with ground features, severe bottoming, etc. The impact sequence places the occupant in vulnerable positions.

Table III-2 shows comparative occupant injury rates in various crash modes. Sidedoor impacts and, especially, single vehicle sidedoor impacts are far more dangerous than any other type. Whereas the occupant fatality rate in all towaway crashes is only 0.9 percent, it is 3.1 percent in sidedoor impacts and 8.9 percent in single-vehicle sidedoor impacts. The AIS $\geq$ 3 injury rate was 3.4 percent in all towaway accidents, 10.1 percent in sidedoor impacts and 24.0 percent in single vehicle sidedoor impacts.

Principal Direction of Force in Sidedoor Impacts

Table III-3 shows that a substantial proportion of the sidedoor impacts involve crash forces other than lateral. Only 59 percent of the sidedoor impacts and 72 percent of the fatalities would be classified as "side" impacts based on direction of force. Many frontal and non-planar impacts could, however, be affected by Standard 214. A study restricted to traditionally defined "side" impacts would lead to an underestimate of the Standard's effectiveness.

TABLE III-2

OCCUPANT FATALITY AND INJURY RATES BY TYPE OF CRASH
(Point of Principal Impact)

Point of Principal Impact	Percent of Towaway-Involved Occupants Suffering			
	Fatal Injury	AIS≫3 Injury	AIS≫2 Injury	Any Injury
Overall	0.9	3.4	7.8	44.7
Front of car	0.7	3.0	7.9	44.5
Back of car	0.1	0.5	1.8	49.1
Top or bottom	2.0	6.1	11.7	50.9
SIDE	1.2	4.1	8.5	43.3
Opposite side from occupant	0.7	2.3	6.0	39.9
Same side as occupant, non-door	0.1	1.2	2.9	32.6
SIDEDOOR IMPACT [4]	3.1	10.1	18.0	57.9
Multivehicle [4]	1.8	7.0	13.9	54.6
Single vehicle [4]	8.9	24.0	33.5	71.5

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[4] Injury rates for occupants of <u>pre-Standard 214 vehicles</u>.

TABLE III-3

DISTRIBUTION OF SIDEDOOR IMPACT CASUALTIES AND INVOLVED OCCUPANTS BY PRINCIPAL DIRECTION OF FORCE (PDOF)

	Deaths	AIS ≥ 3 Injuries	AIS ≥ 2 Injuries	Injuries	Involved Occupants
N of NCSS sidedoor cases	67	217	328	1226	2597
% Frontal PDOF	16%	15%	18%	26%	29%
Side PDOF	72%	78%	75%	65%	59%
Rear PDOF	1%	2%	2%	4%	7%
Non-planar PDOF:					
Rollover	4%	2%	2%	4%	5%
Other non-planar	6%	3%	2%	2%	1%

Severity of Sidedoor Impacts

The severity of sidedoor impacts is described by Figure III-1 and Table III-4. Figure III-1 shows the cumulative distributions of involvements, injuries and deaths by ΔV.[5] It shows that 81 percent of the impacts, 77 percent of the injuries, 59 percent of the AIS ≥ 3 injuries and 25 percent of the fatalities occurred at a ΔV of 20 mph or less. No less than 80 percent of the AIS ≥ 3 injuries and 60 percent of the fatalities occurred at $\Delta V \leq 30$ mph.

TABLE III-4

OCCUPANT FATALITY AND INJURY RATES IN SIDEDOOR IMPACTS AS A FUNCTION OF ΔV

	Percent of Sidedoor-Involved Occupants Suffering			
ΔV	Fatal Injury	AIS ≥ 3 Injury	AIS ≥ 2 Injury	Any Injury
1 - 14 mph	0.4	5.0	9.8	54.8
15 - 29	2.7	11.7	20.3	57.9
30 and up	17.0	40.0	75.0	90.6

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[5] ΔV: The magnitude of the vector denoting the struck car's velocity change during the impact. It was estimated on the NCSS file by using the CRASH accident reconstruction program [20].

FIGURE III-1

CUMULATIVE DISTRIBUTIONS OF
SIDEDOOR IMPACT TOWAWAY INVOLVEMENTS,
INJURIES AND DEATHS BY ΔV

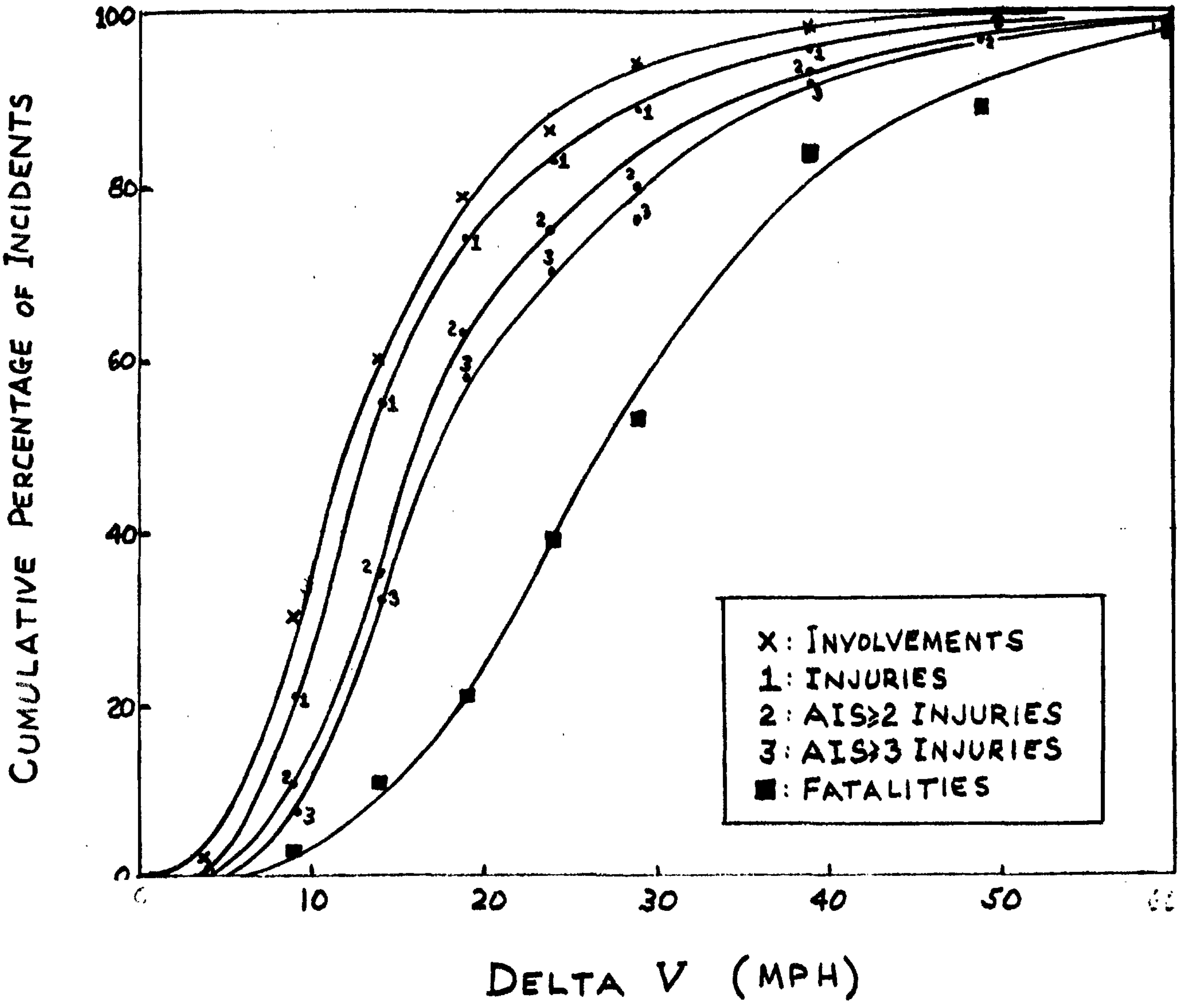

Table III-4 shows the probability of death or injury as a function of ΔV. Whereas the probability increase rapidly with ΔV, it is surprising how many occupants suffered substantial injuries at a low ΔV, and little or no injuries at high ΔV. Most of the substantial injury <u>occurrences</u> (Figure III-1) are at speeds where the <u>probability</u> of injury is still low (Table III-4).

The Problem of Intrusion in Sidedoor Impacts

"Intrusion" means a reduction of the size of the occupant compartment as a result of crash damage. It is common in sidedoor impacts, because only the door structure stands between the striking vehicle or object and the occupant compartment. On the NCSS file, 69 percent of the pre-Standard 214 towaways involving sidedoor impacts had some degree of intrusion. There was intrusion in 80 percent of the impacts at $\Delta V >$ 10 mph.

Side structure intrusion was observed in 92 percent of the sidedoor impacts that caused moderate or greater (AIS $\geq$ 2) occupant injury.

Sidedoor impacts were defined as those in which crash damage either entirely <u>or</u> partially overlapped with the sidedoor area. Intrusion occurred in virtually all of the cases requiring a towaway and where the damage was <u>entirely</u> within the sidedoor area.

The Side Door Strength Standard (FMVSS 214)

Table III-5 gives a summary description of Standard 214.[6]

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[6] Table III-5, with several changes, is quoted from [15], pp. 3f.

TABLE III-5

STANDARD 214 - SIDE DOOR STRENGTH

Item	Description
Effective Date	January 1, 1973
Purpose of Standard	o Specific purpose is to set strength requirements for sidedoors. o General purpose is to minimize the safety hazard caused by intrusion into the passenger compartment in a side impact accident.
General requirements of Standard	Any side door that can be used for occupant egress must meet three crush resistance tests: o Initial crush resistance of not less than 2,250 lbs. o Intermediate crush resistance of not less than 3,500 lbs. o Peak crush resistance of not less than 7,000 lbs. or twice the curb weight of the vehicle whichever is less.
Applicable crash situations	The test conditions most closely resemble a car-to-car impact in which the struck vehicle is damaged primarily in the door area, at the height of the door beam. The standard is also likely to be effective in other side impacts which involve damage to the door beam area plus structural members such as pillars, frame or sill.
Relation of test requirements and injury reduction	The test criteria are based on the assumption of a causal relationship between passenger compartment intrusion and passenger injury.

TABLE III-5 (continued)

STANDARD 214 - SIDE DOOR STRENGTH

Item	Description
Alternative compliance methods	Presently, passenger cars satisfy this Standard by adding sidedoor beams to the door construction. Variously fabricated beams have been used or proposed-- channel beams, roll formed, special high strength low weight configuration, etc.
Extent of compliance	Standard 214 has been in effect for all passenger cars since January 1, 1973. However, starting in 1969, certain models had side beams or other strengthening of side doors. (Therefore, any analysis of this Standard must segregate events by this factor.)
Prior compliance	Information received from the manufacturers as to when side beams were introduced, by make and model, is presented in Table III-9 below.

The Compliance Test For Standard 214

There are three minimum crush resistance forces over three corresponding depths of external door surface crush for any side door used for occupant egress:

- 2250 lb average, over 6 inches of crush (initial crush resistance).
- 3500 lb average, over 12 inches of crush (intermediate crush resistance).
- 7000 lb or twice the vehicle curb weight, whichever is less, as the largest force recorded over the entire 18 inches of crush (peak crush resistance).

The initial and intermediate crush resistances are meant to ensure adequate stiffness in the door structure. The maximum force requirement tests the overall strength and resistance to separation of the side structure. In the compliance test, the vehicle frame is anchored to a rigid foundation, and a test device applies a force to the door being tested. The test device is a rigid steel cylinder or semicylinder, 12 inches in diameter. It is applied in a vertical position to effectively contact the door from a point 5 inches above the bottom of the door to the bottom edge of the window in the center of the door. The impact is measured as the midpoint of the horizontal line 5 inches above the bottom of door. The device is applied at a rate not to exceed 0.5 inches/second for 18 inches within 120 seconds; it is guided to prevent rotation or displacement from the direction of travel, which is perpendicular to the centerline of the vehicle. The forces are measured by plotting a curve of load versus displacement and by obtaining the integral in inch-pounds, then dividing by the specified crush distances to represent the average forces in pounds over distances of 6 and 12 inches. The vehicle must meet or exceed the three specified crush resistance values to pass the standard.[7]

Methods to Achieve Compliance

Initially, manufacturers explored various structural means for complying with the Standard, including beams, structural foam, and honeycombed members. A review of current door structures shows that the method of compliance is primarily with formed or channel-shaped metal beams or stampings positioned near or against the inner side of the outer door sheet metal surface,[8] thereby providing the greatest resistance to intrusion for the prescribed force application. Reinforcing beams are attached by spot or seam welds to the vertical door frame members on the hinge and latch sides of the doors. This method of reinforcing the doors is probably universal in the thin structured doors of small cars. Some of the larger vehicles, with

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[7] The preceding subsection, with several changes, is quoted from [3], pp. 5-1f

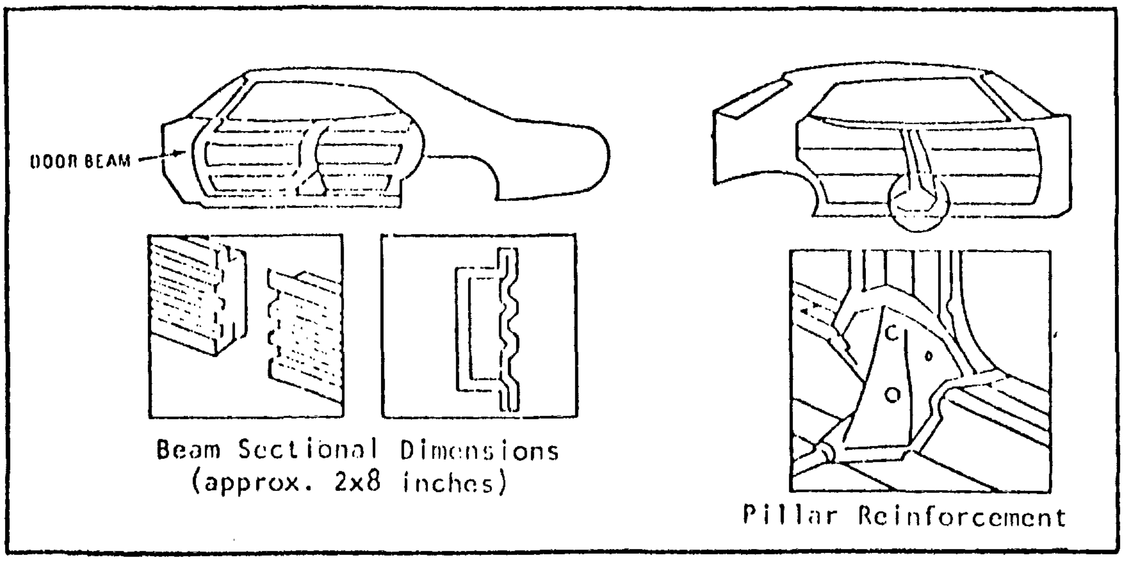
[8] The domestic manufacturers use channel beams with corrugated longitudinal reinforcing and sometimes center plate reinforcement. Volkswagen has used a simple channel beam on their newer models; however, in the VW Beetle the beam flanges narrow at the connection point.

a heavier door thickness between inner and outer panels, appear to accomplish the strength requirement by incorporating heavy metal frames within the door which are functional in supporting the window regulators and latch mechanims, therby reducing the cost of additional structure for the purpose of increasing door strength.

Figure III-2 shows the incremental design changes typically used to meet the Standard. The door beams are approximately eight inches high, two inches deep and run from hinge to lock pillar on every door. They are parallel to and approximately 10 inches above the lower door sill. The pillar support is for local reinforcement for the door pillar. Therefore, the two primary physical items which are introduced to satisfy the Standard are the <u>side beams</u> and the <u>pillar</u>

FIGURE III-2

TYPICAL DESIGN CHANGES FOR STANDARD 214 COMPLIANCE



Beam Sectional Dimensions
(approx. 2x8 inches)

Pillar Reinforcement

supports. The side beams themselves are made up of several components. The minimum components are the channel beam and the end plates. Domestic models have corrugated sheet metal for additional reinforcing and in vehicles with wide doors a center plate may be added. The pillar to floor reinforcement is not required on 2-door sedans.[9]

Compliance Prior to Effective Date

A number of manufacturers introduced side beams into one or more models well before the standard's effective date of January 1, 1973. Those models are listed in Table III-6.[10] General Motors and Ford tended to install side beams in their largest cars first.

Other Standards that Provide Sidedoor Impact Protection

There are 6 other Standards that may have led to improved occupant protection in sidedoor impacts. When evaluating benefits, these must be taken into account so as to arrive at the net benefits attributable to Standard 214.

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[9] The preceeding subsection, with several changes, quoted from [12], pp.1-3f and p. 5-1.

[10] Table III-6, with several changes, is quoted from [15], p. 5.

TABLE III-6

INTRODUCTION DATES OF SIDEDOOR REINFORCEMENT BEAMS

Make	Line	Series	Model Year
AMC	Javelin	SST	1971
		Basic	1971
		AMX	1971
GM			
Buick	Buick	Electra	1969
		Le Sabre	1969
		Riviera	1971
	Special/Skylark	Skylark	1970
		GS	1970
Cadillac	Cadillac	Calais	1969
		De Ville	1969
		Eldorado	1971
		Fleetwood Eldorado	1971
		Fleetwood Brougham	1969
		Fleetwood Seventy-Five	1969
		Fleetwood Sixty Special	1969
Chevrolet	Chevelle	Concours	1970
		Malibu	1970
		Nomad	1970
		Greenbriar	1970
	Chevrolet	Bel Air	1969
		Biscayne	1969
		Caprice	1969
		Kingswood	1969
	Monte Carlo	Monte Carlo	1970
	Vega	Vega	1971
Oldsmobile	F-85/Cutlass	F-85	1970
	Oldsmobile	Delta 88	1969
		98	1969
	Toronado	Toronado	1971
Pontiac	Firebird	Firebird	1970
		Esprit	1970
		Formula	1970
		Trans-Am	1970

TABLE III-9 (continued)
INTRODUCTION DATES OF SIDEDOOR REINFORCEMENT BEAMS

Make	Line	Series	Model Year
	Pontiac	Bonneville	1969
		Catalina	1969
		Executive	1969
		Grand Prix	1969
	Tempest/LeMans	Le Mans	1970
CHRYSLER			
Dodge	Challenger	Challenger	1970
		Challenger RT	1971
FORD			
Ford	Fairlane/Torino	Gran Torino	1972
	Ford	Custom	1971
		Galaxie	1971
		LTD Brougham	1971
	Mustang	Mustang	1971
		Grande	1971
	Pinto	Pinto	1971
	Thunderbird	Thunderbird	1972
Lincoln	Lincoln	Continental	1971
		Mark III & IV	1971
Mercury	Cougar	Cougar	1971
		Cougar XR 7	1971
	Mercury	Marquis	1971
		Marquis Brougham	1971
		Monterey	1971
	Montego	Montego	1972
		Montego MX, Brougham, and GT	1972
ALL OTHERS			1973

Standards 208, 209 and 210, led to increased belt availability, quality and convenience during 1966-75, with a corresponding increase in belt usage. Standard 201, which requires padding of interior surfaces and redesign of some dangerous protruding knobs and handles, is helpful in many side impact situations. But since it took effect on 1-1-68, it would apply to many pre-214 vehicles still on the road (i.e. 70% or more of them) as well as all post-214 cars.

Standard 205, which disallows side-window shattering in specified situations, protects the occupant's head in many side impacts. This standard also became effective on 1-1-68. Most model year 1966 cars already met its requirements. Standard 206, designed to prevent doors from opening, helps reduce occupant ejection in side impacts. This standard took effect on 1-1-68. Most manufacturers were already building cars that apparently met the requirements in model year 1965.

Other design changes, not specifically mandated by safety standards, as well as the techniques for isolating the benefits of Standard 214 are discussed in Chapter VI.

Relationships between Intrusion, Injury and Standard 214

The static crush resistance requirements of Standard 214 are intended to reduce intrusion in sidedoor impact accidents. Because intrusion is thought to cause injuries, the Standard should reduce the number of injuries. But the causal relationships (between Standard 214 and intrusion; between intrusion and injury) have not been firmly established.

The compliance test for Standard 214 resembles a vehicle-to-vehicle collision, at a 90° resultant force to the struck vehicle. The corner of the striking vehicle contacts the sidedoor area of the struck vehicle at the height of the sidedoor beam, but does not contact the sill, pillars or any other component outside the sidedoor area. Only a small fraction of sidedoor impacts are like that. It was not known whether Standard 214 would be less effective (or more effective, for that matter) in reducing intrusion when the impact involves substantial engagement of structural members such as sills, pillars or rails (and most impacts do); or when the resultant force is not at a 90° angle; or when the collision involves a vehicle and a fixed object rather then two vehicles.

Results from accident investigation revealed that side intrusion was often associated with substantial injury. But that does not imply that the intrusion caused the injury [2]. As crash severity (e.g. impact speed) increases, both the likelihood of intrusion and injury should also increase - i.e. injury severity is greater in higher-speed crashes, which just happen to have more intrusion as well.

A fully controlled side impact study would prove whether or not the relationship between intrusion and injury is causal. No such study had been performed at the time Standard 214 was promulgated. Instead, the existence of such a relationship was hypothesized on the basis of engineering calculations, partially controlled statistical studies and anecdotal accident investigation results.

Engineers calculated that injury severity in a side impact depends to a large extent on the velocity with which an occupant collides with the door interior. If the sidedoor is stiff and little or no intrusion occurs, the occupant will strike the door at a speed close to ΔV. If the sidedoor is weak, the occupant will contact the door as it moves into the occupant compartment at a speed close to the impact speed of the bullet vehicle - i.e., considerably faster than ΔV.[11] Thus, a reduction of intrusion accomplished by a stiffening of the sidedoor should lead directly to a reduction of the velocity of the occupant's collision with the door, thereby causing a reduction of injury severity.

Furthermore, if the sidedoor is weak, it can become severely deformed during the impact. If the deformed side structure has pointed or jagged protrusions or open spaces that allow ejection, it would present an even greater danger to occupants.

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[11] For example, in a 90° collision with the bullet vehicle aimed at the center of gravity of a standing target vehicle, the impact speed is roughly twice ΔV.

Three years after Standard 214 was promulgated, a fully controlled laboratory study of side impacts was performed in France [4]. Three target vehicles were struck in simulated side collisions. The collisions were repeated with three other target vehicles, identical in all respects to the first three except that a very stiff shield was attached outside the door area. Because there was less intrusion, the occupant surrogates (dummies) contacted the door interiors at much lower speeds. Thus, the study strongly supports the engineering calculations. But because of the small number of simulated collisions and the limited understanding of biomechanics in side impacts, a quantitative relationship between intrusion and injury could not be established.

Partially controlled statistical studies also suggested a causal relationship between intrusion and injury. A report published in 1969 [13] showed that the likelihood of substantial injury was far greater for occupants seated adjacent to a struck door (intrusion was relevant) than for those seated on the side away from the door (intrusion was not relevant) or those involved in side impacts where the doors were not damaged (intrusion was not relevant). Table III-2, based on the NCSS data, confirms these findings. The difference in injury rates may well be due to the role of intrusion (which was a factor in the first type of crash but not in the other two types). But it could also be due to other differences in the three crash types (e.g. different occupant contact points). Therefore, a causal relationship of intrusion to injury could not be firmly established in this analysis.

Multidisciplinary accident investigation also focused attention on the role of intrusion in side impacts. Detailed case histories showed how occupants were crushed or trapped by deformed side structures in extremely severe crashes. But this also failed to establish a causal relationship of intrusion to injury; in such severe crashes, it is conceivable that the occupants would have suffered grave injury even if there had been less intrusion. Also, the majority of non-minor sidedoor impact injuries do not involve occupant crushing or entrapment.

Accident data with detailed measurements on the location and depth of intrusion would be needed for a statistical analysis addressing the issues. NCSS teams began making these measurements on April 1, 1978. By the summer of 1980, when a substantial number of accident cases with intrusion measurements will be available, the problems discussed here will be analyzed in a follow-up report.

CHAPTER IV

THE COST OF STANDARD 214

Introduction

Standard 214 increased the cost of owning and operating an automobile for two principal reasons: equipment installed to comply with the Standard increased the purchase price of cars; the equipment added weight to the car and increased its fuel consumption. This chapter presents the preliminary results of an investigation of the cost and weight of equipment installed in response to the Standard.

All costs presented in this chapter are expressed in 1977 dollars.

Procedure for Estimating Costs

Teardown analyses [21] were performed on a representative sample of vehicles in order to determine exactly what equipment changes manufacturers made to bring cars in compliance with the Standard. Since the Standard became effective in 1973, vehicles of that model year were selected. The selection of cars included all manufacturer/body style combinations that had substantial sales. The 17 cars that were selected, therefore, represented body styles that accounted for 94 percent of the cars sold in the United States in 1973.

In most teardown analyses, it is necessary to examine, in equal detail, a corresponding sample of pre-Standard vehicles, in order to determine the incremental changes that were made in each component in response to the Standard. In this case, however, the problem was simpler. In 15 of the 17 cars, compliance was achieved by installing a sidedoor beam in the post-Standard vehicle where no such component existed in the corresponding pre-Standard vehicle. No other components were significantly altered.

In only 2 of the 17 cars was there substantial alteration of the door and hinge pillars, thereby requiring detailed teardown of the pre-Standard car in order to determine incremental cost and weight.

The 17 sidedoor beams (plus the 2 pre-Standard and post-Standard door and hinge pillars) were weighed and their direct manufacturing costs were assessed. The cost analysis was performed using procedures standard to the automotive industry [21]. Cost included materials, tooling, assembly and overhead, among other categories. Since costs were to be expressed in 1977 dollars, prices of material, labor rates, and other cost factors were based on 1977 levels.

The increase in the purchase price of cars as a result of the Standard was calculated from the direct manufacturing cost by adding manufacturer's and dealer's markups and taxes. Dealer markups were calculated separately by make and model. They represented the average difference between the dealer's cost and the list price.

The average increase in the purchase price and weight of 1973 model cars as a result of the Standard was computed as follows:

The 1973 models (domestic and imported) were grouped by manufacturer, body size category and number of doors (2 or 4). The 17 groups that contained one of the vehicles in the teardown sample were assigned the actual price and weight of the sample vehicle. The remaining groups (which accounted for a rather small proportion of vehicle sales) were assigned the average price and weight for their body style. Finally, the sales-weighted average (using sales in the 1973 model year) of price and weight was calculated. The estimation procedure is fully described in [21].

Finally, the total cost of Standard 214, per car, is computed by adding the cost of additional fuel consumed over the life of the car (as a result of the weight added to the car) to the increase in the purchase price. Each incremental pound of weight added to a car results in the consumption of an average of 1.1 additional gallons of fuel over the lifetime of the car [10]. Since gasoline cost an average of 65¢ per gallon in 1977, this means that the Standard costs $0.72, in 1977 dollars, for every added pound, over the life of a car.

Findings

The equipment installed in the 1973 model cars in response to the Standard added an average of $30 to the purchase price of those cars. It added an average of 36.1 pounds to the weight of the cars. Since each incremental pound results in an addition of 72¢ to the cost of fuel consumed over the life of the car, the cost to consumers for the added fuel is $26.

Thus, the total lifetime consumer cost averaged $56 (in 1977 dollars) per car, for 1973 model cars.

Since roughly 10 million passenger cars are sold annually in the United States, the cost of Standard 214 is about $560 million per year.

Table IV-1 presents the average total cost (including cost of fuel) by vehicle size category. The cost is highly correlated with the size of the car, ranging from $36 for subcompacts to $68 for luxury size cars. The cost for intermediates is higher ($72) because door and hinge pillars were substantially modified, as well as beams installed, on two high-volume models in this category.

TABLE IV-1

AVERAGE TOTAL COST OF STANDARD 214
BY VEHICLE SIZE CATEGORY
(1977 Dollars)

Sub-compact	$ 36
Compact	$ 43
Intermediate	$ 72
Standard	$ 63
Luxury	$ 68

The cost of Standard 214 had previously been estimated by NHTSA in a study based on questionnaires sent to the manufacturers [6]. A total cost of \$50.40 (in 1977 dollars) was estimated[1]: \$22.40 added to the purchase price of a car, plus \$28 for the fuel consumed as a result of 39 pounds added to the weight of the car. This estimate is \$5.60 lower than what was found in the teardown analysis. The estimate of increased purchase price, based on the questionnaires, is \$7.60 lower than what was found in the tear-down analysis, but the estimated weight increase was 2.9 pounds higher.

Changes in the Cost Since Model Year 1973

A sample of model year 1973 cars was used in calculating that Standard 214 costs \$56 per car. Several changes in the vehicle fleet have taken place since 1973:

(1) There has been a shift in the sales mix to smaller cars, for which the cost of Standard 214 tends to be lower.

(2) Lighter or less expensive equipment that meets Standard 214 requirements may have been designed.

A teardown analysis was conducted on 9 additional cars. They represented most of the body types newly introduced or substantially modified after model year 1973. These models accounted for over half of the cars produced in 1977. The total cost of Standard 214 for these cars (including lifetime

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[1] Costs shown in [6] were changed to 1977 dollars using a 6.5 percent average annual inflation factor.

cost of fuel) averaged roughly 40 percent lower than the models they replaced. Under the assumption that costs did not change for the other models, it appears that the average cost of the Standard for 1977 model year cars (a sales-weighted average based on model year 1977 sales) may be close to 25 percent lower than 1973 model cars.

The teardown analysis was performed on too small a sample of newer cars (9) so far to permit a precise estimate of the cost of the Standard for 1977 models. But there is little doubt that $56, the cost for 1973 model cars, is an overestimate of the current cost of the Standard. Since $56 is the cost figure used in the cost-effectiveness analysis and since benefits are calculated on the basis of accident data involving cars as recent as model year 1977, the assessments of cost-effectiveness made in Chapters II and VI are likely to be conservative.

CHAPTER V

BENEFIT ANALYSIS: DEFINITIONS AND OBJECTIVES

Introduction

The objectives of this evaluation are to determine if Standard 214 performs as intended and whether it provides cost-effective occupant protection. It is necessary to establish whether

1. The likelihood and/or severity of intrusion in Standard 214 equipped cars, struck in the sidedoor area, is lower than in pre-Standard 214 cars involved in comparable impacts.

2. The likelihood of death and the likelihood and/or severity of injury for occupants of Standard 214 cars, struck in the sidedoor area, is lower than it is for occupants of pre-Standard 214 cars involved in comparable impacts.

3. The Standard saves lives, prevents and/or reduces injuries in a cost-effective manner. The Standard meets the need for motor vehicle safety without inflationary impact.

This chapter provides explanations of the terms used in formulating the objectives, especially the terms relating to cost-effectiveness and comparisons of pre-Standard and post-Standard cars. It provides a framework for the analyses that will be presented in Chapter VI.

Definitions

1. Standard 214 cars are those passenger cars that meet the requirements of the Standard - including all passenger cars manufactured after the effective date (January 1, 1973) plus those among the models listed in Table III-9 which met the requirements prior to the effective date. Standard 214 cars will sometimes be called "post-Standard" or "beam-equipped" cars. All other passenger cars are "pre-Standard 214" or "unequipped."

2. Cars involved in sidedoor impacts include all crash-involved passenger cars whose crash damage partially or completely overlaps with any portion of one or more of the side doors. This will not be limited to what are usually defined as "side impacts" - i.e., those in which the principal direction of force (PDOF) is within 45 degrees of lateral. As explained in Chapter III Standard 214 may also be helpful in sidedoor impacts with primarily frontal, rear or non-horizontal forces.

3. Intrusion means any reduction of the size of the occupant compartment as a result of side structure damage. In this study, vehicles that had compartment reduction only by components that are not part of the side structure (e.g., steering column or roof) will be classified as having suffered "no intrusion."

4. Occupants involved in sidedoor impacts are the ones sitting adjacent to the contact area. Occupants sitting in center seats or on the far side of the car are excluded, since the benefits they might receive from Standard 214 are probably limited. (The Standard is primarily designed to reduce intrusion, which seldom extends more than 1/3 of the way across the car.)

5. Injury rates are the proportions of occupants who suffered an injury greater than or equal to a specified level of severity. Four injury rates should be determined for the involved occupants of beam-equipped and unequipped cars, respectively:

a. The proportion of involved occupants who were killed.
b. The proportion who suffered injury at the AIS (Abbreviated Injury Scale - Overall Rating) 3 level or worse.
c. The proportion who suffered injury at the AIS 2 level or worse.
d. The proportion who suffered any injury.

The Abbreviated Injury Scale [1] is applicable for this type of study because it is well defined and is useful for separating minor injuries from significant ones.

The actual occupant injury rates experienced in the National Crash Severity Study are shown in Appendix C.

6. The likelihood of death (or injury) for occupants of Standard 214 cars, R^+, is the hypothetical fatality (or injury) rate that would have occurred in 1977 if all cars on the road had met the requirements of Standard 214. R^+ is calculated from the simple injury rate (see preceding definition) by standardizing the data (a procedure that is explained in Chapter VI).

Similarly, the likelihood of death (or injury) for occupants of pre-Standard cars, R^-, is the hypothetical fatality (or injury) rate that would have occurred in 1977 if none of the cars on the road had met the requirements of Standard 214.

The likelihood of intrusion for post-Standard and pre-Standard vehicles is similarly defined.

7. The effectiveness, $\mathcal{E}$, of Standard 214 is the relative difference of R^+, the likelihood of casualty in post-Standard cars and R^-, the likelihood of pre-Standard cars.

$$\mathcal{E} = 100\ (1 - R^+/R^-)\%$$

This is the proportion of sidedoor impact casualties eliminated as a consequence of Standard 214. In this study, the effectiveness of Standard 214 in preventing fatalities, AIS$\geq$3 injuries, AIS $\geq$ 2 injuries and any type of injury will be determined.

8. Benefits are expressed by the number of deaths (and injuries, classified by AIS level) that Standard 214 will be preventing annually when all cars on the road meet the Standard's requirements (in the mid 1980's). If N are the number of occupants involved in sidedoor impacts anually,

$$\text{Benefits} = (R^- - R^+)\ N = \mathcal{E}\, R^- N$$

9. Benefits can also be expressed in Equivalent Fatality Units (EFU). Each death prevented by Standard 214 is a benefit of 1 EFU. Each non-fatal injury[1] is assigned a fraction of an EFU, according to the AIS level, as shown in Table V-1.

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[1] Only one injury is counted per person. The person's AIS - Overall Rating is assigned to his injury.

TABLE V-1

EQUIVALENT FATALITY UNITS (EFU) OF NON-FATAL INJURIES

AIS Rating	Equivalent Fatality Units
5	.7
4	.3
3	.017
2	.008
1	.0015

The concept of equivalent fatality units is useful for expressing, in a single figure, the cost-effectiveness of a device that saves lives and prevents injuries. The EFU's assigned to injuries at each AIS level are based on the relative costs of the injuries.

10. The cost-effectiveness of Standard 214 is the cost of the Standard per EFU that it eliminates. It is the cost per car times the number of passenger cars built annually divided by the annual benefits expressed in EFU's.

Methods for Evaluating Cost-Effectiveness

One of the objectives of this study, which is part of a regulatory review conducted in response to Executive Order 12044, is to determine if Standard 214 meets the need for motor vehicle safety without inflationary impact. The question of inflationary impact is most readily addressed by specifying a range of values for the highest cost per EFU (Equivalent Fatality Unit) eliminated by a safety program that can still be considered noninflationary. The range, although stated in absolute dollars, could be thought of as a surrogate criterion for a comparison of Standard 214 with alternative safety measures. The maximum acceptable cost per EFU eliminated is asssumed to be somewhere in the range from $300,000 to $600,000. The Standard can be called "cost-effective" and noninflationary if the cost per EFU elminated is near the bottom of the range or below it; it is marginally cost-effective if the cost is toward the higher end of the range. If the cost is definitely above the range, the Standard could be considered to have an inflationary impact.

How effective would Standard 214 have to be to provide cost-effective protection? If Standard 214 had not been promulgated, the deaths and injuries in sidedoor impacts would add up to 8630 EFU's annually.[2] Since the cost of Standard 214 is $560 million per year [3], it would have to

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[2] See Appendix B and Table V-1

[3] See Chapter IV

eliminate at least 1863 EFU's, a 21.6 percent casualty reduction, if the cost per EFU is to be kept under $300,000. The effectiveness would have to be at least 10.8 percent for the Standard to be marginally cost-effective. How effective would Standard 214 have to be in single vehicle sidedoor impact crashes to establish cost-effectiveness on the basis of such crashes alone? Had Standard 214 not been promulgated, 4290 EFU's in single vehicle sidedoor imapct crashes could be expected per year.[4] The casualty-reducing effectiveness in these crashes would have to be 43.4 percent to establish definite cost-effectiveness and 21.7 percent to establish a marginal cost effectiveness.

If the benefits and costs of Standard 214 were known exactly, it would be possible to calculate the cost per EFU eliminated and determine whether the Standard is cost-effective.

In this study, the benefits are estimated from a sample (The National Crash Severity Study accident file). The calculated cost-effectiveness, based on the sample, may be higher or lower than the true value. A technique is required to determine and confidently state in which of the three zones the true cost-effectiveness stands. - definitely, marginally, or not cost-effective - based on the sample results. If the sample size is too

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[4] See Appendix B and Table V-1.

small to establish the zones, the technique should provide information on how much larger a sample is required before the confidence bounds on true effectiveness are narrow enough to permit a conclusion on cost-effectiveness.

There are two statistical techniques that essentially meet these requirements, Bayesian Decision Theory and Acceptance Sampling.

Bayesian Decision Theory

Under the Bayesian approach, the observed effectiveness, $\hat{\mathcal{E}}$, based on the sample[5] and its standard deviation, σ, are used to establish a probability distribution for the actual effectiveness of Standard 214[6]. The probability distribution is then compared to the specific value $\mathcal{E}_o$ of effectiveness needed to show that the Standard is cost-effective. (Separate Bayesian analyses are required to establish if the Standard is definitely cost-effective and marginally cost-effective). If the bulk of the probability distribution lies to the right of $\mathcal{E}_o$, the Standard is cost-effective; if to the left, it is not.

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[5] See definition 7 earlier in this Chapter

[6] The normal distribution $\varphi(\hat{\mathcal{E}},\sigma)$ is a reasonably close approximation, adequate for the Bayesian analysis - See Chapter VI.

But if substantial portions of the distribution lie on both sides of $\mathcal{E}_o$, the cost-effectiveness of the Standard is uncertain. The reason for the uncertainty is that the size of the accident data sample was not large enough to permit an estimate of effectiveness within narrow bounds.

The Bayesian method is unique in that it provides a measurement of the uncertainty, called the Expected Value of Perfect Information (EVPI). The EVPI is measured in dollars. It is used to determine how large a sample of additional accident data, if any, needs to be collected: since additional accident data would reduce the uncertainty about the actual effectiveness of the Standard, it will reduce the EVPI by an amount called the Expected Value of Sample Information (EVSI). But there is also a cost, C, to collect the additional data. The difference between EVSI and C is called the Expected Net Gain due to Sampling (ENGS). The number of additional accident cases that should be collected is the one that maximizes ENGS.

When ENGS is maximized by not collecting any additional accident data,(i.e when any additional data cost more than they reduce EVPI), it can be confidently concluded that the Standard is cost-effective if $\hat{\mathcal{E}} \geq \mathcal{E}_o$ and not cost-effective if $\hat{\mathcal{E}} < \mathcal{E}_o$. When ENGS is maximized for some positive number of additional accident cases, n, the n additional cases should be collected and $\hat{\mathcal{E}}$, EVPI, etc, recalculated.

The accident data used in this report are derived from the National Crash Severity Study (NCSS). There are slightly over 5500 NCSS cases on file. About the same number of additional cases will be collected each year at a cost of roughly $3 million per year.[7] This is the cost per sample that should be used when calculating ENGS. Formulas for the calculations may be found, for example, in [28].

The usual procedure, when applying the Bayesian approach, is to treat each problem separately. The EVPI is calcualted and so are the ENGS for several alternative timespans of additional data collecting (e.g., 6 months, 1 year, 2 years). Whereas the exact relationship of EVPI and ENGS varies from problem to problem, the following paradigm seems to work quite well for the problems under consideration in this report:

(1) If EVPI $\leq$ \$11 million and $\hat{\varepsilon} \geq \varepsilon_0$, the Standard is cost-effective

(2) If EVPI $\leq$ \$11 million and $\hat{\varepsilon} < \varepsilon_0$ the Standard is not cost-effective

(3a) If \$11M < EVPI $\leq$ \$17M, collect data for 6 more months and then reevaluate

(3b) If \$17M < EVPI $\leq$ \$31M collect data for one more year

(3c) If EVPI > \$31M, collect data for two more years.

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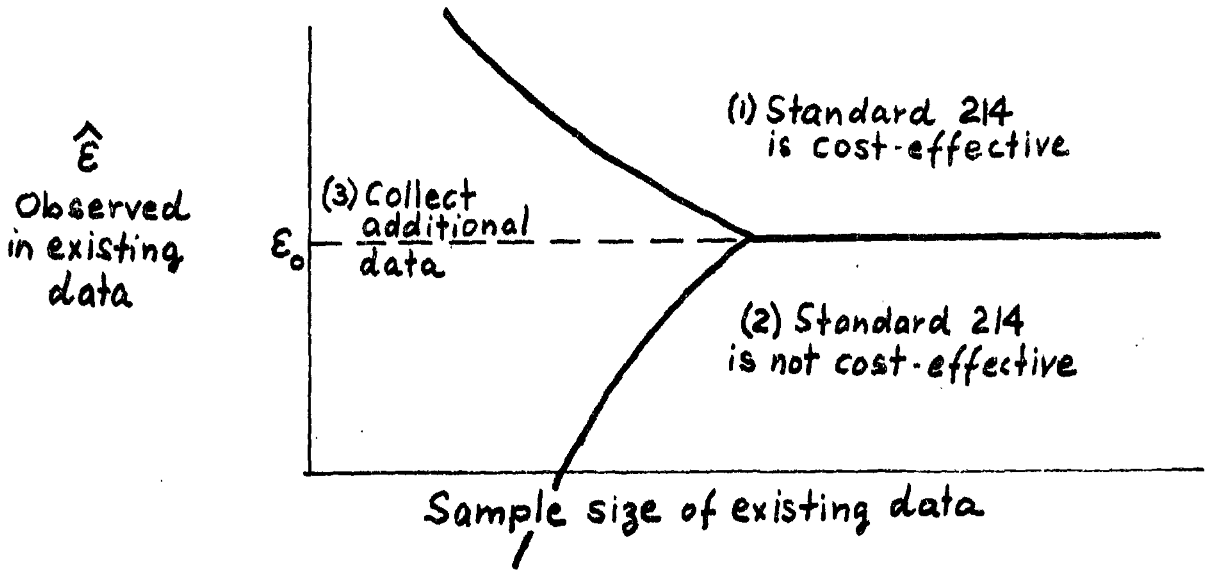
[7] This is the full cost of collecting and processing NCSS data - not merely the cost of the sidedoor impact cases. Since NCSS data are used for other purposes, one could make a case for allocating only a part of the cost to this evaluation.

Figure V-1 illustrates what conclusion would be drawn, depending on the sample size of the existing data and the observed $\hat{\mathcal{E}}$.

FIGURE V-1

CONCLUSION REGIONS WITH BAYESIAN APPROACH



Four sets of Bayesian analyses will be performed in Chapter VI. It will be determined if Standard 214 is:

(a) Definitely cost effective ($300,000 or less per EFU eliminated), based on $\hat{\mathcal{E}}$ observed in all types of sidedoor impacts,

(b) At least marginally cost-effective ($600,000 or less per EFU) based on $\hat{\mathcal{E}}$ observed in all types of sidedoor impacts,

(c) Definitely cost-effective, based on $\hat{\mathcal{E}}$ observed in single-vehicle sidedoor impact crashes,

(d) At least marginally cost-effective, based on $\hat{\mathcal{E}}$ observed in single-vehicle sidedoor impact crashes.

A detailed discussion of Bayesian decision theory may be found in [28] and in many other textbooks on applied statistics.

Acceptance Sampling

Although the Bayesian technique is well-suited to the objectives of this study, it is not universally accepted by statisticians. Acceptance sampling, which is sometimes called classical decision theory, can be modified to offer an alternative procedure that comes reasonably close to meeting the objectives.

In an orthodox acceptance sampling plan, the evaluator determines whether or not he should accept a batch of items, on the basis of a sample selected from the batch and an attribute estimated from the sample. Before choosing the sample, the evaluator must specify two distinct values for the attribute, a "good" value X_0 and a "bad" value X_1 (assume $X_1 < X_0$). He also specifies a probability α of rejecting the batch when the actual value X of the attribute for the entire batch equals X_0 and a probability β of accepting the batch when the actual value is X_1. Then he selects a sample of size n and a critical value M such that when the attribute is estimated from the sample, the estimate $\hat{X}$ satisfies

(a) Probability $(\hat{X} < M/x = x_0) = 1 - \alpha$

(b) Probability $(\hat{X} > M/x=x_1) = \beta$

In this study, the "batch" is the fleet of passenger cars; the "sample" is the NCSS data file; the "attribute" is the effectiveness of Standard 214; a "good" value for $\mathcal{E}$ is $\mathcal{E}_0$, the effectiveness required for definite cost-effectiveness; a "bad" value for $\mathcal{E}$ is zero.

In this study, however, the data have already been collected and the sample size was not under the evaluator's control. It is possible that not enough accident cases were collected and that the effectiveness $\hat{\mathcal{E}}$ observed in the sample is statistically compatible with both $\mathcal{E}_0$ and 0. It is also possible that so many cases were collected that $\hat{\mathcal{E}}$ is compatible with neither $\mathcal{E}_0$ nor 0 if it is close to $1/2\mathcal{E}_0$.

For this reason, a modified acceptance sampling procedure will be used. Three alternative hypotheses on Standard 214 effectiveness will be tested (with one-sided $\alpha = .05$).

(i) $H_0 : \varepsilon = \varepsilon_o$, the amount needed for definite cost-effectiveness

(ii) $H_1 : \varepsilon = 0$

(iii) $H_2 : \varepsilon = \frac{1}{2}\varepsilon_o$, the amount needed for marginal cost-effectiveness.

Based on the test results, the following conclusions are drawn:

(1a) If observed effectiveness is so high that H_2 must be rejected, conclude that the Standard is cost-effective.

(1b) If observed effectiveness is high enough to reject H_1 but compatible with H_2, tentatively conclude that the Standard is cost-effective with a suggestion to collect more data.

(2a) If observed effectiveness is so low that H_2 must be rejected, conclude that the Standard is not even marginally cost-effective.

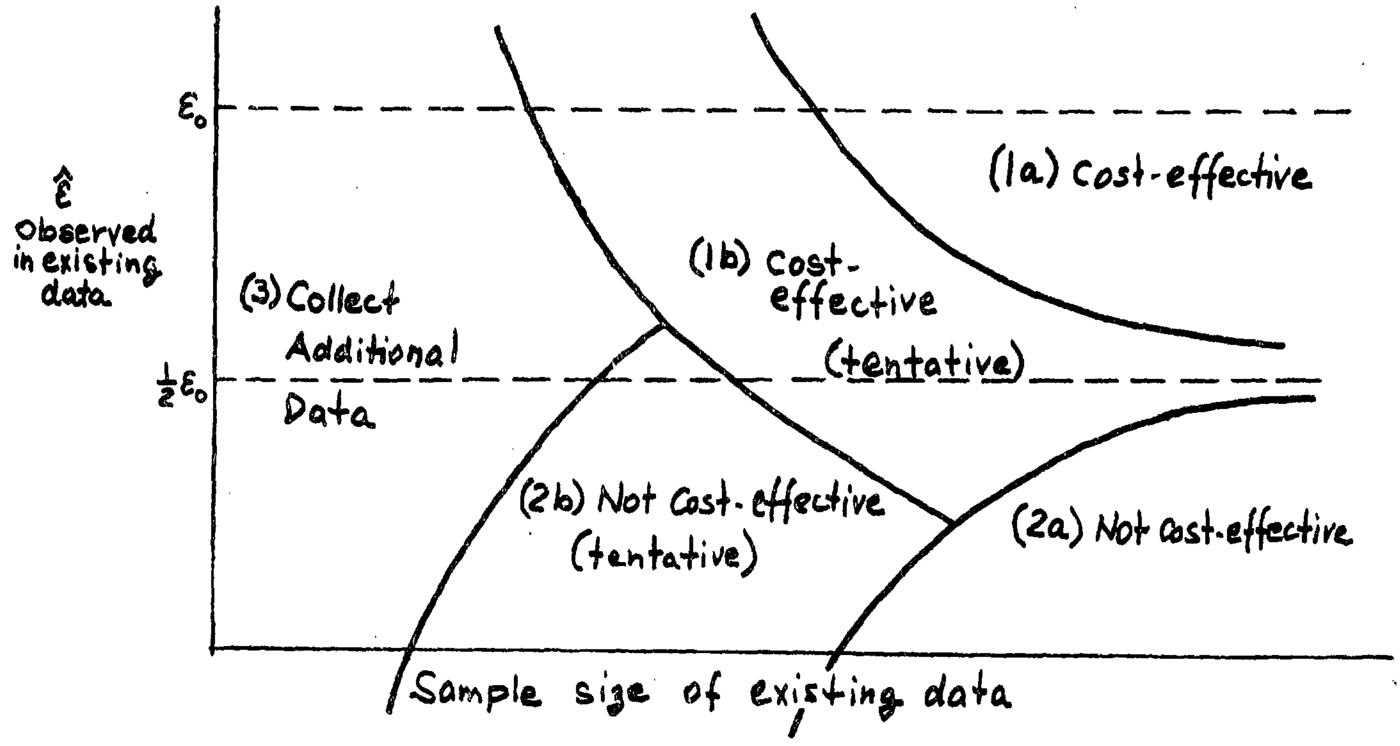
(2b) If observed effectiveness is low enough to reject H_0 but compatible with H_1 and H_2 tentatively conclude that the Standard is not cost-effective with a suggestion to collect more data.

(3) If the observed effectiveness, due to the small sample size on which it is based, is compatible with all three hypotheses, collect additional data, up to a sample size sufficient to assure rejection of at least one hypothesis.

Figure V-2 illustrates what conclusions would be drawn, depending on the amount of data collected so far and the effectiveness of beams observed in the data.

FIGURE V-2

CONCLUSION REGIONS WITH ACCEPTANCE SAMPLING APPROACH



Two sets of acceptance sampling analyses will be conducted in Chapter VI:

(a) Based on $\hat{\varepsilon}$ observed in <u>all</u> types of sidedoor impacts

(b) Based on $\hat{\varepsilon}$ observed in <u>single-vehicle</u> sidedoor impact crashes.

A detailed discussion of acceptance sampling may be found in [8] and in most other textbooks on quality control.

Alternative Methods for Evaluating Cost-Effectiveness

The most important statistic in the methods discussed so far was ε, the effectiveness of Standard 214. The parameter ε is estimated from a sample (NCSS) and is not known with certainty. The actual benefits of Standard 214 are the product of ε and the baseline number of casualties - the number that would have occurred in 1977 if the Standard had not been promulgated. The cost-effectiveness evaluation methods discussed so far assumed that the baseline number of casualties was known with certainty.

In this report, however, the baseline number of casualties is itself estimated from the NCSS sample (e.g., see Appendix B). A more conservative evaluation approach would be to treat both ε and the baseline as imperfectly known - i.e., as being estimates from NCSS. Both the Bayesian and acceptance sampling methods, with a few changes in the techniques discussed above, readily lend themselves to this approach. The application of these methods to the NCSS data under the assumption that baseline casualties are imperfectly known is carried out in Appendix E.

Methods for Evaluating Intrusion Reduction

Since no quantitative relationship between intrusion and occupant casualties has been established (see Chapter III) it would not be meaningful to establish a "cost-effective" level of intrusion reduction for Standard 214. The Bayesian and acceptance-sampling approaches are not appropriate for establishing if the Standard is effective in reducing intrusion.

The only feasible test of intrusion-reducing effectiveness, then, is to test the simple hypothesis that effectiveness is zero. Since there appears to be no meaningful alternative hypothesis at this time, any results of such a test should be viewed with caution.

Furthermore, results on intrusion are not an adequate substitute for results on casualty reduction. For example, if Standard 214 were demonstrated <u>not</u> to reduce casualties, almost any decision-maker would consider it a poor standard, regardless of what it does for intrusion.

The purpose of the intrusion reduction analysis, in other words, is to provide additional insight on the conclusions of the cost-effectiveness analysis. Specifically,

(1) If the cost-effectiveness analysis is inconclusive, a clear positive result on intrusion reduction would at least demonstrate that the Standard is performing as intended. Since intrusion in sidedoor impacts is more frequent than severe injury (See Chapter III) it may be possible to obtain significant results on the former with a substantially smaller amount of accident data.

(2) If the cost-effectiveness analysis leads to clear positive or negative results but the intrusion reduction analysis leads to the opposite result, the former should be carefully reviewed. It is possible that the discrepancy is due to certain biases in the data that were not controlled for, or even due to a counterintuitive relationship between Stanard 214, intrusion and injury.

(3) If the results on intrusion and injury are in the same direction, it would strengthen confidence in any conclusions.

CHAPTER VI

BENEFIT ANALYSIS: PROCEDURES AND FINDINGS

Introduction

Since the fall of 1976, NHTSA's National Center for Statistics and Analysis has been conducting a National Crash Severity Study (NCSS). This is the first ongoing system for obtaining nationally representative accident data at a level of detail suitable for evaluating Federal Motor Vehicle Safety Standards. Arrangements were made with the National Center to collect on each NCSS case the specific variables required for evaluating Standard 214.

This chapter begins with a discussion of the NCSS data file and special considerations that apply when using the data. Next, there is an explanation of the procedures for deriving the effectiveness of the Standard from the observed injury rates. (The need for such procedures was first discussed in Chapter V, definitions 5-7.) The findings on the casualty-reducing effectiveness of Standard 214, based on 5557 NCSS cases on file in Batch 21, are then presented. Finally, cost-effectiveness and intrusion reduction are analyzed, using the statistical methods proposed in Chapter V.

The NCSS Data

Seven multidisciplinary accident investigation teams under contract to NHTSA are collecting the NCSS data. The geographical areas in which they work were purposely chosen by NHTSA to represent the United States as a whole. They have almost the same distribution of central city, suburban, small-town and rural population as the nation; there is at least one NCSS team in each of the nation's four demographic regions. The team selects accidents for investigation within its area according to a strict probability sampling scheme. The sampling frame consists of police-reported "automobile towaway accidents" - i.e., crashes in which at least one passenger car was towed from the scene due to crash damage and in which a police officer filed an accident report. The NCSS file has an occupant-oriented record structure: there is a record for each occupant of a towed passenger car. The record contains vehicle and crash configuration information as well as a description of the occupant and his injuries.

The variables collected by the NCSS investigators include those that would typically be desired for analyses of crashworthiness: accident configuration; crash severity (ΔV, the vehicle's velocity change during the contact phase calculated using the CRASH accident reconstruction program [20].); principal direction of crash force (PDOF); location of damage on the vehicle; vehicle make, model and model year; occupant seating position, belt usage, injury severity (AIS-Abbreviated Injury Scale), specific injury type and injury source. NCSS is the first file ever to contain all these variables. Furthermore, for the purpose of this evaluation, NCSS investigators reported whether there was occupant compartment intrusion, what was the source of thc intrusion and (after April 1, 1978) how deep it was (measured in inches).

There were 5557 accident cases in Batch 21 of the NCSS file, containing about 15,000 occupant records. (Fewer than 5 percent of these occupants were involved in sidedoor impacts). The file is growing at the rate of about 5000 accident cases per year. Data should accumulate indefinitely since, even after the planned NCSS phase-out, it will be replaced by a comparable system.[1] A detailed discussion of the NCSS can be found in [16].

Special Considerations for Using NCSS Data

Five characteristics of the NCSS file need to be given special consideration before proceeding with analyses of Standard 214 effectiveness.

1. The NCSS file, as used in this report, consists exclusively of occupants of towed passenger cars. (The full NCSS file also contains a small and non-representative sample of non-towed car occupants. They were not included in the analyses of this report.) Two potential biases in beam effectiveness calculations could result. First, calculations based on the NCSS data do not account for injuries that might occur in non-towaway

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[1] NHTSA's National Accident Sampling System (See [27]).

crashes. Since, however, only a few percent of the severe injuries occur in non-towaway crashes, the consequent bias is negligible and can be disregarded. (See, for example, J. O'Day, A. Wolfe & R. Kaplan, Design for NASS (Volume 2), DOT HS-801-914; or H. Joksch, "Design of Field Passive Restraint Evaluation," Center for the Environment and Man Report No. 4250-641).

A more serious potential bias is that the presence of beams could influence whether a car needs to be towed. For example, beams might alleviate crash damage to the extent that a beam-equipped car would still be operable after a crash that would have caused a non-beam-equipped car to be towed. In that case the beam-equipped car would not be on the NCSS file but the unequipped car would be. As a result, the beam and non-beam populations on NCSS would not be comparable. The former would be a more severe class of accidents.

A preliminary analysis was performed on the NCSS file to see if, indeed, beams reduced the need for towing. The analysis consisted of looking at those front-to-side two-car crashes in which the striking (frontal damage) vehicle had to be towed. How often did the struck vehicle also need towing in these crashes? It turned out that 66 percent of the beam-equipped struck vehicles needed towing, but only 60 percent of the unequipped struck vehicles. The differences in proportions is not statistically significant.

Based on this analysis, it cannot be concluded that beams reduce the need for towing. This source of potential bias, then, can probably be disregarded.[2] Additional analyses of the problem will be conducted in the follow-up reports.

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[2] Sue Partyka, National Center for Statistics and Analysis, NHTSA performed this analysis.

2. The NCSS investigators select which accidents are to be investigated by a rigorous probability sampling scheme. But NCSS is not a simple random sample. It is a stratified random sample, with three strata and unequal sampling proportions. All accidents in which at least one towed car occupant is killed or hospitilized overnight are investigated. If no towed car occupant is killed or hospitalized overnight, but at least one is transported from the accident scene to a medical treatment facility, there is a 25 percent chance it will be selected for NCSS. A 10 percent sample of all other accidents involving towed passenger cars is taken.

The objective of the stratified sampling with unequal proportions was to obtain substantially more precise estimates of injury and fatality rates than would have been possible from a simple random sample of towaway accidents of the same size or cost. That objective was admirably achieved; nevertheless, the sampling plan somewhat complicates statistical analyses.

A reliable empirical method for adjusting the significance levels lies in the use of replicated estimates. The Highway Safety Research Institute [29] will develop this method for application to NCSS, but their programs will not be available for some time.

In this study, significance levels will be adjusted by a simpler technique. There will be a single adjustment factor for all analyses of the effect of Standard 214 on AIS $\geq$ 3 injury, another factor for analyses of AIS $\geq$ 2 injury etc.

The adjustment factor for AIS $\geq$ 3 analyses will be calculated as follows: The rate of AIS $\geq$ 3 injury in the <u>entire</u> NCSS file is calculated. The standard deviation of this rate is calculated by two techniques.

(1) The spuriously low standard deviation that is calculated from the weighted tabulation, where one pretends one has a simple random sample of the size given in the table.

(2) The true standard deviation for this rate calculated using the formula [17] that applies to stratified samples.

The NCSS data are shown in Table VI-1

The first standard deviation,

$$\sigma_{\text{srs}} = \frac{1}{39053}\sqrt{\frac{38052 \times 1001}{39053}} = .00080$$

The second standard deviation,

$$\sigma_{\text{NCSS}} \cong \frac{1}{39053}\sqrt{\left(\frac{2566 \times 815}{3381} + \frac{9256 \times 136}{2348} + \frac{26230 \times 50}{2628}\right)} = .00104$$

TABLE VI-1

NCSS DISTRIBUTION*OF INJURY BY SAMPLING STRATUM

A. Actual NCSS Sample

Stratum	Actual Number of Occupants AIS < 3	AIS $\geq$ 3	Total
100%	2566	815	3381
25%	2314	34	2348
10%	2623	5	2628
			8357

B. Weighted by Inverse Sampling Fraction (Counts that would appear in tabulations)

Stratum	Tabulated Number of Occupants AIS < 3	AIS $\geq$ 3	Total
100%	2566	815	3381
25%	9256	136	9392
10%	26230	50	26280
	38052	1001	39053

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* Includes only the unrestrained occupants of towed passenger cars for whom one could reliably determine whether or not AIS was greater than or equal to 3 (see also Appendix C.)

The quotient of the two statistics, $\sigma_{srs}/\sigma_{NCSS} = .769$ is the proportion by which any statistics on AIS ≥ 3 injuries, proportional to the square root of the sample size and calculated from NCSS tabulations, shall be diluted to reflect the actual amount of data in the NCSS sample. Z-scores and confidence intervals, in particular, are proportional to the square root of the sample size, χ^2 values, CONTAB information statistics and other quantities proportional to the sample size will be diluted by $\sigma^2_{srs}/\sigma^2_{NCSS} = .592$.[3] The dilution factors for AIS $\geq$ 2 injury are similarly calculated and are .685 and .469, respectively, for the two types of statistics. For fatality statistics, no dilution is necessary, since all fatalities are in the 100 percent stratum. Dilution factors for other statistics are shown in Table VI-2.

The use of a single dilution factor for a given injury criterion is, of course, not entirely accurate. The correct factor would vary somewhat from specific analysis to analysis. Nevertheless, the bias in using a single

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[3] The NCSS sample, in other words, has the power of a simple random sample of size 23119 = .592X39053 when it comes to providing information about AIS $\geq$ 3 injuries. Since the actual NCSS sample size (see upper half of Table VI-1) is only 8357, the precision gains due to the stratified sampling plan are impressive.

TABLE VI-2

DILUTION FACTORS NEEDED TO ACCOUNT FOR NCSS SAMPLING PLAN

Subject of Statistic:	Dilution Factor for Statistics Related to:	
	Square-Root of Sample Size	Sample Size
Fatalities	1.0	1.0
AIS $\geqslant$ 3 injury	0.769	0.592
AIS $\geqslant$ 2 injury	0.685	0.469
Any injury	0.466	0.217
Presence of Intrusion	0.376	0.141

factor is probably negligible in comparison to the sampling errors that will be typically encountered in these analyses. More importantly, failure to use any factor would have lead to a much more serious problem of spurious significant results, especially on intrusion and AIS $\geqslant$ 2 injury reduction.

3. In the NCSS data that have been automated so far, intrusion is defined as "any reduction of space in occupant compartment." Thus, any side impact which resulted even in a negligible inward deformation of the interior surface of the door was classified as "side intrusion." As a consequence of the definition, it can be expected that:

(1) intrusion is very common in all but the most trivial impacts

(2) there is a limited utility of the "intrusion" variable in explaining the effect of FMVSS 214, which is primarily aimed at reducing the severity of moderate intrusion rather than reducing minor intrusion to none.

As a result, the failure to obtain clear positive results on intrusion reduction by FMVSS 214 in the NCSS data should certainly not be viewed as a failure of the standard in this area.

After April 1, 1978, the NCSS investigators began coding the <u>depth</u> of intrusion, in inches, as well as its mere presence. When a substantial number of cases with the new variable become available, better analyses can be conducted.

4. The rather high rate of unknown and missing data on injury severity in NCSS creates a potential for significant bias. The overall AIS is recorded unknown or missing for 33% of NCSS occupants.

In this study, an attempt has been made to reduce the missing data somewhat by taking into account the type of treatment the occupant received. If AIS is coded "unknown" but it is known that the occupant received "no treatment" it is assumed that AIS $<$ 2 (since over 98% of AIS 2 injuries require some medical treatment [11]). If AIS is "unknown" but the occupant was "not transported" to a treatment facility, it is assumed that AIS$<$3 (since 96 percent of AIS 3 injuries require immediate attention and transport for treatment [11]). With these modifications, the "missing" data" rate on AIS ≥ 2 has been reduced from 33 percent to 21 percent and on AIS ≥ 3 all the way down to 9 percent. For fatalities, there is no problem of missing data, since detailed injury information is not required.

The missing data rates of 21% and 9% for AIS$\geq$2 and AIS$\geq$ 3 can be considered tolerably low for the purpose of estimating beam effectiveness - i.e. one may simply ignore the cases with missing data when performing the effectiveness calculation. It should be kept in mind that "effectiveness" is a ratio of injury rates, so if both injury rates are biased about the same due to missing data, the biases will cancel out when the ratio is taken. The ratio would only be biased if the injury rates for beam-equipped and non-equipped vehicles are biased <u>in different ways</u> as a result of missing data. There is no reason to assume however, that substantial differences exist. In fact, as Table VI-3 shows, the rates of missing data are almost identical for the two vehicle classes. Although this does not prove that the AIS distributions within the missing data are identical for the two groups, it is reassuring evidence that the differences, if any, are small.

TABLE VI-3

MISSING INJURY-SEVERITY DATA RATES FOR OCCUPANTS OF BEAM EQUIPPED AND UNEQUIPPED CARS

	Not Beam Equipped	Car Was Beam Equipped
No. of occupants	18624	22065
AIS $\geqslant 2$		
N missing	3915 21%	4574 21%
AIS $\geqslant 3$		
N missing	1685 9%	1892 9%

ΔV , the velocity change during impact, is coded missing or unknown in 30 percent of sidedoor impacts. But ΔV is only used secondarily as a control or standardizing variable. There are no large differences in either the known ΔV distributions or missing data rates of beam-equipped and unequipped cars. In the context of this study, then, missing ΔV is unlikely to be a serious source of bias.

5. The primary Collision Deformation Classification (CDC) [5] is used to determine which vehicles were involved in sidedoor impacts. The first letter of the CDC (which specifies the general area of damage) has to be L (left side of the car) or R (right side). The second letter (specific horizontal location of damage) has to be P (sidedoor area), Y (sidedoor area + front fender area), Z (sidedoor area + rear fender area) or D (sidedoor area + both fender areas). With this classification, all cars

that have any sidedoor damage are included among the sidedoor impacts even if most of the damage due to the primary impact is in the fender area. It is in harmony with the definition of a sidedoor impact that was given in Chapter V. The secondary CDC will not be used for classifying the impacts.

Factors that Confound Effectiveness Estimates

The fatality and injury rates for occupants involved in impacts of pre-Standard and post-Standard cars are shown in Appendix C. The rates are lower in the post-Standard cars. The differences are partly due to the casualty-mitigating effect of Standard 214 and partly due to other differences between pre-Standard and post-Standard cars.

The definition of effectiveness given in Chapter V, however, is the proportion of sidedoor impact casualties eliminated as a consequence of Standard 214. All the other differences between pre-Standard cars and post-Standard cars that make the latter safer must be identified. Statistical techniques must be developed that will remove the injury reduction due to the extraneous factors. Whatever injury reduction then remains is due to the Standard, alone, and is a measure of its effectiveness.

The most obvious difference between the pre-standard and post-standard cars is that the former are older. The latter meet more of the Federal Motor

Vehicle Standards that were subsequently promulgated, and are heavier (the NCSS data were collected largely before the current downsizing campaign). Moreover, there is a so-called "age effect" that, in general, causes occupants of newer cars to have lower injury rates according to most accident data (see, for example, [9]). These three factors - other Standards, increased vehicle weight and "age effect" -- will now be clarified in turn. Moreover, preliminary assessments of the relative size of each factor will be developed on the basis of the literature. Finally, some additional potential confounding factors, none of which proved to have much effect in NCSS, will be discussed.

1. Effects of Other Motor Vehicle Safety Standards: Parallel standards that could mitigate injury in sidedoor impacts were discussed in Chapter III. It was concluded that only Standards 201, 205, 206, 208, 209 and 210 were relevant. Standards 201, 205 and 206 became effective 5 years before Standard 214 and 9 years before NCSS data collection began and there was extensive early compliance. Thus, 70-90 percent of the pre-Standard 214 cars on the NCSS file are post-Standard 201, 205 and 206. At most a negligible difference in the injury rates of beam-equipped and unequipped cars could be attributed to these 3 standards.

Standards 208, 209 and 210, on the other hand, could have a non-negligible confounding effect because they were responsible for an increase in safety belt usage. Table VI-4 shows the trend toward increasing seatbelt usage in NCSS accidents. Belt usage is 2 percent in the pre-Standard 214 cars and 9 percent in the post-Standard cars. The 7 percent increase in belt use, coupled

TABLE VI-4

TIME TRENDS IN BELT USAGE BY PERSONS INVOLVED IN SIDEDOOR IMPACTS

	Percent Belt Usage			
	Model Years 1968 & Earlier	Model Years 1969 - 1972	Model Years 1973 & Later	All Model Years
Cars without beams	1	3	N.A.	2
Cars with beams	N.A.	5	10	9
All cars	1	4	10	6

TABLE VI-5

TIME TRENDS IN THE WEIGHT OF CARS STRUCK IN THE SIDEDOOR

	Mean Vehicle Weight (pounds)			
	Model Years 1968 & Earlier	Model Years 1969 - 1972	Model Years 1973 & Later	All Model Years
Cars without beams	3381	3071	N.A.	3217
Cars with beams	N.A.	3869	3308	3444
All cars	3381	3432	3308	3363

with a 40-60 percent effectiveness of belts when used [25], yields an injury reduction of approximately 3-4 percent for occupants of Standard 214 cars that is due to belts and not to beams. Belt usage rates in the NCSS (towaway accidents) are much lower than those reported for the non-accident population [30]. The former rates are the ones that are relevant to the analysis of a crash standard such as FMVSS 214.

2. Weight Gain: Table VI-5 shows that the Standard 214 cars on the NCSS file weighed an average 227 pounds more than the pre-Standard 214 cars. Additional mass provides resistance to velocity change, in a collision with a movable object, and increased structural strength in many types of crashes. Each incremental 100 pounds reduces serious injury rates by about 5 percent [14]. About 3/5 of that is due to ΔV being reduced in collisions with moveable objects. The confounding effect of ΔV on injury rates is discussed below. The remainder, about 2 percent per 100 pounds, is the confounding effect due solely to vehicle weight. Since Standard 214 cars are 227 pounds heavier, one might expect a 4 1/2 percent injury reduction due to weight and not to beams.

   Table VI-5 shows that the heavier weight of the Standard 214 cars is the result of beams being introduced on larger cars earlier than on small ones (see also Table III-9). Beam-equipped cars of model years 1969-72 are 798 pounds heavier then non-equipped cars of that period. The older non-equipped cars, though, are actually 73 pounds heavier, on the average, than the newer beam-equipped ones.

3. <u>The "Age Effect"</u>: One explanation given for the higher injury rates of older cars is that they are driven in a manner that results in more severe accidents. It can be expected then, that older cars have a higher average ΔV in accidents. Table VI-6 shows that in fact, the non-Standard 214 cars had a mean ΔV of 15.0 mph in the sidedoor impacts, versus 14.2 for the new cars. The difference is so small, probably because:

(1) The towaway criterion in the NCSS makes its accidents a somewhat more homogeneous class than, say, the accidents found on Traffic Records Systems,

(2) In sidedoor impacts, the driver of the struck vehicle is usually not culpable, so this class of accidents would be less reflective of driving habits than frontals.

Nevertheless, a 0.8 mph reduction in ΔV, coupled with a reduction in injury rates of roughly 6-7 percent for each decrement of 1 mph in average ΔV (See, for example, Table III-4), yields an injury reduction of about 5 percent of occupants of Standard 214 cars that is due to ΔV and not to beams.

TABLE VI-6

TIME TRENDS IN THE SEVERITY OF SIDEDOOR IMPACTS

Mean Delta V (mph)

	Model Years 1968 & Earlier	Model Years 1969 - 1972	Model Years 1973 & Later	All Model Years
Cars without beams	14.8	15.2	N.A.	15.0
Cars with beams	N.A.	12.6	14.8	14.2
All cars	14.8	14.0	14.8	14.5

There may be an additional "age effect" unexplained by ΔV. Owners of older cars may be less likely to report non-injury accidents. As a result, the injury rate would be somewhat higher in those accidents that are reported. The main reason for underreporting of non-injury accidents of older cars is the legal reporting criterion that applies in most States: "personal injury or $250 (or a similar amount) of property damage." Since a car's value declines steeply with age, the class of non-injury accidents that need not be reported because they fail to meet the minimum property damage requirement is larger for older cars than for newer ones.

Moreover, one would expect a lower degree of underreporting in multivehicle crashes than in single vehicle crashes. In the former type of crash, chances are fairly high that at least one of the cars involved is fairly new and sustains reportable damage. Even if all of the cars are old, there is a high probability that the sum of the damage costs for all cars exceeds the reporting criterion. Finally, in a multivehicle crash, one of the involved parties is likely to make an insurance claim against another party and he will desire an accident report to substantiate his claim.

In a single vehicle crash, on the other hand, if the lone involved vehicle has a replacement cost less than the reporting criterion and if there is no significant damage to other property, there is neither a requirement nor a motivation to report the accident.

One would expect, then, to find substantial underreporting only of single vehicle accidents of cars that are quite old (i.e., have replacement value less than the reporting criterion - typically cars more than 10 years old). For cars of medium age (6-10 years) one would expect much less underreporting: their replacement value usually exceeds the reporting criterion and their repair costs (if below the replacement value) do not differ too greatly from those of new cars.

The NCSS data were analyzed for reporting bias using two different techniques. The analyses are documented in Appendix F. The results confirm what was expected, based on the above discussion, i.e.,

- No underreporting of older cars or other unexplained age effect in multivehicle crashes.
- No underreporting or age effect in single vehicle crashes for cars up to 10 years old (model years 1967-77 on NCSS).
- Substantial underreporting in single vehicle non-injury crashes of cars over 10 years old (model year 1966 and earlier on NCSS) resulting in a doubling of the reported injury rate for those cars.

The analyses of Appendix F, then, suggest that about 27-46 percent of the single vehicle crashes involving cars of model year 1966 or earlier are not reported. These cars account for 25 percent of the pre-Standard 214 cars on the NCSS file. Thus, in all, about 7-11 1/2 percent of the single vehicle crashes of pre-Standard cars are unreported. One may expect the reported injury rates of these cars to be overstated by that amount.

The four principal confounding factors and their effects are summarized separately for single and multivehicle crashes in Table VI-7. The composite effect of the four factors, 12 percent in multivehicle crashes and 20 percent in single vehicle crashes, are the amounts by which we might expect injury rates in beam-equipped cars to be lower even if beams were totally ineffective.

In Chapter V it was shown that Standard 214 could be considered cost-effective if it reduced deaths and injuries by 10.8 percent or more.

TABLE VI-7

SUMMARY OF FACTORS THAT MAY CONFOUND
FMVSS 214 EFFECTIVENESS ESTIMATES

Factor[4]	Expected Effect[5] In Multivehicle Crashes	Expected Effect[5] In Single Vehicle Crashes
1. Increased belt usage	3 1/2%	3 1/2%
2. Increased vehicle weight	4 1/2%	4 1/2%
3. Reduced accident severity	5%	5%
4. Age effect other than accident severity reduction	0	9%
COMPOSITE EFFECT[6]	12%	20%

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[4] Difference between FMVSS 214 cars vis-a-vis non-FMVSS 214 cars

[5] Reduction in injury rates of FMVSS 214 cars due to factor

[6] 100% - (96 1/2%) . (95 1/2%) . (95%) = 12%

Erroneous attribution to Standard 214 of effects actually due to confounding factors could potentially lead to a spurious conclusion that the standard is cost effective.

4. Other Potential Confounding Factors. Since the post-Standard cars are generally newer than the pre-Standard cars, it is possible that some change in vehicle design other than Standard 214, that took place at about the same time as the Standard's effective date, may be confounding the results. Design changes mandated as FMVSS were previously discussed. Vehicles of the model year close to 1969-73 (when Standard 214 was implemented) were studied for possible major design changes not made specifically in response to Federal standards. The major design trends appeared to be (1) an increased proportion of cars with B pillars - 65 percent of the Standard 214 cars had B pillars, versus 45 percent of the pre-Standard cars. (2) An increased proportion of 2 door cars - 60 percent of the Standard 214 cars versus 50 percent of the pre-Standard cars. (3) An increased proportion of bucket and split bench seats (which may have better lateral crashworthiness because they are fastened to the floor in more places than bench seats) - 50 percent of the Standard 214 cars versus 35 percent of the pre-Standard cars. In no case were the distributions sufficiently different between pre-Standard and post-Standard 214 cars to substantially confound effectiveness estimates. Also, possible design changes affecting the likelihood of ejection are not confounding the results because the effectiveness estimates shown in the rest of this chapter change by just a few percent if all ejectees are removed from the calculations. (Furthermore, to the extent that Standard 214 itself may be effective in reducing ejection, it is probably not valid to exclude the ejectees from the calculations).

The accident and occupant distributions on NCSS were also examined for possible major differences in the pre-Standard and post-Standard cars. Specifically, older cars are thought by some to be overinvolved in rural accidents. In fact, on NCSS, 22 percent of the pre-Standard car involvements were rural, versus 25 percent of the post-Standard cars. It has also been said that older persons tend to ride in older cars. In fact, on NCSS 16 percent of the pre-Standard car occupants involved in sidedoor impacts were age 50 or more, versus 17 percent of the post-Standard car occupants.

In short, no major source of confounding or bias has been found, other than restraint usage, vehicle weight, ΔV and the underreporting of old cars in single vehicle crashes.

The effects shown in Table VI-7 are those that one <u>might expect</u> to find in the NCSS data, based on the literature on seat belts, vehicle weight, etc. The purpose of the calculations was to provide an impression of how important the confounding factors might be and how much effort to eliminate them would be worthwhile. In the estimates of Standard 214 effectiveness that follow, however, the <u>actual</u> confounding effects in the NCSS data will be estimated empirically from the data themselves and automatically removed from the injury reduction attributed to beams, using statistical techniques that will now be described.

Techniques for Eliminating the Confounding Factors

The key statistical technique for removing confounding efffects is a combination of "standardizing" and "smoothing" the data. The technique was used quite successfully by Hochberg, Reinfurt and others in estimating seat belt effectiveness from Restraint Systems Evaluation Project data. A detailed description may be found in [24] or [25]; only a brief summary is needed here.

"Standardizing" the data has also been called "normalizing" the data, "controlling" for other variables, "adjusting" the marginals to reflect the population, "post-stratification," and "using a Mantel-Haenszel estimator." It means adjusting the beam-equipped and unequipped populations to have the same marginal distributions on all confounding variables (ΔV, vehicle weight, etc.). This process removes any difference in injury rates that might have been due to those confounding factors. The difference in injury rates of the two standardized populations is attributed to Standard 214.

For illustration, a fictitious example of standardizing the data for a hypothetical FMVSS 800 is given in Table VI-8. Note that the relative difference in the injury rates for the unstandardized data (53 percent) greatly overstates the effectiveness of the standard. The difference is, to a large extent, due to the fact that the post-standard vehicles had less severe accidents (only 20 percent had $\Delta V \geqslant 20$, as opposed to 60 percent for the pre-standard cars). After standardizing the populations, the true effectiveness of "Standard 800" is found to be only 35 percent. In the standardized populations, the ΔV distributions for pre- and post "Standard 800" vehicles are identical and are the same as the distribution would be for the combined pre- and post "Standard 800" populations in the unstandardized data.

When there are a number of confounding variables and relatively little data there is a risk of substantial statistical error if data are standardized. It is like trying to adjust too many marginals at the same time, given the

TABLE VI-8

FICTITIOUS EXAMPLE SHOWING TECHNIQUE OF STANDARDIZING THE DATA TO EVALUATE "FMVSS 800"

(a) Unstandardized (raw) data

Pre-FMVSS 800 cars

		$\Delta V < 20$	$\Delta V \geq 20$	
AIS ≥ 2	#	100	300	400
	%	25%	50%	40%
AIS < 2	#	300	300	600
	%	75%	50%	60%
		400	600	

FMVSS 800 cars

		$\Delta V < 20$	$\Delta V \geq 20$	
AIS ≥ 2	#	240	140	380
	%	15%	35%	19%
AIS < 2	#	1360	260	1620
	%	85%	65%	81%
		1600	400	

Relative difference in injury rates = $\frac{.4 - .19}{.4}$ =53%

(b) Standardized data

Pre-FMVSS 800

		$\Delta V < 20$	$\Delta V \geq 20$	
AIS ≥ 2	#	500	500	1000
	%	25%	50%	33%
AIS < 2	#	1500	500	2000
	%	75%	50%	67%
		2000	1000	

Post FMVSS 800

		$\Delta V < 20$	$\Delta V \geq 20$	
AIS ≥ 2	#	300	350	650
	%	15%	35%	22%
AIS < 2	#	1700	650	2300
	%	85%	65%	78%
		2000	1000	

Actual effectiveness of FMVSS 800 = $\frac{.333 - .216}{.333}$ =35%

amount of data available. A "smoothing" technique, such as multidimensional contingency table analysis (CONTAB) reduces the risk of error. CONTAB looks at the confounding variables and their interactions and tells the analyst which effects are so unimportant (in a statistical sense) that they can safely be excluded from the standardization process. Moreover, CONTAB tells the analyst, after standardizing the important confounding effects, whether or not the difference in the standardized injury rates is statistically significant. A detailed discussion of CONTAB appears in [7] and [18]. Its application to the problem of estimating effectiveness of seat belts is described in [24] and [25][7].

The technique of standardizing and smoothing will do a good job for removing the confounding effects of vehicle weight and ΔV differences in the beam-equipped and unequipped populations. According to Table VI-7, these were expected to be the two most serious confounding factors. Strictly speaking, one cannot standardize or apply CONTAB directly to vehicle weight or ΔV, since these are continuous variables whereas the models require categorical variables, such as "male -female." In this study, vehicle weight and ΔV are transformed into categorical variables as follows:

(1) Weight < 3500 lbs. or unknown; weight $\geq$ 3500 lbs.; each category contains very nearly half the vehicles on NCSS. (Vehicle weight is unknown in fewer than 1 percent of the NCSS sidedoor impact cases.)

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[7] Note, however, that Hochberg, Reinfurt and Silva did not use the CONTAB program. They used ECTA and GENCAT, which serve the same purpose.

(2) $\Delta V < 17$; $\Delta V \geq 17$; ΔVunknown; each category contains close to 33 percent of the sidedoor impact AIS $\geq$ 3 injuries on NCSS. This technique of transforming continuous variables into dichotomies and choosing the boundary between categories is similar to what Hochberg and Reinfurt did.

The technique is not useful for removing the confounding effect of increased belt usage, because the belt usage among occupants of pre-Standard 214 vehicles is so low (2 percent) that there would not be enough data to allow meaningful standardization of rates. The confounding effect of belt usage is easily eliminated, however, by performing all analyses using unrestrained occupants only. There are so few belt users (6 percent) in NCSS that, by disregarding them, one sacrifices little in terms of sample size. The risk of bias is also negligible.

The "age effects" other than ΔV, i.e., underreporting of old cars in single vehicle impacts, cannot be easily controlled for, since they are not described by any specific variable that can be used for standardizing and smoothing.[8]

The potential techniques for removing these effects, none of them entirely satisfactory, are:

(1) Assuming the effect is negligible.

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[8] "Vehicle age" cannot be used as a standardization variable because there are no beam-equipped cars more than 10 years old and no unequipped cars less than 7 years old.

(2) Excluding vehicles of model year 1966 and earlier from the calculation of effectiveness in single vehicle crashes. This removes the reporting bias at the expense of reducing the sample-size of pre-Standard cars.

(3) Using non-sidedoor impacts as a "control group" to be compared with sidedoor impacts. The ratio of the injury rates of occupants of post-Standard and pre-Standard 214 cars is calculated for both the sidedoor impacts and the control groups. The effectiveness of Standard 214 is estimated by the relative difference of the ratios. This technique is also unsatisfactory because it increases sampling error and because the age effect may have been different in the sidedoor impacts and the control group.

All three techniques will be used in obtaining estimates of Standard 214 effectiveness, but preference will be given to results using the first technique, since the sampling errors are smaller.

Findings on the Effectiveness of Standard 214

Based on the NCSS data collected so far, it can be concluded that Standard 214 is very effective in preventing fatalities and non-minor injuries in single-vehicle sidedoor impacts. Table VI-9 shows that beams eliminate an estimated 74 percent of the fatalities in such crashes. Since there were about 3750 single vehicle sidedoor impact fatalities per year prior to the promulgation of Standard 214 (See Table II-2 and Appendix B), this means that the Standard, when available for the whole vehicle fleet (i.e., by the mid 1980's), will save nearly 2800 lives a year in this type of crash alone. Moreover, beams reduce the likelihood of AIS $\geq$ 3 injury by 66 percent and AIS $\geq$ 2 injury by 60 percent; the Standard will prevent nearly 4000 severe or life-threatening injuries and 3000 moderate injuries per year. These results are precise, in a statistical sense: Table VI-9 shows that the standard deviation of each estimate is approximately 11. The confidence interval for estimated fatality reduction ranges from 56 percent up to 92 percent. Even if the actual fatality reduction were near the bottom of the range, it would still be impressive. The observations of effectiveness are all significantly greater than zero, in a statistical sense. Because of the clearly positive result and the narrow confidence bounds, the NCSS data collected so far provide a definitive answer on single vehicle sidedoor impacts. Additional data might result in quantitative changes in estimated effectiveness, but not in a qualitative change.

For all types of sidedoor impacts (single vehicle and multivehicle combined), the results are far less definitive. As Table VI-10 shows, the observed effectiveness for fatalities, AIS $\geq$ 3 and AIS $\geq$ 2 is not significantly greater than zero. The confidence bounds are relatively large and, for AIS $\geq$ 3 and AIS $\geq$ 2, include negative numbers. The observed effectiveness in all three cases, however, is in the right direction (31 percent fatality reduction, 17 percent AIS $\geq$ 3 reduction and 18 percent AIS $\geq$ 2 reduction) and approaches statistical significance. When one additional year of NCSS data becomes available, there may well be significant results in all three categories.

TABLE VI-9

ESTIMATED EFFECTIVENESS OF STANDARD 214 IN SINGLE VEHICLE SIDEDOOR IMPACTS

Type of Injury	Estimated Effectiveness	Standard Deviation of Estimate	Confidence Bounds for Effectiveness		Effectiveness Significantly Different From Zero?
			Lower	Upper	
Fatalities	74%	11.1	56%	92%	Sig. > 0
AIS $\geqslant 3$	66%	10.8	48%	84%	Sig. > 0
AIS $\geqslant 2$	60%	11.4	41%	79%	Sig. > 0
Any Injury	18%	13.1	- 4%	39%	No

TABLE VI-10

ESTIMATED EFFECTIVENESS OF STANDARD 214 IN ALL TYPES OF SIDEDOOR IMPACTS

Type of Injury	Estimated Effectiveness	Standard Deviation of Estimate	Confidence Bounds for Effectiveness		Effectiveness Significantly Different From Zero?
			Lower	Upper	
Fatalities	31%	16.6	4%	58%	No
AIS $\geqslant 3$	17%	14.2	- 7%	40%	No
AIS $\geqslant 2$	18%	12.3	- 2%	38%	No
Any Injury	1%	8.2	-13%	39%	No

Beams do not appear very effective in reducing minor injury in sidedoor impacts (1 percent) or even in single vehicle sidedoor impacts (18 percent).

The raw data tabulations from the NCSS file, which form the basis for effectiveness calculations, may be found in Appendix C.

Procedures for Calculating Effectiveness

The estimates of effectiveness and other statistics shown in Tables VI-9 through VI-15 are derived from the raw tabluations by the procedures summarized here (Some procedures were discussed in more detail in the preceeding sections.):

(1) The sample sizes n_1/n_2 and proportions p_1, p_2 of injured occupants in the beam-equipped and unequipped populations, respectively, are taken from the raw data tables.

(2) Standardizing and smoothing is performed to obtain new proportions p_1' and p_2' of injured occupants.

(3) $\hat{\mathcal{E}} = 100\ (1 - P_1'/p_2')$ the relative difference in standardized injury rates, is the estimated percent effectiveness of Standard 214. This is the left most number in each row of Tables VI-9 through VI-15.

(4)
$$\sigma_1^2 = \frac{p_1'(1-p_1')}{n_1} \quad \text{and} \quad \sigma_2^2 = \frac{p_2'(1-p_2')}{n_2}$$

are rather good estimates of the sample variances of the standardized injury rates.[9] Since standardization is a form of post-stratification, the exact sample variance would be given by the more complex formula for post-stratified samples. But Hochberg, Reinfurt et al. showed that the simple formula used above gives nearly the same results [25].

(5) The standard deviation of the effectiveness estimate,[10] using the customary Taylor series approximation [17], is

$$\sigma_r \doteq (100-\hat{\varepsilon})\sqrt{(\sigma_1/p_1')^2 + (\sigma_2/p_2')^2}$$

(6) σ_r is diluted to reflect the NCSS sampling plan. The diluted standard deviation, σ_r' , is the second number shown in each row of Tables VI-9 through VI-15. For example, in working with AIS $\geqslant$ 3 injury rates,

$$\sigma_r' = \frac{1}{.769}\,\sigma_r$$

(7) The lower and upper confidence bounds shown in each row of Tables VI-9 through VI-15 are $\hat{\varepsilon} - 1.64\sigma_r'$ and $\hat{\varepsilon} + 1.64\sigma_r'$, respectively. They are "one-sided 95 percent confidence bounds." One-sided bounds are what Reinfurt [25] used to express belt effectiveness and they are the best way to present confidence intervals for effectiveness of safety standards. Most observers who look at a point estimate of a standard's effectivenss will

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[9] No dilution to account for the NCSS sampling plan has been made up to this point.

[10] No dilution to account for the NCSS sampling plan has been made up to this point.

typically say either, "that's too high; what's the lowest it could be?" or, "that's too low; what's the highest it could be?" In other words, they are only interested in one of the bounds. Since they feel the true value could not be in the other tail, they will accept a bound giving 5 percent chance of error on one side.

The confidence bounds are approximate, not exact. Small errors were introduced in steps (4) and (6). The observed effectiveness, $\hat{\varepsilon}$, which is a ratio of proportions, deviates from the normal distribution, especially if σ_r' is large; thus, slightly more than 5 percent of the distribution may lie beyond $1.64\sigma_r'$ on one side of the mean.

(8) The observed results are tested against the hypothesis that beams have zero effectiveness, by one of two alternative techniques.

In the first technique, the tabulated data were entered into the CONTAB program. The simplest model adequately explaining the data is selected. The standardized effect of the interaction BEAMS*INJURY is read from the CONTAB results and diluted to account for the NCSS sampling plan (e.g., multiplied by .769 when dealing with AIS $\geqslant$ 3 injury). If the diluted effect is greater than 1.645, the hypothesis of zero effectiveness is rejected; otherwise, it is accepted.

In the second technique (which introduces a small additional error), an ordinary contigency table X^2 test on the simple 2X2 table, is performed. The marginals of the table are the same as the raw (unstandardized) data and the entries imply that the effectiveness of beams is $\hat{\mathcal{E}}$ (the relative difference of the standardized injury rates). The resulting X^2 statistic is diluted to account for the NCSS sampling plan (e.g., multiplied by .592 when dealing with AIS $\geqslant 3$ injury). If the diluted X^2 is greater than 2.706, the hypothesis of no effectiveness is rejected; otherwise, it is accepted. In other words, this is a one-tailed test with $\alpha = .05$.

The results of these tests are the last entries in each row of Tables VI-9 through VI-15.

While the second procedure introduces a small error, none of the χ^2 statistics calculated for Tables VI-9 through VI-15 came close enough to 2.706 to raise concern about an erroneous attribution of significance when there was none, or vice versa.

On the other hand, failure to dilute statistics because of the NCSS sampling plan would have given spurious significance to many non-significant results in Tables VI-9 through VI-15.

In some rows of Tables VI-9 through VI-15, the confidence interval for effectiveness may exclude zero while the hypothesis of zero effectiveness is accepted. This is not an indication of error in the procedures. Interval estimation and hypothesis testing are not equivalent (except in the special case of a normal distribution with known σ). The results of one cannot be applied to infer the results of the other.

Observed Effects of the Confounding Factors

The values of Standard 214 effectiveness given in Tables VI-9 and VI-10 are best estimates. The confounding effects of restraint usage, vehicle weight and ΔV were removed, using the techniques recommended in a previous section.

In order to display the effects of the confounding factors, relative differences in injury rates were also calculated using other techniques -- viz., removing only one or two of the confounding effects and/or attempting to control for the unexplained "age effect" by the alternative techniques suggested earlier. The results are presented in Tables VI-11 (single vehicle impacts) and VI-12 (all types of sidedoor impacts).

TABLE VI-11

EFFECTIVENESS OF STANDARD 214 IN SINGLE VEHICLE SIDEDOOR IMPACTS: RESULTS OF ALTERNATIVE PROCEDURES TO REMOVE CONFOUNDING FACTORS

Procedure	Estimated "Effectiveness"	Standard Deviation of Estimate	Confidence Bounds for Effectiveness		"Effectiveness" Significantly Different from Zero?
			Lower	Upper	
		(a) Fatality reduction			
BEST ESTIMATE (Control for Restraint Use, Weight & ΔV)	74%	11.1	56%	92%	Sig. > 0
Control for Restraint & Weight	74%	11.3	55%	92%	Sig. > 0
Control for Restraint & ΔV	71%	12.2	51%	91%	Sig. > 0
Control for Restraint Use	71%	12.3	50%	91%	Sig. > 0
Control for Restraint, Weight & ΔV using only post-1966 cars	70%	13.4	48%	92%	Sig. > 0
		(b) AIS $\geq$ 3 reduction			
BEST ESTIMATE (control for Restraint Use Weight & ΔV)	66%	10.8	48%	84%	Sig. > 0
Control for Restraint & Weight	64%	11.3	45%	82%	Sig. > 0
Control for Restraint & ΔV	65%	10.9	47%	83%	Sig. > 0
Control for Restraint Use	64%	11.3	45%	82%	Sig. > 0
Control for Restraint, Weight & ΔV using only post-1966 cars	61%	13.4	39%	83%	Sig. > 0
		(c) AIS $\geq$ 2 reduction			
BEST ESTIMATE (Control for Restraint Use Weight & ΔV)	60%	11.4	41%	79%	Sig. > 0
Control for Restraint & Weight	60%	11.5	41%	79%	Sig. > 0
Control for Restraint & ΔV	59%	11.5	40%	79%	Sig. > 0
Control for Restraint Use	64%	12.0	38%	77%	Sig. > 0
Control for Restraint, Weight & ΔV using only post-1966 cars	59%	12.6	38%	80%	Sig. > 0

TABLE VI-11 (continued)

EFFECTIVENESS OF STANDARD 214 IN SINGLE VEHICLE SIDEDOOR IMPACTS: RESULTS OF ALTERNATIVE PROCEDURES TO REMOVE CONFOUNDING FACTORS

Procedure	Estimated "Effectiveness"	Standard Deviation of Estimate	Confidence Bounds for Effectiveness Lower	Confidence Bounds for Effectiveness Upper	"Effectiveness" Significantly Different from Zero?
		(d) Injury reduction			
BEST ESTIMATE (Control for Restraint Use, Weight & ΔV)	18%	13.1	- 4%	39%	No
Control for Restraint & Weight	18%	13.1	- 4%	39%	No
Control for Restraint & ΔV	22%	12.2	2%	42%	No
Control for Restraint Use	22%	12.2	2%	42%	No

TABLE VI-12

EFFECTIVENESS OF STANDARD 214 IN ALL TYPES OF SIDEDOOR IMPACTS: RESULTS OF ALTERNATIVE PROCEDURES TO REMOVE CONFOUNDING FACTORS

Procedure	Estimated "Effectiveness"	Standard Deviation of Estimate	Confidence Bounds for Effectiveness Lower	Confidence Bounds for Effectiveness Upper	Is "Effectiveness" Significantly Different from Zero?
(a) Fatality reduction					
BEST ESTIMATE (Control for Restraint Use, Weight & ΔV)	31%	16.6	4%	58%	No
Control for Restraint & Weight	28%	17.4	- 1%	56%	No
Control for Restraint & ΔV	29%	17.1	1%	57%	No
Control for Restraint Use	28%	17.4	- 1%	57%	No
Compare with nonside impact control group,	31%	19.1	- 1%	62%	No
(b) AIS ≥ 3 reduction					
BEST ESTIMATE (Control for Restraint Use, Weight & ΔV)	17%	14.2	- 77%	40%	No
Control for Restraint & Weight	15%	14.6	- 9%	39%	No
Control for Restraint & ΔV	17%	14.0	- 6%	40%	No
Control for Restraint Use	16%	14.2	- 7%	39%	No
Comparison with nonside impact control group, controlling for Weight, ΔV and Restraint Use	3%	19.2	- 29%	34%	No

TABLE VI-12 (continued)

EFFECTIVENESS OF STANDARD 214 IN ALL TYPES OF SIDEDOOR IMPACTS:
RESULTS OF ALTERNATIVE PROCEDURES TO REMOVE CONFOUNDING FACTORS

Procedure	Estimated "Effectiveness"	Standard Deviation of Estimate	Confidence Bounds for Effectiveness Lower	Upper	Is "Effectiveness" Significantly Different from Zero?
		(c) AIS $\geqslant$ 2 reduction			
BEST ESTIMATE (Control for Restraint Use, Weight & ΔV)	18%	12.3	- 2%	38%	No
Control for Restraint & Weight	16%	12.6	- 5%	37%	No
Control for Restraint & ΔV	21%	11.8	1%	40%	No
Control for Restraint Use	20%	11.8	1%	39%	No
Compare with nonside impact control group, controlling for Weight, ΔV and Restraint Use	11%	14.7	- 14%	35%	No
		(d) Injury reduction			
BEST ESTIMATE (Control for Restraint Use, Weight & ΔV)	1%	8.2	- 13%	14%	No
Control for Restraint & Weight	2%	8.2	- 12%	15%	No
Control for Restraint & ΔV	6%	7.7	- 7%	18%	No
Control for Restraint Use	7%	7.7	- 6%	20%	No
Compare with nonside impact control group	3%	19.2%	- 29%	34%	No

The differences in the results are small compared to the overall sampling errors, thereby confirming the predictions based on the literature that the confounding effects would not be excessive. In no case did confounding factors make a nonsignificant result significant, or vice-versa. The confounding effects themselves are subject to sampling errors several times larger than the effect. As a result, the confounding effects of ΔV and/or vehicle weight in the actual NCSS data are occasionally negative when one expects them positive (i.e., the observed standardized effectiveness is slightly higher than the difference of the raw injury rates). This is merely due to sampling error and not the result of an incorrect model or procedures.

The exclusion of cars of model years 1966 and earlier from the effectiveness calculations only makes a few percentage points difference in the results, but increases their variance. Similarly, when control for the "age effect" is attempted by comparing to a "control group" of nonside impacts, the estimates of Standard 214 effectiveness are little changed, but their precision is decreased.

Effectiveness of Standard 214 in Selected Subclasses of Sidedoor Impacts

Estimates of Standard 214 effectiveness in selected subclasses of sidedoor impacts are less precise than the estimate of overall effectiveness. Nevertheless, there are enough data to provide three statistically significant results on comparative effectiveness:

(1) Beams are definitely more effective in preventing deaths and injuries in single vehicle crashes then in multivehicle crashes.

(2) Beams are definitely better in sidedoor impacts with non-lateral (frontal, rear or non-planar) Principal Direction of Force (PDOF) than in impacts with side PDOF.

(3) Beams are probably better in higher-speed ($\Delta V \geqslant 17$ mph) impacts than low-speed impacts.

The CONTAB program [7] was used to test comparative effectiveness. In each case, CONTAB was applied to a three-way table: presence of beams vs. presence of injury (e.g. AIS $\geqslant 2$) vs. subclass (e.g. single vehicle, multivehicle). *A model consisting of all effects and interactions* <u>except</u> the three-way interaction was hypothesized. Intuitively the model embodies the hypothesis that effectiveness of beams is the same in the two subclasses. CONTAB calculates the information statistic (which measures how much the hypothesized model is out of touch with the actual data). The statistic is diluted to reflect the NCSS sampling plan. If, after the dilution, it still exceeds 2.706, beams are significantly more effective in one subclass of accidents than in the other.[11]

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[11] This is a one-sided test with $\alpha = .05$

Beam effectiveness in single vehicle and multivehicle accidents is compared in Table VI-13. Beams are significantly more effective in single vehicle sidedoor impacts in saving lives (74 percent in single vehicle versus -20 percent in multivehicle); and in reducing AIS $\geqslant$ 3 injury (66 percent versus -20 percent); and in reducing AIS $\geqslant$ 2 injury (60 percent versus -4 percent). The observed negative effectiveness of beams in multivehicle accidents is of no statistical significance (the confidence bounds are wide and include fairly large positive values). It would be desirable to collect considerably more data and obtain a more precise estimate of what beams do in multivehicle accidents.

Beam effectiveness in non-lateral and lateral PDOF impacts is compared in Table VI-14. Beams are significantly more effective when the forces are not lateral - i.e. when the sidedoor is struck with a primarily frontal, rear or non-horizontal force. They prevented a larger percentage of deaths (65 percent vs. 3 percent), AIS $\geqslant$ 3 injuries (71 percent vs. - 21 percent) and AIS $\geqslant$ 2 injuries (51 percent vs. 4 percent) in the non-lateral impacts. Beam performance in lateral side impacts appears poor - although not enough data have been collected for statistically precise results.

These large differences in effectiveness may perhaps be due to some extent to another factor: the sidedoor beam may, itself, affect the resultant force. In a fairly low speed, oblique collision, the beam may cause the striking car to "slide by" the struck car, thus changing the appearance of the resultant damage. The investigator might classify the resultant force as primarily frontal, based on the damage, when he would have classified it as lateral in the absence of the beam. The net result would be a lower injury rate in nonlateral crashes for post-Standard cars. This possibility will be studied further in the follow-up reports.

TABLE VI-13

COMPARATIVE EFFECTIVENESS OF STANDARD 214 IN SINGLE AND MULTIVEHICLE SIDEDOOR IMPACTS

Crash Type	Observed Effectiveness	Significantly Higher In Single Vehicle Impacts?	Standard Deviation of Effectiveness	Confidence Bounds for Effectiveness Lower	Confidence Bounds for Effectiveness Upper	Effectiveness Significantly Different from Zero?
			(a) Fatality reduction			
Single Vehicle	74%	Yes	11.1	56%	92%	Sig. > 0
Multivehicle	-20%		38.3	-83%	43%	No
			(b) AIS $\geq$ 3 reduction			
Single Vehicle	66%	Yes	10.8	48%	84%	Sig. > 0
Multivehicle	-20%		25.4	-62%	22%	No
			(c) AIS $\geq$ 2 reduction			
Single Vehicle	60%	Yes	11.4	41%	79%	Sig. > 0
Multivehicle	- 4%		18.8	-35%	27%	No
			(d) Injury reduction			
Single Vehicle	18%	No	13.1	- 4%	39%	No
Multivehicle	2%		9.2	-13%	17%	No

TABLE VI-14

COMPARATIVE EFFECTIVENESS OF STANDARD 214 IN SIDEDOOR IMPACTS WITH NONLATERAL AND LATERAL PRINCIPAL DIRECTION OF FORCE

Principal Direction of Force	Observed Effectiveness	Significantly Higher in Non-Lateral PDOF Impacts?	Standard Deviation of Effectiveness	Confidence Bounds for Effectiveness Lower	Confidence Bounds for Effectiveness Upper	Effectiveness Significantly Different from Zero?
			(a) Fatality Reduction			
Frontal, Rear or Non-Planar	65%	Yes	16.7	37%	92%	Sig. > 0
Side	3%		28.1	-44%	49%	No
			(b) AIS $\geq$ 3 Reduction			
Frontal, Rear or Non-Planar	71%	Yes	11.2	53%	90%	Sig. > 0
Side	-21%		23.4	-59%	18%	No
			(c) AIS $\geq$ 2 Reduction			
Frontal, Rear or Non-Planar	51%	Yes	15.3	25%	76%	Sig. > 0
Side	4%		16.2	-23%	30%	No.
			(d) Injury Reduction			
Frontal, Rear or Non-Planar	20%	No	12.0	1	40%	No
Side	- 4%		9.7	-19%	12%	No

Since Standard 214 is highly effective in non-lateral impacts and in single vehicle crashes, it is natural to question the extent to which these crash modes overlap. Single vehicle crashes are more frequently nonlateral (57%) than multivehicle crashes (38%). But, because multivehicle crashes are much more common overall, the majority (74%) of nonlateral impacts are multivehicle. Thus, the overlap of the crash modes is limited. While the sample sizes are not large enough to attach much statistical significance to the numbers, the standard was observed to be nearly as effective in nonlateral multivehicle crashes (32% AIS $\geq$ 3 reduction) and in lateral single vehicle crashes (59%) as it was in nonlateral single vehicle crashes (70%).

Beam effectiveness is tabulated by crash severity in Table VI-15. Two categories of crash severity were used: $\Delta V \geq 17$ mph and $\Delta V < 17$ mph. About half of the AIS $\geq$ 2 and AIS $\geq$ 3 injuries lie in each category. (The analysis could not be performed in a statistically meaningful manner for fatalities and minor injuries). At the AIS $\geq$ 3 level, beams did a signficantly better job of preventing injury in high-speed crashes (34 percent vs. -34 percent). A similar difference, although not statistically significant, was found for the AIS $\geq$ 2 injuries.*

Side impacts have often been stereotyped as two-car right-angle intersection collisions; Standard 214 is most effective in one-car non-perpendicular crashes. The compliance test for Standard 214 is close to a 90° hit at low speed; the standard is most effective at higher speed hits from directions at angles far beyond the perpendicular.

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*It is possible that the algorithm used to calculate ΔV is confounded by the presence/absence of beams, therebybiasing these effectiveness estimates. The issue will be examined in a follow-up report.

TABLE VI-15

COMPARATIVE EFFECTIVENESS OF STANDARD 214 IN HIGHER-SPEED AND LOW-SPEED ACCIDENTS

Crash Severity	Observed Effectiveness	Significantly Higher In Higher Speed Crashes?	Standard Deviation of Effectiveness	Confidence Bounds for Effectiveness Lower	Confidence Bounds for Effectiveness Upper	Effectiveness Significantly Different from Zero?
(a) AIS $\geqslant$ 3 reduction						
$\Delta V \geqslant$ 17 mph	34%	Yes	16.3	8%	61%	Sig. > 0
$\Delta V <$ 17 mph	-34%		46.2	-111%	41%	No
(b) AIS $\geqslant$ 2 reduction						
$\Delta V \geqslant$ 17 mph	36%	No	14.6	12%	60%	Sig. > 0
$\Delta V <$ 17 mph	4%		25.5	-37%	46%	No

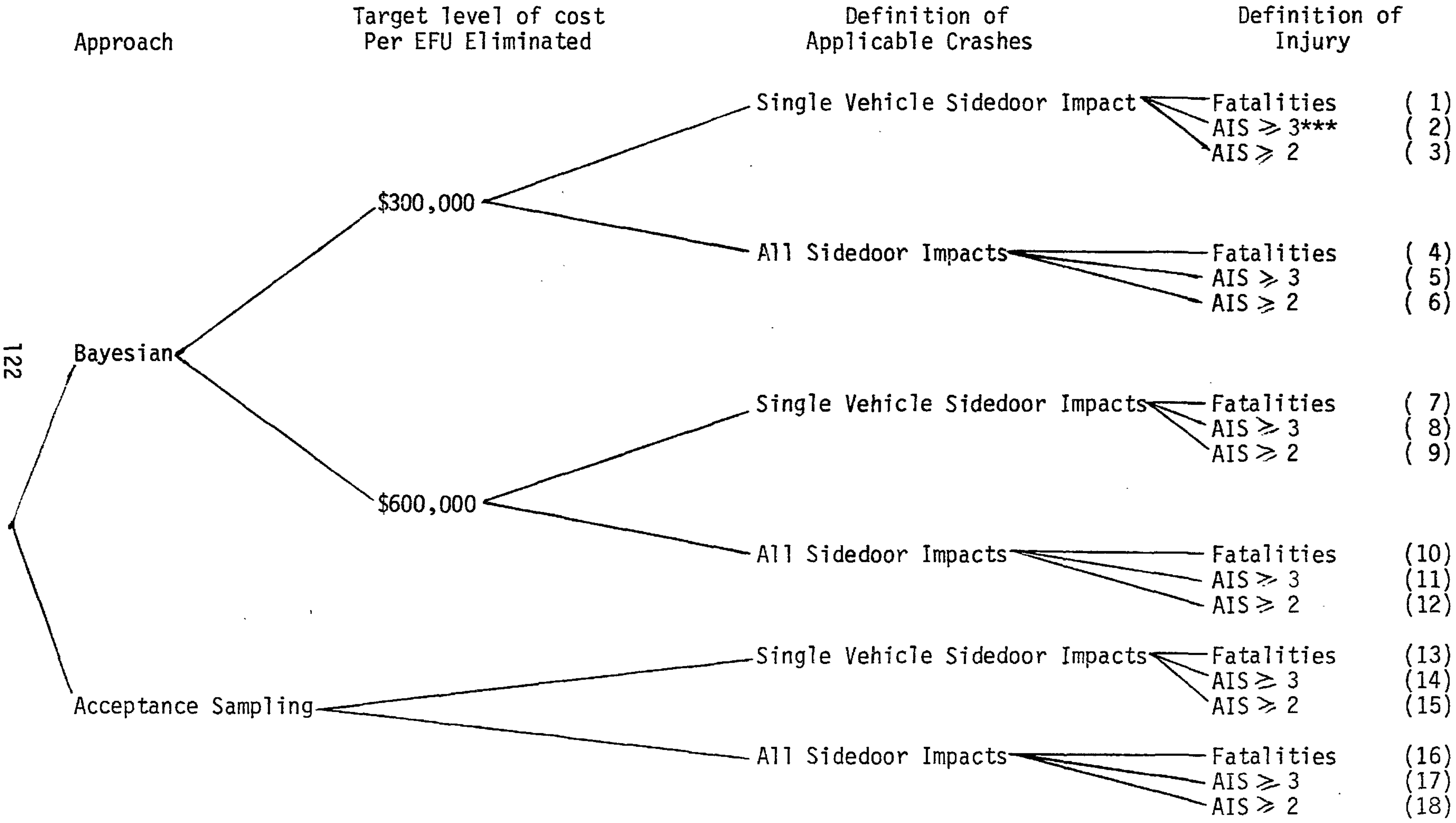
Findings on the Cost-Effectiveness of Standard 214

Two statistical approaches for evaluating the cost-effectiveness of Standard 214 were described in Chapter V: Bayesian Decision Theory and Acceptance Sampling. The results of applying each approach to the NCSS data collected so far will now be presented. Costs are expressed in 1977 dollars throughout this section. The calculations in this chapter assume that the baseline casualties are known with certainty. Appendix E contains calculations under the assumption that the baseline is imperfectly known.

Each approach can be applied in a number of different ways. In all, 18 alternatives will be considered. The tree diagram shown in Figure VI-1 shows why there are so many alternatives: to begin with, the Bayesian or Acceptance Sampling approach can be used. Within the Bayesian approach, two alternative target levels of cost per Equivalent Fatality Unit (EFU) eliminated were established in Chapter V. Either approach could be applied based on the effectiveness observed in single-vehicle impacts alone or on that observed in all types of sidedoor impacts (See Chapter V). Finally, the "observed effectiveness" of Standard 214 could mean its observed effectiveness in preventing fatalities, or AIS $\geq$ 3 injuries, or AIS $\geq$ 2 injuries. (AIS 1 is not useful in this context: AIS $\geq$ 1 effectiveness is primarily a measure of the impact of beams on minor injuries but, as Table V-1 and Appendix B show, these make only a small contribution to the EFU's resulting from sidedoor impacts. In fact, the AIS $\geq$ 2 effectiveness is only usable because the AIS $\geq$ 2 reduction, for most Standards, is thought to be fairly close to the fatality reduction.)

FIGURE VI-1

ALTERNATIVE COST-EFFECTIVENESS EVALUATION PROCEDURES



*** Recommended approach

Actually, only one result is needed for a conclusion on cost-effectiveness. From the 18 alternatives pursued here, the decision maker should choose the one that is thought to best model the problem and abide by the results of the calculations for that alternative.

Perhaps the most meaningful alternative is (2) on Figure VI-1: Bayesian approach, target cost of \$300,000 per EFU, AIS $\geqslant$ 3 reduction in single vehicle sidedoor impacts. The Bayesian approach, because it is more informative than acceptance sampling; the target cost of \$300,000 per EFU, because there would be little dispute among highway safety decision makers that Standards which achieve this target are cost-effective; AIS $\geqslant$ 3 injuries, because the effectiveness of Motor Vehicle Standards can be calculated with reasonable statistical precision and because the effectiveness for AIS $\geqslant$ 3 is also a fairly accurate and somewhat conservative estimate of the fatality reduction; single vehicle sidedoor impacts, because this is an important crash mode in which beams are likely to have a clear and measurable beneficial effect.

But the calculations will also be performed for the other 17 alternatives. In addition to providing decision makers with some more options, the additional calculations will also serve as a consistency check.

For the Bayesian approach, four parameters are needed: the observed effectiveness $\hat{\mathcal{E}}$ of beams in the NCSS data, the standard deviation σ of effectiveness, the effectiveness ε_0 of which Standard 214 would achieve the target cost per EFU and the incremental benefit t for each percentage point of incremental effectiveness.[12]

The first two parameters can be taken directly from Tables VI-9 and VI-10. They are used for constructing the Bayesian prior distribution: it is the normal distribution in these two parameters. (In fact, since effectiveness was calcualted from NCSS using a ratio estimator, the assumption of normality is somewhat erroneous. Schlaifer, however, has shown that the Bayesian procedure is robust [26] and that moderate deviations from normality in the prior distribution have a negligible impact on results.) The last two parameters were derived in Chapter V.

The Expected Value of Perfect Information (EVPI) is calculated from these four parameters (see Chapter V).[13] The Expected Net Gains from Sampling (ENGS) are subsequently calculated for alternative timeframes of additional sampling. In general, the optimal sampling timeframe bears the following relation to the EVPI:

(1) If $\hat{\varepsilon} \geq \varepsilon_0$ and EVPI $\leq$ \$11M, the Standard is cost-effective.
(2) If $\hat{\varepsilon} < \varepsilon_0$ and EVPI $\leq$ \$11M, the Standard is not cost-effective.
(3a) If \$11M < EVPI $\leq$ \$17M, collect data for 6 months.
(3b) If \$17M < EVPI $\leq$ \$31M, collect data for 1 year.
(3c) If EVPI > \$31M, collect data for 2 years.

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[12] t equals the number of EFU's eliminated by each incremental of effectiveness multiplied by the target cost per EFU.

[13] EVPI = t $L_N(|\hat{\varepsilon}-\varepsilon_0/\sigma|)$, where L_N is the unit normal loss function (See [28]).

The results, with a target cost of \$300,000 per EFU,[14] are shown in Table VI-16. The recommended approach (AIS $\geqslant$ 3 injuries in single vehicle impacts) leads to the immediate conclusion that the Standard is cost-effective. The Standard costs only \$198,000 for every EFU that it eliminates, which is well below the target cost. The observed effectiveness (66 percent) exceeds the breakeven point (43 percent) by more than 2 standard deviations. The EVPI - the cost of uncertainty - is less than \$1,000,000. It would not be worth spending millions of dollars to collect more data when the cost of uncertainty, based on available data, is less than \$1,000,000.

The results for single vehicle impacts, but using fatality or AIS $\geqslant$ 2 reduction as measures of effectiveness, are virtually identical to the above result. The observed costs per EFU eliminated by Standard 214 are \$176,000 and \$218,000 and the EVPI's are \$120,000 and \$4,700,000 respectively. The choice of measure of effectiveness has little influence on the result because Standard 214 is about equally effective at all AIS levels above 1.

The results based on <u>all</u> types of sidedoor impacts, however, present a striking contrast. Observed cost per EFU eliminated is within the range of what could be considered cost-effective, varying from \$209,000 to \$382,000. But substantial uncertainty is associated with these costs. The EVPI's

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[14] Alternatives (1) - (6) on Figure VI-1.

TABLE VI-16

COST EFFECTIVENESS EVALUATION USING BAYESIAN APPROACH AND $300,000 AS TARGET COST PER EFU ELIMINATED

Effectiveness defined as	Observed cost per EFU eliminated	$\hat{\varepsilon}$	ε_0	σ	t	EVPI	Conclusions
(a) Based on Single Vehicle Sidedoor Impacts							
(1) Fatality reduction	$ 176,000	74	43.4	11.1	$12.9M	$ 120,000	Standard is cost-effective
(2)** AIS ≥3 reduction	$ 198,000	66	43.4	10.8	$12.9M	$ 950,000	Standard is cost-effective
(3) AIS ≥ 2 reduction	$ 218,000	60	43.4	11.4	$12.9M	$ 4,700,000	Standard is cost-effective
(b) Based on All Types of Sidedoor Impacts							
(4) Fatality reduction	$ 209,000	31	21.7	16.6	$25.9M	$ 76,000,000	Collect data for 2 more years
(5) AIS ≥ 3 reduction	$ 382,000	17	21.7	14.2	$25.9M	$ 93,000,000	Collect data for 2 more years
(6) AIS ≥ 2 reduction	$ 360,000	18	21.7	12.3	$25.9M	$ 85,000,000	Collect data for 2 more years

** Recommended approach and conclusion

range from $76,000,000 to $93,000,000. Available data provide so little information that it is unknown where beam effectiveness stands relative to the target values. The wisest decision is to collect more data. Two more years worth of NCSS data would reduce the risk of wrong conclusion (the EVPI) by $20-50 million.

The contrast in the results for single vehicle impacts and all types of sidedoor impacts is due to the following factors:

(1) The latter population includes crash modes where beams are considerably less effective. This "muddies the water," statistically speaking, and nearly always leads to less definitive results.

(2) Moreover, the <u>observed</u> effectiveness of beams in multivehicle crashes was slightly negative. When making a decision based on single vehicle crashes only, one implicitly assumes that beam effectiveness in multivehicle crashes is zero at worst. That assumption, obviously, is based on intuitive grounds, not on the NCSS data. Essentially what the EVPI says is that more NCSS data are needed to test the intuitive assumption that beams do not increase injury in multivehicle impacts.

Most decision makers will probably accept the assumption that beams do not increase injury in multivehicle impacts and, as a result, will accept the positive results based on the single vehicle impacts. But the high EVPI's obtained when using all types of sidedoor impacts do serve as a warning that, even though a positive conclusion is now warranted, it would be wise to re-evaluate as more NCSS data accumulate.

The results of the Bayesian analyses using a target cost of $600,000 per EFU eliminated[15] are shown in Table VI-17. They are virtually identical to the results in Table VI-16: clearly positive for single vehicle impacts and no conclusion based on all types of sidedoor impacts. Whereas observed cost per EFU eliminated is lower than $600,000 in every case, the uncertainty concerning the observed effectiveness leads to high EVPI's.

The acceptance sampling approach, as developed in Chapter V, consists of testing three hypothesized values of beam effectiveness, $\mathcal{E}$, using the observed data. The three hypotheses are:

$$H_0: \mathcal{E} = \mathcal{E}_0,$$
$$H_1: \mathcal{E} = 0$$
$$H_2: \mathcal{E} = 1/2\,\mathcal{E}_0,$$

where $\mathcal{E}_0$ is the effectiveness at which EFU's cost $300,000 to eliminate. One-sided tests with $\alpha = .05$ are used.

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[15] Alternatives (7) - (12) on Figure VI-1.

TABLE VI-17

COST EFFECTIVENESS EVALUATION USING BAYESIAN APPROACH AND $600,000 AS TARGET COST PER EFU ELIMINATED

Effectiveness Defined as:	Observed Cost Per EFU Eliminated	$\hat{\varepsilon}$	ε_0	σ	t	EVPI	Conclusion
			(a) Based on Single Vehicle Sidedoor Impacts				
(7) Fatality reduction	$ 176,000	74	21.7	11.1	$25.8M	$ 75	Standard is cost-effective
(8) AIS ≥ 3 reduction	198,000	66	21.7	10.8	25.8M	1,500	Standard is cost-effective
(9) AIS ≥ 2 reduction	218,000	60	21.7	11.4	25.8M	30,000	Standard is cost-effective
			(b) Based on All Types of Sidedoor Impacts				
(10) Fatality reduction	209,000	31	10.8	16.6	51.8 M	47,000,000	Collect data for 2 more years
(11) AIS ≥ 3 reduction	382,000	17	10.8	14.2	51.8 M	165,000,000	Collect data for 2 more years
(12) AIS ≥ 2 reduction	360,000	18	10.8	12.3	51.8 M	111,000,000	Collect data for 2 more years

Based on the test results, conclusions may be drawn as follows: ("+" means that observed $\hat{\varepsilon}$ is significantly greater than hypothesized value, "-" means significantly less, "0" means accept hypothesized value).

	Result of Hypothesis Test		
Conclusion	$H_0: \varepsilon = \varepsilon_0$	$H_1: \varepsilon = 0$	$H_2: \varepsilon = \frac{1}{2}\varepsilon_0$
1a. Standard is cost-effective	any	+	+
1b. Standard is cost-effective (tentative)	0 or -	+	0
2a. Standard is not cost-effective	-	any	-
2b. Standard is not cost-effective (tentative)	-	0	0
3. Collect more data	0	0	0

Any other combination of test results is mathematically impossible. The ε_0 effectiveness levels were found in Chapter V to be 43.4 percent in single vehicle impacts alone and 21.6 percent in all types of sidedoor impacts.

A test against some specified non-zero level of effectiveness is a test of ratios of proportions. Also, the observed effectiveness has been standardized to remove confounding factors. The tests that will be conducted, then, are somewhat unconventional and require an explanation.

A technique for testing the hypothesis that effectiveness was zero was presented among "Procedures for Calculating Effectiveness," earlier in this Chapter. (See step (8) there.) A simple 2X2 table was constructed. Call it the "observed" table. Its marginals were the same as in the raw data and its entries implied that the effectiveness of beams was the observed standardized effectiveness. Then, an ordinary contingency table χ^2 test was performed. This meant that another 2X2 table, called the "expected" table was constructed. Its marginals were the same as in the raw data and its entries implied that the effectiveness of beams was zero.

$$\chi^2 \text{ statistic} = \sum_{1}^{4} \frac{(\text{"observed" table entry} - \text{"expected" table entry})^2}{\text{"expected" table entry}}$$

(This is nothing other than an ordinary χ^2 test)

Now, a new "expected" table is constructed whose marginals are still the same as in the raw data but whose entries imply that the effectiveness of beams is the hypothesized value. The χ^2 statistic is calculated by the above formula, but using the entries for the new "expected" table. The χ^2 statistic is diluted to account for the NCSS sampling plan. If the result exceeds 2.706, the hypothesized value of effectiveness is rejected.

This technique does introduce a small error in the calculation of the χ^2 statistics. None of the statistics calculated below, however, came close enough to 2.706 to raise concern about erroneous attributions of significance. The CONTAB program could likely be modified to permit more exact hypothesis testing of this type.

The results using the acceptance sampling approach[16] are shown in Table VI-18. They are exactly the same as with the Bayesian approach. Analysis of single vehicle sidedoor impacts, alone, leads to the immediate conclusion that the Standard is cost-effective, no matter what injury criterion is used for calculating $\hat{\varepsilon}$. In fact, the fatality and AIS ≥ 3 reduction due to Standard 214 are both significantly higher than ε_0.

When all types of side impacts are studied, however, the sample size is too small to permit any conclusion using acceptance sampling. The χ^2 statistics for the tests of zero effectiveness, however, average over half the critical value. If the current observed effectiveness were to persist over one more year of NCSS data collection, it might be possible to establish tentatively that the Standard is cost-effective based on these impacts too.

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[16] Alternatives (13) - (18)on Figure VI-1.

TABLE VI-18

COST-EFFECTIVENESS EVALUATION USING ACCEPTANCE SAMPLING APPROACH

Effectiveness Defined as:	Observed Cost Per EFU Eliminated	$\hat{\varepsilon}$	ε_o	Result of Hypothesis Test: $H_0: \varepsilon = \varepsilon_o$	$H_1: \varepsilon = 0$	$H_2: \varepsilon = \frac{1}{2}\varepsilon_o$	Conclusion
(a) Based on Single-Vehicle Sidedoor Impacts							
(13) Fatality reduction	$ 176,000	74	43.4	+	+	+	Standard is cost-effective
(14) AIS $\geq$ 3 reduction	198,000	66	43.4	+	+	+	Standard is cost-effective
(15) AIS $\geq$ 2 reduction	218,000	60	43.4	0	+	+	Standard is cost-effective
(b) Based on All Types of Sidedoor Impacts							
(16) Fatality reduction	209,000	31	21.6	0	0	0	Collect more data
(17) AIS $\geq$ 3 reduction	382,000	17	21.6	0	0	0	Collect more data
(18) AIS $\geq$ 2 reduction	360,000	18	21.6	0	0	0	Collect more data

Note: "+" - reject hypothesis (one-sided $\alpha = .05$); observed effectiveness sig. greater than hypothsized value
"-" - reject hypothesis, observed sig. less than hypothesized value
"0" - accept hypothesis

Findings on Intrusion Reduction due to Standard 214

Standard 214 significantly reduces the likelihood of intrusion in sidedoor impacts. Table VI-19 shows that only 59 percent of beam-equipped vehicles struck in the sidedoor had some occupant compartment intrusion, versus 69 percent of unequipped cars. This means that beams reduce the likelihood of intrusion by about 14 percent.

At the beginning of this Chapter, it was pointed out that the definition of "intrusion" used in NCSS (i.e., any occupant compartment shrinkage whatsoever) would make it difficult to show an effect for Standard 214. Thus, it is all the more gratifying that the results are statistically significant and it is likely that they understate the true effectiveness of Standard 214.

The extremely broad definition of intrusion in NCSS leads to the expectation that:

(1) Rates of intrusion would be high, even in low speed crashes.

(2) The effect of Standard 214 in reducing severe intrusion to moderate intrusion in higher speed crashes would be masked, since NCSS classifies either type as "intrusion".

TABLE VI-19

FREQUENCY OF SIDE INTRUSION IN PRE-STANDARD AND POST-STANDARD CARS INVOLVED IN TOWAWAY SIDEDOOR IMPACT ACCIDENTS

	Percent of Cars with Side Intrusion		
	Pre-Standard cars	Post-Standard cars	Are Rates Significantly Different?
OVERALL	69%	59%	Standard 214 sig. less intrusion
BY ΔV			
1-9 mph	66%	50%	Standard 214 sig. less intrusion
10-19 mph	77%	73%	No
20+	84%	73%	No
BY VEHICLE WEIGHT			
$<$ 3500 lbs	70%	59%	Standard 214 sig. less intrusion
$\geq$ 3500 lbs	68%	60%	No
BY CRASH TYPE AND DIRECTION OF FORCE			
Multivehicle, nonlateral	59%	44%	Standard 214 sig. less intrusion
Multivehicle lateral	75%	73%	No
Single vehicle nonlateral	47%	43%	No
Single vehicle lateral	65%	72%	No
No of tabulated cases	1412	2589	

The data fully bear out the expectations. The rate of intrusion is over 50 percent in crashes with $\Delta V < 10$ mph. It is in these low speed crashes that Standard 214 causes a large and statistically significant reduction of intrusion - from 66 percent to 50 percent. In impacts with $\Delta V \geq 10$ mph, the probability of intrusion is very high in all cars and it is not significantly lower in the beam equipped cars.

Table VI-19 shows that the rate of intrusion is only slightly higher when $\Delta V \geq 20$ mph than when ΔV is between 10 and 19. It is probably due to the very inclusive definition of "sidedoor impact" used in this study: an impact with any exterior damage whatsoever in the sidedoor area. It includes impacts primarily to the front or rear fender areas with minor spillover into the door areas. The rate of intrusion for cars with damage strictly in the sidedoor area (2nd letter of Collision Deformation Classification [5] is P) was 100 percent at all $\Delta V \geq 10$ mph.

Table VI-19 shows that Standard 214 significantly reduced the likelihood of intrusion in smaller (< 3500 lbs.) cars, from 70 percent to 59 percent. The reduction in larger cars was comparable, from 68 percent to 60 percent, but not quite statistically significant.

One of the most important findings shown in Table VI-19 is the substantial and statistically significant benefit of beams in <u>multivehicle</u> <u>nonlateral</u> crashes. Standard 214 reduced the likelihood of intrusion from 59 percent to 44 percent. It means that beams are about 25 percent effective in preventing intrusion in nonlateral vehicle-to-vehicle collisions. It appears, then that the Standard is accomplishing its purpose in these crashes. By contrast, no substantial reduction of intrusion was observed in the lateral multivehicle crashes. Thus, in multivehicle crashes, the results on intrusion reduction are consistent with the results on injury reduction.

Table VI-19 shows that the rate of intrusion in <u>single vehicle</u> crashes did not differ significantly in beam-equipped and unequipped cars. The sample size for single vehicle crashes is not large enough to allow a meaningful determination of beams' effectiveness in reducing intrusion. It is not even possible to infer that beams more effectively reduce intrusion in multivehicle than in single vehicle impacts. More importantly, without measurements of the depth of intrusion, it is impossible to determine whether the Standard has an intrusion-reducing effect in the more severe single vehicle crashes. The question of intrusion in single vehicle crashes, as well as the more general question of <u>why</u> beams are so effective in reducing casualties in these crashes, will be more thoroughly examined in a follow-up report when the depth measurements will be available on NCSS.

The results on intrusion were obtained as follows:

(1) The "intrusion" variable on NCSS was collapsed to three categories: yes, no, unknown. Yes, if there was "side" intrusion, "side + sill" or "other area combinations."[17] No, if there was "none" or if there

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[17] It was assumed that "other area combination" in a side impact would usually mean side intrusion plus something else.

was exclusively frontal, rear, or top intrusion (i.e., steering column, A-pillar, steering column and A-pillar, rear-end, or roof). Only 1 percent of vehicles were coded "unknown."

(2) The data were standardized to remove the effect of vehicle weight differences (except, of course, in the tabulations "by vehicle weight"). The intrusion rates in Table VI-19 are standardized rates. Vehicles with "unknown" intrusion are excluded from the calculation of rates.

(3) The significance tests were performed with the same technique used for injury rates. The dilution factor to account for the NCSS sampling plan is especially severe here (.141 for χ^2 statistics) because intrusion is common in minor accidents, which are undersampled in NCSS. Statistically significant results were obtained despite the drastic dilution.

Modifications are now underway in the NCSS to collect precise measurements of intrusion (See the discussion at the beginning of this Chapter). When the enhanced data file becomes available, the results on intrusion, which are already statisically significant, will become definitive. It may also become possible to shed light on the relationship between intrusion and occupant injury (See Chapter III).

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APPENDIX A

CALCULATION OF DISTRIBUTION OF CASUALTIES BY CRASH MODE IN 1977 IF STANDARD 214 HAD NOT BEEN PROMULGATED

(Example Showing Calculation for AIS $\geqslant$ 3)

Crash Mode	Observed (NCSS) N of Persons	Observed (NCSS) AIS $\geqslant$ 3 Injury Rate In all cars	Observed (NCSS) AIS $\geqslant$ 3 Injury Rate In pre-Standard cars	Calculated N of injuries	Calculated % of injuries
Sidedoor multivehicle	1,957		7.0%	137	12.7
Sidedoor single vehicle	429		24.0%	103	9.6
Sidedoor				240	22.3
Same side non-door	1,886	1.2%		23	2.1
Opposite side	4,754	2.3%		109	10.1
Side damage				372	34.6
Front damage	19,710	3.0%		600	55.8
Rear damage	1,753	0.5%		9	0.8
Top or bottom damage	1,556	6.1%		95	8.8
All crashes				1076	100.0

APPENDIX B

CALCULATION OF NUMBER OF SIDEDOOR IMPACT CASUALTIES IN 1977 IF STANDARD 214 HAD NOT BEEN PROMULGATED

	Observed		Calculated							
Severity	N of auto occupant casualties, 1977	NCSS Ratio to fatalities	Adjustment for NCSS missing data	Adjustment for non-towaways	Ratio to fatalities	N of auto occupant casualties 1977	In all types of sidedoor impacts		In single vehicle side-door impacts	
							%	N	%	N
Fatalities	27,353	1.0	-	-	1.0	27,353	25.8	7,060	13.7	3,750
AIS 5 (non-fatal)		0.1	-	-	0.1	2,750	19.0	520	7.2	200
AIS 4 (non-fatal)		0.4	-	-	0.4	11,000	19.0	2,100	7.2	800
AIS 3		2.0	0.3	0.2	2.5	69,000	19.0	13,100	7.2	5,000
AIS 2		3.7	0.7	0.6	5.0	137,000	11.8	16,200	3.8	5,200
AIS 1		36.0	9.0	25.0	70.0	1,910,000	8.2	157,000	1.4	27,200

APPENDIX C

TABULATIONS OF OCCUPANT CASUALTIES IN SIDEDOOR IMPACTS FROM THE NATIONAL CRASH SEVERITY STUDY FILE

1. File Definition:

   NCSS Batch 21 (5557 accident cases)

   Occupant File

2. Cases selected

   a. Towed Passenger Cars

   b. Sidedoor Impacts

      (1) 1st letter of 1st CDC is L or R

      (2) 2nd letter of 1st CDC is P,Y,Z or D

   c. Unrestrained occupants

      RESTRINV = 0 or 8

   d. Occupants sitting in outboard seats (front or rear) on same side as vehicle damage - i.e. if CDCGADPR = L then LOCATION = 1 or 5 and if CDCGADPR = R then LOCATION = 3 or 7.

3. Definition of "Beam-Equipped" - See Table III-6 in report

4. Definition of injury

   a. Fatal injury

      (1) Yes if NCSSCLAS = 1, 2 or 3 (fatal categories)

      (2) No otherwise

   b. AIS ⩾ 3 injury

      (1) Yes if OVERALLA ⩾ 3 or NCSSCLAS = 1, 2, 3

      (2) Unknown if OVERALLA = 8, 9 and NCSCLAS = 4, 5, 9

      (3) No otherwise

c. AIS $\geqslant 2$ injury

(1) Yes if OVERALLA $\geqslant 2$ or NCSSCLAS = 1, 2, 3

(2) Unknown if OVERALLA = 8, 9 and NCSSCLAS = 4, 5, 6, 7, 9

(3) No otherwise

d. Any injury

(1) Yes if OVERALLA = 1, 2, 3, 4, 5, 6 or 8 or NCSSCLAS = 1, 2, 3

(2) No if OVERALLA = 0

(3) Unknown otherwise

5. Single vehicle crashes are those in which NUMVEH = 1; all others are multivehicle.

(WEIGHTED) OCCUPANT CASES

(1) Single Vehicle Sidedoor Impacts

	Pre-214	Post-214
Killed	17 8.9%	8 2.6%
Alive	173	296

	Pre-214	Post-214
AIS $\geqslant 3$	41 24.0%	24 8.8%
AIS < 3	130	250

	Pre-214	Post-214
AIS $\geqslant 2$	56 33.5%	34 14.2%
AIS < 2	111	205

	Pre-214	Post-214
Injured	123 71.5%	145 55.8%
Not injured	49	115

(2) All Types of Sidedoor Impacts

	Pre-214	Post-214
Killed	32 3.1%	35 2.2%
Alive	999	1531

	Pre-214	Post-214
AIS ≥ 3	95 10.1%	122 8.5%
AIS < 3	843	1313

	Pre-214	Post-214
AIS ≥ 2	144 18.0%	184 14.4%
AIS < 2	654	1091

	Pre-214	Post-214
Injured	519 57.9%	707 53.8%
Not Injured	378	606

(UNWEIGHTED) OCCUPANT CASES
(not suitable for statistical analysis and
tabulated only to show size of underlying file)

(1) Single Vehicle Sidedoor Impacts

	Pre-214	Post-214
Killed	17	8
Alive	65	83

	Pre-214	Post-214
AIS ≥ 3	35	21
AIS < 3	37	52

	Pre-214	Post-214
AIS ≥ 2	47	31
AIS < 2	24	37

	Pre-214	Post-214
Injured	72	70
Not Injured	7	13

(2) All Types of Sidedoor Imapcts

	Pre-214	Post-214
Killed	32	35
Alive	285	406

	Pre-214	Post-214
AIS $\geq$ 3	80	98
AIS $<$ 3	180	263

	Pre-214	Post-214
AIS $\geq$ 2	114	142
AIS $<$ 2	126	191

	Pre-214	Post-214
Injured	240	320
Not Injured	54	78

APPENDIX D

FORTRAN PROGRAM FOR CALCULATING STANDARD 214 EFFECTIVENESS AND TESTING HYPOTHESES

(Note: Statistics calculated by the program need to be diluted to account for the NCSS sampling plan)

```
C***********************************************************************
C
C  THIS PROGRAM STANDARDIZES A THREE OR FOUR WAY DATA SET AND
C  CALCULATES THE STANDARDIZED INJURY RATES FOR OCCUPANTS OF
C  STANDARD 214 AND PRE-STANDARD CARS.  NEXT, IT CALCULATES THE
C  EFFECTIVENESS OF STANDARD 214 AND THE STANDARD DEVIATION OF
C  THE EFFECTIVENESS, GIVING CONFIDENCE BOUNDS FOR THE OBSERVED
C  EFFECTIVENESS.  FINALLY, THE OBSERVED EFFECTIVENESS IS TESTED
C  AGAINST THE HYPOTHESIS THAT EFFECTIVENESS IS ZERO AND AGAINST
C  THE HYPOTHESIS OF ANY OTHER VALUE OF EFFECTIVENESS THAT IS
C  SPECIFIED.
C
C***********************************************************************

      DIMENSION DR(2,2),DS(2,2),DINJ(2),DBEAM(2),DE(2,2)
      DIMENSION D(2,2,4,4),B(4,4),E(2,4,4),A(74)
C
C  D=RAW DATA(BEAMS,INJURY,1ST CONTROL VAR,2ND CONTROL VAR)
C  DR=RAW DATA MARGINALS(BEAMS,INJURY)
C  DS=STANDARDIZED DATA(BEAMS,INJURY)
C  DE=HYPOTHESIZED DATA(BEAMS,INJURY)
C  DINJ=RAW DATA MARGINALS(INJURY)
C  DBEAM=RAW DATA MARGINALS(BEAMS)
C
    4 CONTINUE
      READ(5,1)NEX
      IF(NEX)10,9,10
    9 STOP
   10 CONTINUE
C
C  ENTER NEX=0 TO QUIT THE PROGRAM
C
C  ENTER THE NUMBER OF LEVELS FOR THE CONTROL VARS AND A LABEL
C
      READ(5,1)N3,N4,(A(II),II=1,74)
    1 FORMAT(2I3,74A1)
```

```
C***********************************************************************
C
C   ENTER THE RAW DATA
C
C***********************************************************************
      DO 2 I=1,2
      DO 2 J=1,2
      DO 2 K=1,N3
      DO 2 L=1,N4
      READ(5,3)D(I,J,K,L)
    3 FORMAT(F5.0)
    2 CONTINUE
C***********************************************************************
C
C   CALCULATE THE MARGINALS AND THE EFFECTIVENESS BASED ON RAW DATA
C
C***********************************************************************
      DO 11 I=1,2
      DO 11 J=1,2
      DR(I,J)=0.
      DO 11 K=1,N3
      DO 11 L=1,N4
      DR(I,J)=DR(I,J)+D(I,J,K,L)
   11 CONTINUE
      DINJ(1)=DR(1,1)+DR(2,1)
      DINJ(2)=DR(1,2)+DR(2,2)
      DBEAM(1)=DR(1,1)+DR(1,2)
      DBEAM(2)=DR(2,1)+DR(2,2)
      ERAW=(DR(1,1)/DBEAM(1))/(DR(2,1)/DBEAM(2))
      ERAW=100.*(1.-ERAW)
      WRITE(6,8)ERAW
C***********************************************************************
C
C   STANDARDIZE THE DATA AND CALCULATE THE EFFECTIVENESS BASED
C   ON STANDARDIZED DATA
C
C***********************************************************************
      DO 5 K=1,N3
      DO 5 L=1,N4
      B(K,L)=D(1,1,K,L) + D(1,2,K,L) + D(2,1,K,L) + D(2,2,K,L)
    5 CONTINUE
      DO 6 I=1,2
      DO 6 K=1,N3
      DO 6 L=1,N4
      E(I,K,L) = D(I,1,K,L)*B(K,L)/(D(I,1,K,L)+D(I,2,K,L))
    6 CONTINUE
      E1=0.
      E2=0.
      DO 7 K=1,N3
      DO 7 L=1,N4
      E1=E1 + E(1,K,L)
      E2=E2 + E(2,K,L)
    7 CONTINUE
      ESTD=E1/E2
      STD= 100. * ((E2-E1)/E2)
      WRITE(6,8)STD,(A(II),II=1,74)
    8 FORMAT(1X,F8.1,74A1)
```

```
C********************************************************************
C
C  CALCULATE THE ENTRIES OF THE STANDARDIZED TABLE, THE STANDARD
C  DEVIATION OF THE EFFECTIVENESS, BASED ON THIS TABLE, AND THE
C  CONFIDENCE BOUNDS
C
C********************************************************************
      DS(1,1)=ESTD*DBEAM(1)*DINJ(1)/(DBEAM(2)+(ESTD*DBEAM(1)))
      DS(2,1)=DINJ(1)-DS(1,1)
      DS(1,2)=DBEAM(1)-DS(1,1)
      DS(2,2)=DINJ(2)-DS(1,2)
      SIG=DS(1,2)/(DBEAM(1)*DS(1,1))+DS(2,2)/(DBEAM(2)*DS(2,1))
      SIG=ESTD*(SIG**.5)*100.
      WRITE(6,8)SIG
      STD=STD-1.64*SIG
      WRITE(6,8)STD
      STD=STD+3.28*SIG
      WRITE(6,8)STD
C********************************************************************
C
C  BUILD THE TABLE WHOSE ENTRIES IMPLY THAT THE EFFECTIVENESS OF
C  STANDARD 214 IS 'EHYP' AND WHOSE MARGINALS ARE THE SAME AS
C  THOSE OF THE RAW AND STANDARDIZED DATA TABLE.  ON THE FIRST
C  EXECUTION OF THIS LOOP, 'EHYP' IS SET TO ZERO--THIS IS A TEST
C  OF WHETHER THE STANDARDIZED EFFECTIVENESS IS SIGNIVICANTLY
C  DIFFERENT FROM ZERO.  CALCULATE THE CHI-SQUARE STATISTIC USING
C  THE STANDARDIZED TABLE AS THE 'OBSERVED' TABLE AND THE TABLE
C  BUILT HERE AS THE 'EXPECTED' TABLE.
C
C********************************************************************
      EHYP=0.
   12 CONTINUE
      EHYP=1.-(EHYP/100.)
      DE(1,1)=EHYP*DBEAM(1)*DINJ(1)/(DBEAM(2)+(EHYP*DBEAM(1)))
      DE(2,1)=DINJ(1)-DE(1,1)
      DE(1,2)=DBEAM(1)-DE(1,1)
      DE(2,2)=DINJ(2)-DE(1,2)
      CHIS=0
      DO 13 I=1,2
      DO 13 J=1,2
      CHIS=CHIS+(DE(I,J)-DS(I,J))*(DE(I,J)-DS(I,J))/DE(I,J)
   13 CONTINUE
      WRITE(6,14)CHIS
C********************************************************************
C
C  NOW ENTER A NEW VALUE FOR 'EHYP' AND TEST WHETHER THE STANDARDIZED
C  EFFECTIVENESS DIFFERS SIGNIFICANTLY FROM THIS VALUE.  IN ORDER TO
C  QUIT WORKING WITH THIS DATA SET AND START A NEW ONE, ENTER 0.0
C
C********************************************************************
   14 FORMAT(1X,F8.4)
      READ(5,3)EHYP
      IF(EHYP)12,4,12
      END
```

APPENDIX E

COST EFFECTIVENESS EVALUATION ASSUMING IMPERFECT KNOWLEDGE OF BASELINE CASUALTIES

According to the Fatal Accident Reporting Systems (FARS), there were 27,353 automobile occupant fatalities in the United States in 1977. Although, strictly speaking, this number is only an estimate, it is far more accurate than just about any other available national statistic about automobile crashes. For all practical purposes, it can be considered known with "certainty."

Batch 21 of the NCSS file contains 35,002 (weighted) unrestrained occupants of cars whose damage location and crash forces were known. This report was based on a study of these occupants. Since 300 of the 35,002 occupants were killed, one can use NCSS to obtain national estimates of the statistics in this report by multiplying each (weighted) occupant on NCSS by 27,353/300, i.e., by 91.18.

The estimated number of casualties that would have occurrred in 1977 if Standard 214 had not been promulgated is:
91.18 (Standardized casualty rate - pre 214) X (No. of involved NCSS occupants - pre and post 214) = 91.18 $R^{-}n$.

This is the <u>baseline</u> number of casualties - i.e. the number of casualties that could be prevented if Standard 214 were 100 percent effective. Since this baseline is an estimate based on the NCSS sample, it is possible to calculate its standard deviation. If R^- (a casualty rate or proportion) is based on a sample of n_1 (weighted) occupants and if n is substantially larger than R^-n_1, the standard deviation is approximately

$$91.18 \; nf \sqrt{R^- (1 - R^-)/n_1}.$$

where f is the dilution factor needed to account for the NCSS sampling plan, discussed in Chapter VI.

Similarly, the number of casualties that would have occurred in 1977 if all cars met Standard 214 is $91.18 \; R^+ n$, where R^+ is the standardized casualty rate in post-214 cars.

The estimated number of casualties prevented by Standard 214 is

$$\Delta = 91.18 \; (R^- - R^+) \; n$$

and its standard deviation is approximately

$$S_\Delta = 91.18 \; n \; f \sqrt{(R^- (1 - R^-)/n_1) + (R^+ (1 - R^+)/n_2)}$$

Where n_2 is the (weighted) sample size on which R^+ is based.

It is also possible to test the hypothesis that the number of casualties prevented equals some fixed Δ_x. There are hypothetical injury rates R_1 (for pre-Standard cars) and R_2 (for post-Standard cars) such that

$$\Delta_x = 91.18\ (R_1 - R_2)\ n$$

and

$$R_1\ n_1 + R_2\ n_2 = R^- n_1 + R^+ n_2$$

These are 2 linear equations that are readily solved for R_1 and R_2. After R_1 and R_2 are calculated, $H_0 : \Delta = \Delta_x$ is accepted if

$$\Delta - \Delta_x \leq 1.64\left(91.18\ nf \sqrt{R_1\ (1 - R_1)/n_1 + R_2\ (1 - R_2)/n_1}\right).$$

otherwise, $H_1 : \Delta > \Delta_x$ is accepted.

In the special case where $\Delta_x = 0$,

$$R_1 = R_2 = R$$

$$R = \frac{R^- n_1 + R^+ n_2}{n_1 + n_2}$$

i.e., this is the ordinary test of a difference of proportions.

On Batch 21 of NCSS, $n = 494$ for single vehicle sidedoor impacts and $n = 2597$ for all types of sidedoor impacts. Values of f for alternative casualty rates are the reciprocals of the numbers in the left column of Table VI-2. Values of n_1 and n_2 may be found in Appendix C. R^- and R^+ are the fatality and injury rates that have been standardized on ΔV, vehicle weight and restraint usage (see Chapter VI).

Tables E-1 and E-2 show the estimated casualty reduction due to Standard 214 in single vehicle sidedoor impacts and all types of sidedoor impacts, respectively, as calculated by this technique.

TABLE E-1

ESTIMATED CASUALTY REDUCTION DUE TO STANDARD 214 IN SINGLE VEHICLE SIDEDOOR IMPACTS

(Annual nationwide casualty prevention that would have occurred in 1977 if all cars met Standard 214)

Type of Casualty	Annual Casualty Reduction	Standard Deviation of Estimate	Reduction Significantly greater than Zero?
Fatalities	3100	1030	Yes
AIS $\geq$ 3 injuries	7200	2160	Yes
AIS $\geq$ 2 injuries	9000	2800	Yes

TABLE E-2

ESTIMATED CASUALTY REDUCTION DUE TO STANDARD 214 IN ALL TYPES OF SIDEDOOR IMPACTS

(Annual nationwide casualty prevention that would have occurred in 1977 if all cars met Standard 214)

Type of Casualty	Annual Casualty Reduction	Standard Deviation of Estimate	Reduction Significantly greater than Zero ?
Fatalities	2350	1560	No
AIS $\geq$ 3 injuries	4000	3780	No
AIS $\geq$ 2 injuries	7500	5800	No

The Standard will prevent an estimated 3000 deaths, 7000 AIS $\geqslant 3$ injuries and 9000 AIS $\geqslant 2$ injuries annually when it becomes available on all cars. All of these estimates are statistically significant. Whereas the estimates of casualty prevention are less precise than the esimates of effectiveness (Table VI-9) there is still little doubt that the standard is having a substantial impact in these types of crashes. If $\Delta - 1.64s_{\Delta}$ is taken as a lower bound for casualty reduction, the standard will save a minimum of 1400 lives a year.

Thus, even under this conservative estimation technique which makes no prior assumptions about the baseline number of sidedoor impact casualties, one must conclude that the standard provides substantial benefits in single vehicle crashes.

On the other hand, the estimates of casualty reduction in all types of sidedoor crashes are not statistically signficant. In each case, the estimate is just slightly larger than its standard deviation. If, however, the observed trends were to persist in the NCSS data for one more year, the reductions would become significant. The casualty reduction estimates in all types of crashes are somewhat lower than those in single vehicle crashes because a slightly negative casualty reduction was observed in the multivehicle crashes.

Cost-effectiveness evaluation can be performed using the estimated casualty reductions (of this Appendix) in place of the estimated effectiveness (see Chapter VI). The only difficulty is that the target levels for cost-effectiveness were given in dollars per Equivalent Fatality Unit (See Chapter V) while the estimated casualty reductions are given in fatalities, AIS $\geqslant$ 3 injuries or AIS $\geqslant$ 2 injuries. It is necessary to define a relationship betweeen EFU and casualties, using ratios obtained from Appendix B. For example, since there were 3750 fatalities (Appendix B) and 4290 EFU (Chapter V) in single vehicle crashes, one life saved corresponds to a reduction of 4290/3750 or 1.14 EFU. Thus, a target cost of $300,000 per EFU prevented corresponds to a target cost of 1.14 x 300,000 or $340,000 per life saved. (These correspondences are based on the assumption that Standard 214 is about equally effective for fatalities and non-minor injuries - see Chapter VI).

The results, using the Bayesian approach and a target cost of $300,000 per EFU, are shown in Table E-3; using a target cost of $600,000 per EFU in Table E-4; and using an acceptance sampling approach in Table E-6. The EVPI's are all higher than those calculated in Chapter VI (where the baseline casualties were assumed known with certainty). But the overall conclusions are virtually the same: the Standard is cost-effective, based on single vehicle crashes alone; no conclusion can be drawn based on all types of sidedoor impacts. The only difference between the results of Chapter VI and the present approach is that the sample is not quite large enough here to prove that the Standard costs less than $300,000 per EFU prevented; nevertheless, the $600,000 target and accceptance sampling criteria are easily met in the single vehicle crashes.

TABLE E-3

COST EFFECTIVENESS EVALUATION USING BAYESIAN APPROACH AND $300,000 AS TARGET COST PER EFU ELIMINATED

(Assuming imperfect knowledge of baseline casualties)

Benefits defined by:	EVPI	Conclusion
	(a) Based on Single Vehicle Sidedoor Impacts	
Fatalities prevented	$ 12 M	Collect data for 6 more months
AIS $\geqslant$3 injuries prevented	$ 11.2M	Collect data for 6 more months
AIS $\geqslant$ 2 injuries prevented	$ 25 M	Collect data for 1 more year
	(b) Based on All Types of Sidedoor Impacts	
Fatalities prevented	$ 108 M	Collect data for 2 more years
AIS $\geqslant$3 injuries prevented	$ 123 M	Collect data for 2 more years
AIS $\geqslant$2 injuries prevented	$ 125 M	Collect data for 2 more years

TABLE E-4

COST EFFECTIVENESS EVALUATION USING BAYESIAN APPROACH AND $600,000 AS TARGET COST PER EFU ELIMINATED

(Assuming imperfect knowledge of baseline casualties)

Benefits defined by:	EVPI	Conclusion
	(a) Based on Single Vehicle Sidedoor Impacts	
Fatalities prevented	$ 3.3 M	Standard is Cost-effective
AIS $\geq$ 3 injuries prevented	$ 1.8 M	Standard is Cost-effective
AIS $\geq$ 2 injuries prevented	$ 3.6 M	Standard is Cost-effective
	(b) Based on All Types of Sidedoor Impacts	
Fatalities prevented	$ 46 M	Collect data for 2 more years
AIS $\geq$ 3 injuries prevented	$ 195 M	Collect data for 2 more years
AIS $\geq$ 2 injuries prevented	$ 136 M	Collect data for 2 more years

TABLE E-5

COST EFFECTIVENESS EVALUATION USING ACCEPTANCE SAMPLING APPROACH

(Assuming imperfect knowledge of baseline casualties)

Benefits defined by:	Conclusion
(a) Based on Single Vehicle Sidedoor Impacts	
Fatalities prevented	Standard is cost-effective
AIS $\geq$ 3 injuries prevented	Standard is cost-effective
AIS $\geq$ 2 injuries prevented	Standard is cost-effective
(b) Based on All Types of Sidedoor Impacts	
Fatalities prevented	Collect more data
AIS $\geq$ 3 injuries prevented	Collect more data
AIS $\geq$ 2 injuries prevented	Collect more data

In summary, even with the more conservative approach taken in this Appendix, it appears that the Standard prevents a substantial number of casualties in single vehicle crashes and is cost-effective based on its benefits in these crashes. But the failure to substantiate these findings when one looks at all types of sidedoor crashes suggests that more data be collected before the positive results are accepted as final. These are the very same conclusions that were reached using the approach of Chapter VI.

APPENDIX F

ANALYSIS OF AGE EFFECTS ON THE NCSS FILE

The age effect - the tendency of occupants of older cars to have higher reported injury rates - was discussed in Chapter VI. The causal factors that were cited were

1. Underreporting of non-injury crashes of old cars.
2. Safety improvements in new cars - especially increased restraint system usage.
3. More severe accidents of older cars, due to the exposure and driver differences.

Factors 2 and 3 were analyzed and quantified in Chapter VI; factor 1 remains to be discussed.

Two approaches will be used to analyze underreporting of older cars in NCSS. First, the reported injury rates (in non-sidedoor impacts) will be examined for cars of different ages. If (after standardizing out the other factors which influence injury rates) the older cars have higher injury rates, the difference in rates can be attributed to underreporting of non-injury accidents. Second, the reported number of accidents on the file will be examined for cars of different ages. If the older cars have a smaller number of accidents then expected, the difference from the expected value is the number of accidents that presumably occurred but were not reported.

Analysis of Injury Rates

The AIS $\geqslant$ 2 injury rates for unrestrained occupants of cars involved in non-sidedoor multivehicle towaway crash impacts are shown in Table F-1. The cars are grouped into 3 model year brackets: 1966 and earlier; 1967-71 and 1972-77. The first group consists of cars more than 10 years old at the time NCSS data were collected. The second group consists of cars up to 10 years old from model years in which most cars were not beam-equipped. The third group consists of the model years in which most cars were beam-equipped. The injury rates are virtually invariant with respect to vehicle age: 5.8 percent for cars of model year 1966 and earlier versus 5.5 percent for cars of model year 1972 and later. After controlling for differences in ΔV and vehicle weight, even these small differences in the injury rates vanish. There appears to be little or no underreporting of older cars involved in multivehicle crashes.

The time trend in AIS $\geqslant$ 2 injury rates for unrestrained occupants in non-sidedoor single vehicle crashes is quite different (See table F-2). The injury rate in the cars of model year 1966 and earlier (20.6%) is almost twice as high as the rate in cars 10 years old or less (10.8%). On the other hand, there is little difference between the cars of model years 1967-71 (9.8%) and 1972-77 (11.9%), the injury rate actually being somewhat higher in the newest cars. Thus, there appears to be little or no underreporting or other age effect in single vehicle crashes for cars up to 10 years old. But the cars up to 10 years old have a 46% lower injury rate (after controlling for differences in ΔV and vehicle weight) than the cars over 10 years old. Thus, a maximum of 46% of the single vehicle accidents of cars over 10 years are not reported (because this level of underreporting would explain the entire difference in injury rates).

TABLE F-1

AIS $\geq$ 2 INJURY RATES OF UNRESTRAINED OCCUPANTS IN MULTIVEHICLE NON-SIDEDOOR IMPACTS, BY VEHICLE MODEL YEAR, NCSS

Vehicle Model Years	AIS $\geq$ 2 Injury Rate	Weighted N of Occupants
1966 and earlier	5.8%	2247
1967-71	5.9%	7163
1972-77	5.5%	9613
1971 and earlier	5.9%	
1972-77	5.5%	
1966 and earlier	5.8%	
1967-77	5.7%	

TABLE F-2

AIS $\geq$ 2 INJURY RATES OF UNRESTRAINED OCCUPANTS IN SINGLE VEHICLE NON-SIDEDOOR IMPACTS, BY VEHICLE MODEL YEAR, NCSS

Vehicle Model Year	AIS $\geq$ 2 Injury Rate	Weighted N of Occupants
1966 and earlier	20.6%	749
1967-71	9.8%	3204
1972-77	11.9%	2997

1971 and earlier	11.8%	
1972-77	11.9%	

1966 and earlier	20.6%	
1967-77	10.8%	

Analysis of the Reported Number of Accidents

The degree of underreporting of older cars in single vehicle accidents can be inferred by comparing the number of such accidents actually reported to the number that would have been "expected," based on the older cars' involvement in multivehicle accidents. The main problem is to determine how many accidents would have been "expected." The technique used here is an adaptation of Cerrelli's methods of computing indirect exposure and failure indices.*

The technique relies on some very simplified assumptions about the characteristics of accident involvement. The resultant measure of underreporting can be considered as little better than a crude approximation. Nevertheless, the concepts of indirect exposure and failure indices were shown in the past to have considerable empirical validity.

The following assumptions are made:

(1) Underreporting (if any) occurs only among single vehicle crashes of older cars - not among newer cars or multivehicle crashes.

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* E.C. Cerrelli "Driver Exposure - Indirect Approach for Obtaining Relative Measures." Pub. No. DOT HS-820 179, NHTSA, 1972.
E.C. Cerrelli "Failure Indices - New Improved Measures of Performance." Pub. No. DOT HS-820 302, NHTSA, 1973.

(2) There are two types of crash involvements: "at fault" and "not at fault."

(2.1) All single vehicle crash involvements are "at fault."

(2.2) All multivehicle side impact involvements are "not at fault."

(2.3) Other multivehicle crash involvements may be "at fault" or "not at fault."

(3) In multivehicle crashes, there are an equal number of "at fault" and "not at fault" involvements, in the aggregate.

(4) The propensity to have a single vehicle crash is proportional to the propensity to have an "at fault" multivehicle crash involvement.

The following symbols are defined:

Statistics from NCSS:

0_1 = reported single vehicle crashes of older cars

n_1 = reported single vehicle crashes of newer cars

0_2 = repoted multivehicle crash involvlements of older cars

0_s = reported involvements of older cars struck in the side in a multivehicle crash

and thus also n_2, n_s for newer cars

calculated parameters:

0^+ = "at fault" involvements of older cars in multivehicle crashes

0^- = "not at fault" involvements of older cars in multivehicle crashes

and thus also n^+, n^- for newer cars k = constant proportion of single vehicle crashes to "at fault" multivehicle crash involvements

r = reporting rate for older cars in single vehicle crashes.

There are 6 unknowns: 0^+, 0^-, n^+, n^-, k and r.

The assumptions provide 6 equations:

(1) $0_2 = 0^+ + 0^-$

(2) $n_2 = n^+ + n^-$

(3) $0^+ + n^+ = 0^- + n^-$

(4) $0^-/n^- = 0_s/n_s$

(5) $n_1 = k\ n^+$

(6) $0_1 = r\ k\ 0^+$

The equations were solved under 2 different conditions:

(a) When the "older" cars on NCSS are those of model year 1971 or earlier.

(b) When the "older" cars are of model year 1966 or earlier.

The input data from NCSS, which are shown in Table F.3, are used in the equations to solve for the reporting rate r.

TABLE F-3

INPUT DATA TO CALCULATE UNDERREPORTING OF OLDER CARS IN SINGLE VEHICLE CRASHES, NCSS

Input Data Item	Definiton of "Older Cars" MY 1971 and earlier	MY 1966 and earlier
0_1	4,985	1,040
n_1	4,062	8,007
0_2	12,891	3,207
n_2	13,095	22,779
0_s	3,674	768
n_s	4,344	7,250

The solution for the reporting rate r, for cars of model year 1971 and earlier is 0.98 - i.e., about 2 percent of the single vehicle crashes of these cars are unreported. Thus, the model suggests that there is no systematic problem of underreporting among the pre-Standard 214 cars.

The solution for r, for cars of model year 1966 and earlier, on the other hand, is 0.73 - i.e. about 27 percent of the single vheicle crashes of these cars are unreported. Thus, the model suggests a large degree of underreporting of single vehicle crashes of cars more than 10 year old. The calculated rate of 27 percent may be considered a lower bound, because the model assumes no underreporting of any type of crash except single vehicle crashes of older cars. If, in fact, any other crash type is underreported, the calculated rate is understated.

Summary

The preceding analyses suggest that

1. There is little or no underreporting or age effect in multivehicle crashes, for cars of any age.

2. There is little or no underreporting or age effect in single vehicle crashes, for cars up to 10 years of age.

3. There is substantial underreporting of single vehicle crashes involving cars more than 10 years old. Estimates of the percentage of crashes not reported range from 27 percent (using a technique that would tend to underestimate the problem) to 46 percent (by a technique that would tend to overstate it). The actual degree of underreporting is likely to be somewhere between the two estimates.

APPENDIX G

FATAL ACCIDENT REPORTING SYSTEM: PRELIMINARY FINDINGS ON STANDARD 214 IN SIDE IMPACTS

The Fatal Accident Reporting System (FARS), which is managed by NHTSA's National Center for Statistics and Analysis, contains a virtual census of traffic accident fatalities that occurred in the period 1975 - late 1978. The results on fatality reduction based on NCSS data involved a fairly small sample of fatalities (a total of 67 sidedoor impact fatalities on Batch 21, the file used in this report). Some of the NCSS results are statistically unreliable because of the small sample size. It is desirable to perform comparable analyses using the much larger FARS file.

A synopsis of two preliminary analyses of FARS data is presented here. The analyses were performed by Sue Partyka and James Hedlund of the National Center. They will be refined in the follow-ups to this report.

FARS cannot be used to provide results directly comparable to NCSS, because

(1) FARS does not contain the level of detail that NCSS does. Sidedoor impacts cannot be reliably distinguished from other categories of side impacts.

(2) FARS only contains fatal accidents. It is not possible to calculate fatality rates per 100 exposed occupants or to measure the effectiveness of a standard in the ordinary manner.

It is possible, however, to impute relative fatality risks under certain conditions by using special algebraic techniques. Both of the analyses that follow are of this type. Despite their limitations (i.e., dealing with side rather than sidedoor impacts and using imputed rather than direct measures of effectiveness) the analyses are useful as indicators of the likely effectiveness of Standard 214.

Effectiveness of Standard 214 in Multivehicle Crashes

A principal shortcoming of the NCSS analyses was the failure, due to inadequate sample size, to produce a statistically meaningful result on multivehicle crashes. In fact, a 20 percent increase in fatalities was observed for post-Standard cars, but this was statistically compatible with a wide range of positive and negative fatality reductions.

The effectiveness of the Standard can be imputed from FARS data as follows. Consider all front-to-side car-to-car impacts in which a person in the striking vehicle was killed. Since the risk of a fatality in the striking car is only influenced to a limited extent by the characteristics of the struck car, these crashes should be of roughly equal severity for pre-Standard and post-Standard struck vehicles. Thus, the reduction of the fatality risk for post-Standard, struck vehicle occupants who were sitting on the side of the car that was struck should give an indication of the effectiveness of Standard 214 in multivehicle crashes. The fatality risks are shown in Table G-1.

TABLE G-1

FATALITY STATUS OF STRUCK VEHICLE, NEARSIDE OCCUPANTS IN FRONT-TO-SIDE CRASHES INVOLVING A FATALITY IN THE STRIKING VEHICLE, FARS 1975-78

	Struck Car Model Year	
Fatality Status	1968 and Earlier (Pre-Standard)	1973 and Later (Post-Standard)
Killed	82	122
Not killed	410	727
N of occupants	492	849
Percent killed	16.7	14.4

The FARS data suggest a nearside occupant fatality reduction of 14 percent (i.e. 1 - 14.4/16.7) for post-Standard cars in multivehicle side impact crashes.

The above analysis deals with nearside occupants in all types of side impacts, not just sidedoor impacts. The effects of restraint usage and other standards have not been controlled for. The transitional model years (1969-72) were excluded from the tabulations because the data processing needed to assign them to pre-Standard or post-Standard groups could not be performed within the time constraints of this study. The accidents involving a fatality in the striking vehicle are not necessarily representative of fatal multivehicle front-to-side crashes, generally.

The same analytic procedure was applied to several other data sets:

(1) The above analysis was performed using only <u>unrestrained</u> occupants of the struck vehicles (this approach is considered less meaningful because of the unreliability and high missing data rate (25-30%) of restraint usage of FARS).

(2) Instead of crashes with a fatality in the striking vehicle, crashes with a farside occupant fatality in the struck car were used. (This approach is considered less meaningful, because the farside occupant fatality risk in the struck car is substantially influenced by the characteristics of the struck car - i.e. the crahses need not be of equal severity for the pre- and post-Standard cars.)

(3) A combination of (1) and (2).

The effectiveness of Standard 214 in these alternative analyses ranged from -12 percent to +29 percent.

The results from FARS all fall within the confidence bounds for effectiveness in multivehicle accidents derived from the NCSS analysis. The FARS data suggest that the effectiveness of Standard 214 in multivehicle crashes is probably not negative (as observed in the small NCSS sample) but most likely has some modest positive value (i.e. close to 14 percent).

Single versus Multivehicle Crashes

One of the most statistically reliable findings in the NCSS analysis was that Standard 214 is more effective in single vehicle sidedoor impact crashes than in multivehicle crashes. The size of the difference of effectiveness, however, could not be reliably measured by NCSS (because the effectiveness in multivehicle crashes was not reliably measured). The observed difference was very large (the standard was observed to be 78 percent more effective in single vehicle than in multivehicle sidedoor impacts).

Whereas the FARS data cannot be used to calculate (by ordinary means) the absolute effectiveness in either single or multivehicle accidents, they can be used to calculate the relative effectiveness and compare it to the one osbserved in NCSS. The data in Table G-2 are used. The data show pre- and post-Standard fatalities in side (not sidedoor) impacts resulting from single and multivehicle crashes.

TABLE G-2

OCCUPANT FATALITIES IN SIDE IMPACTS
FARS 1975-78

	Vehicle Model Year	
Type of Crash	1968 and Earlier (Pre-Standard)	1973 and Later (Post-Standard)
Single vehicle	1786	2301
Multivehicle	3773	6173

The post-Standard vehicles (which are far more numerous than the pre-Standard cars) produced 64 percent more multivehicle fatalities than the pre-Standard vehicles, but only 29 percent more single vehicle crash fatalities. Thus, the Standard is 21 percent* more effective in single vehicle side impacts than in multivehicle side impacts.

The FARS data, then, confirm the NCSS finding that Standard 214 is substantially more effective in single vehicle crashes than in multivehicle crashes. On the other hand, the size of the differences of effectiveness

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* i.e., 1 - 1.29/1.64

is so much smaller in FARS than in NCSS that one may question whether the discrepancy could be due to chance alone. Note, however, that the FARS data are based on all types of side impacts, but the NCSS data only on sidedoor impacts; the FARS data exclude the model years 1969-72, but the NCSS data include them; FARS includes restrained occupants, but NCSS does not. In order to compare NCSS and FARS in a meaningful way, it is necessary to tabulate the NCSS data under the same definitions that were used for FARS (Table G-2). The result is shown in Table G-3:

TABLE G-3

OCCUPANT FATALITIES IN SIDE IMPACTS, NCSS

	Vehicle Model Year	
Type of Crash	1978 and Earlier (Pre-Standard)	1973 and Later (Post-Standard)
Single vehicle	14	11
Multivehicle	24	41

Based on the data in Table G-3, the NCSS data suggest that the Standard is only 54 percent more effective in single vehicle side impacts than in multivehicle side impacts (versus a 78 percent difference in sidedoor impacts). So the difference in side impacts observed in FARS (21 percent) may understate the difference that might have been found if it had been possible to look only at sidedoor impacts.

Furthermore, a CONTAB analysis showed no significant difference between the fatality distributions in FARS (Table G-2) and NCSS (Table G-3).* Thus, while the difference in effectiveness is higher in NCSS than in FARS, it is not so much higher as to make the data files statistically inconsistent.

Summary

The preceding analyses of FARS data

(1) confirm the findings, based on NCSS, that Standard 214 is substantially more effective in single vehicle than in multivehicle crashes.

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* The CONTAB program was run on the combined Tables G-2 and G-3. No significant effects were found other than the main effects and the interaction of "Number of Vehicles" and " Standard 214 Status" - i.e., this latter interaction (which measures the difference of effectiveness) is independent of the data file.

(2) suggest that the effectiveness of Standard 214 in multivehicle crashes is not negative (as was observed in NCSS) but rather has a relatively small positive value, on the order of 10-15 percent (a value which is statistically compatible with the NCSS results).

(3) suggest that the fatality-reducing effectiveness of Standard 214 in single vehicle crashes might not be quite as high as what was observed in NCSS (74 percent) but is nevertheless quite substantial, on the order of 35-60 percent (depending on the interpretation of the preceding analysis results).

(4) support the overall conclusions of this evaluation.

APPENDIX H

TRENDS IN SIDE IMPACT CASUALTY RATES

This report has, so far, dealt only with Standard 214. All the analyses were aimed at isolating the benefits of one Standard and isolating one type of crash - sidedoor impacts with nearside occupants - in which the Standard was likely to be effective.

It is appropriate to conclude this report with a brief look at the larger problem of side impacts - not just sidedoor impacts - and to consider all possible factors that may have reduced the casualty risk - not just Standard 214.

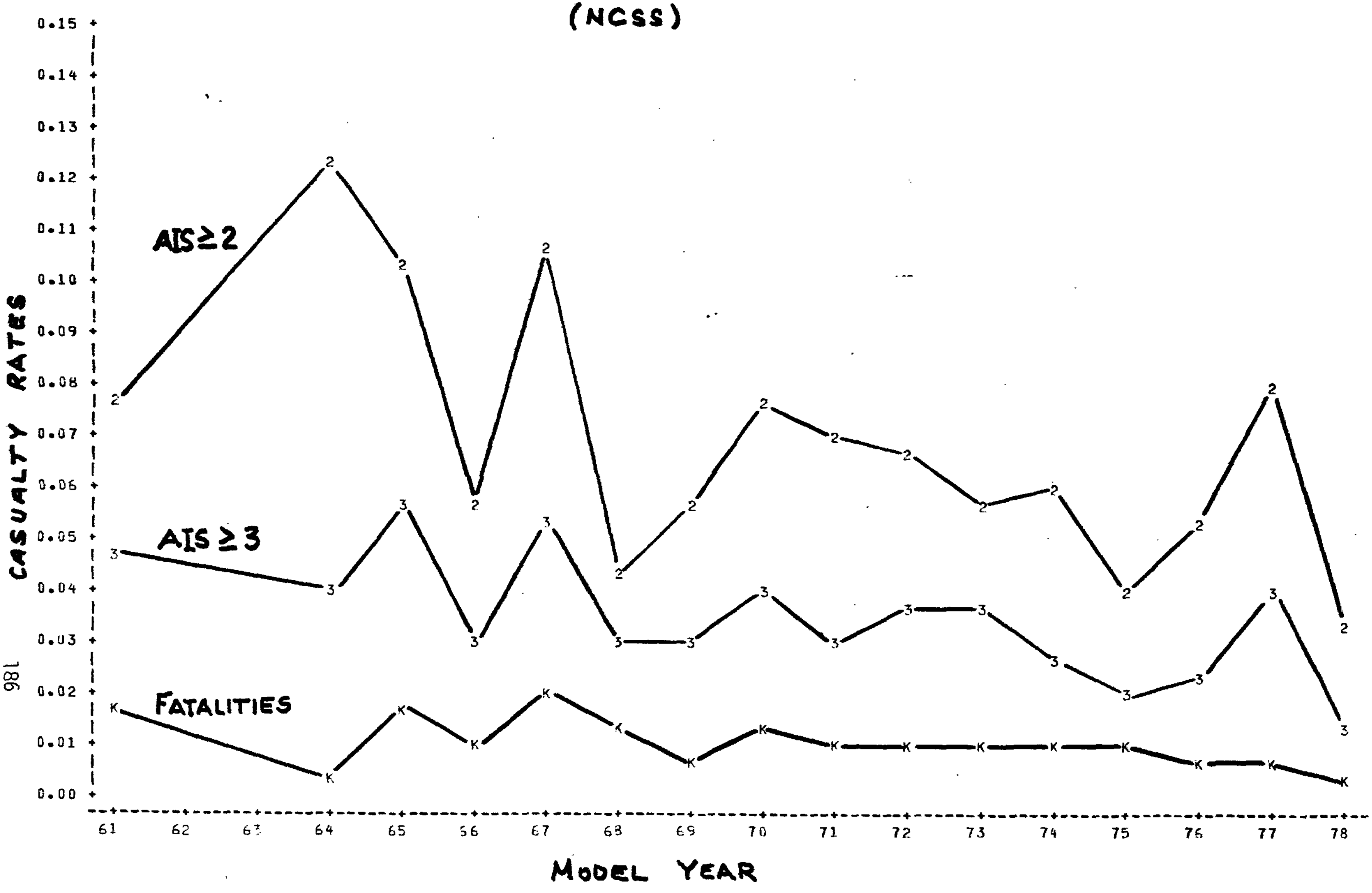
The problem is best examined by graphing the casualty rates from NCSS by model year and looking for differences between the older and newer cars.

Since the NCSS data were all collected at more or less the same time (i.e., they are cross-sectional rather than time-series data) the differences between the old and new cars are not due to secular factors such as improved roads or reduced speed limits. (One of the shortcomings of time-series studies of fatality rates, for example, is the difficulty of isolating the effect of roadway improvements from vehicle improvements.)

The differences in the casualty rates from one model year to the next on NCSS can be attributed primarily to the following factors:

FIGURE H-1

CASUALTY RATES IN SIDE IMPACTS
BY MODEL YEAR
(NCSS)



(1) Real improvements in crashworthiness

  (a) Federal Motor Vehicle Safety Standards

  (b) Increased restraint usage, partially in response to Standards

  (c) Other improvements (not directly mandated by Standards)

(2) Real factors other than "crashworthiness improvements"

  (a) Changing vehicle mix (e.g., more large cars, fewer convertibles)

  (b) Changing driver/exposure mix (e.g., older cars have more severe accidents)

(3) Spurious factors

  (a) Non-sampling error: underreporting of property damage accidents of old cars, resulting in high reported injury rates (see Appendix F)

  (b) Non-sampling error: Peculiar vehicle mix for certain model years due to local conditions at the NCSS sites. (There is no evidence of a substantial error of this sort.)

  (c) Sampling error: The casualty rate for a single model year on NCSS is based on a rather small sample (300-1900 weighted or 75-500 actual persons) and may diverge widely from the casualty rate that would be observed for a census of the nation's side-impact involved persons.

FIGURE H-2

AIS≥2 INJURY RATES IN SIDE IMPACTS BY MODEL YEAR TREND LINE AND OBSERVED RATES (NCSS)

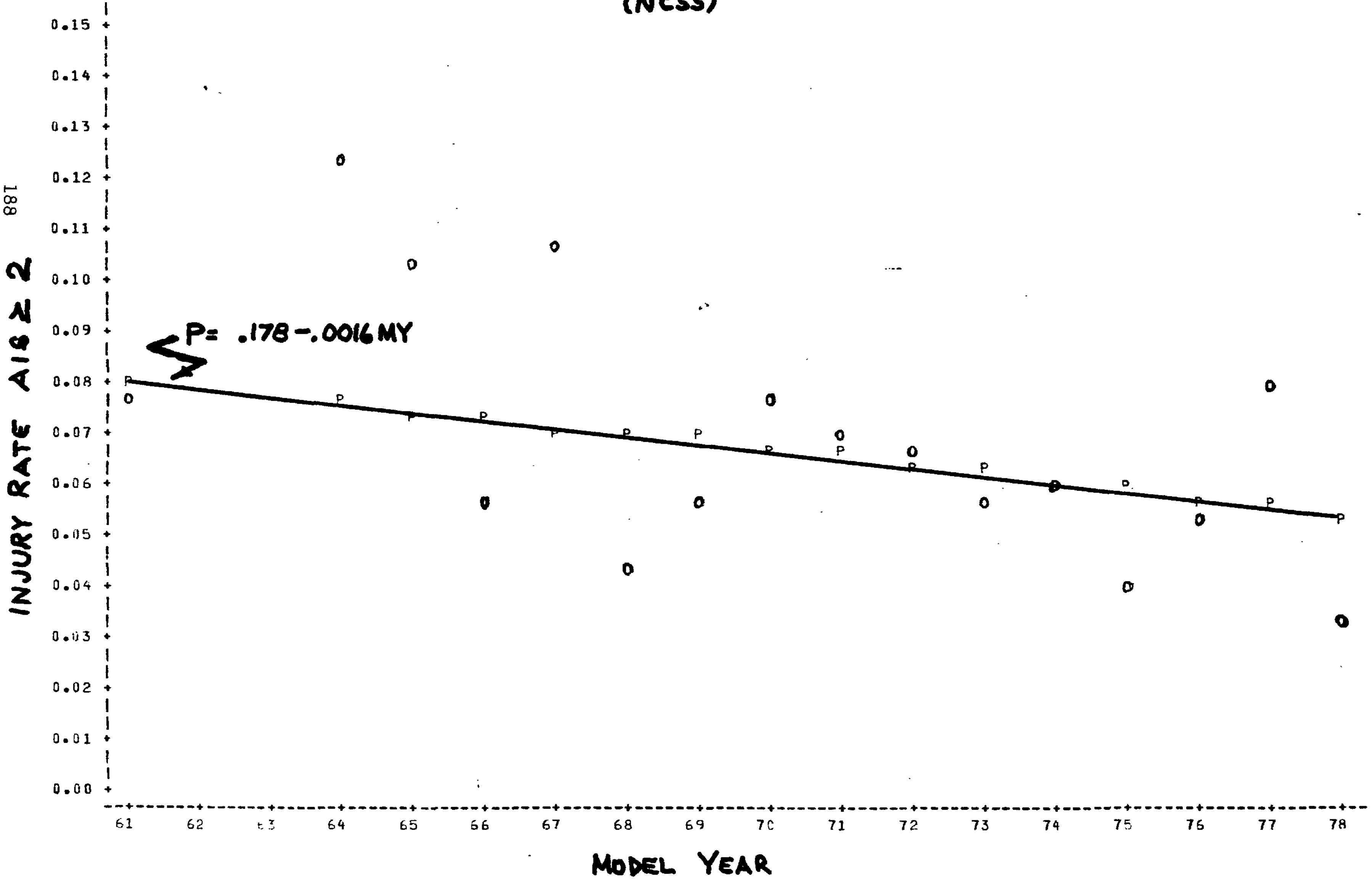
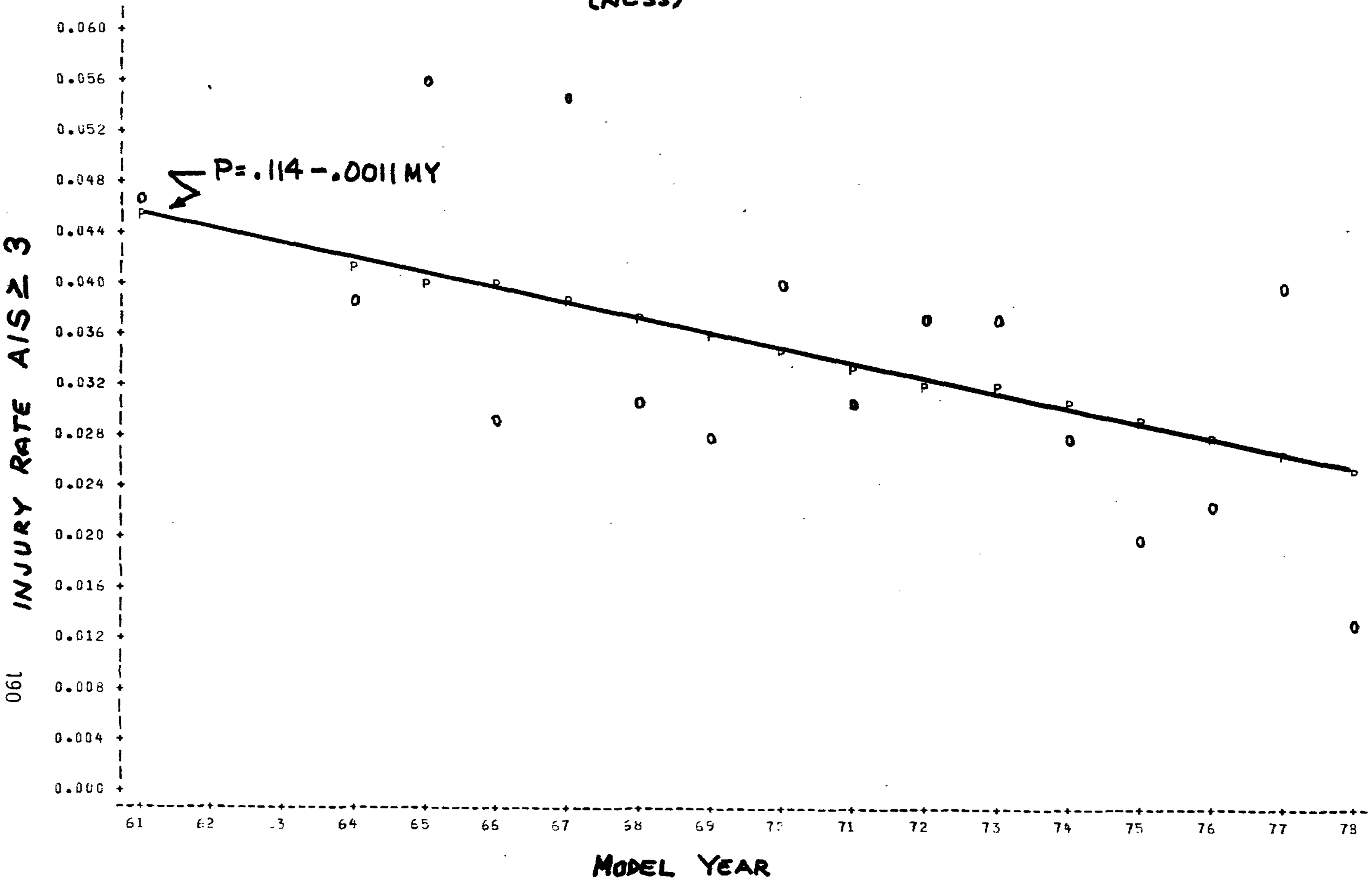


Figure H-1, displays the casualty rates in side impacts, by model year, on NCSS. The rates of AIS $\geqslant$ 2 injury, AIS $\geqslant$ 3 injury and fatalities are graphed. The most noticeable feature of the graphs is the large, seemingly random fluctuation from one model year to the next. The fluctuation seems to overwhelm other patterns that might be contained in the graphs. Factor 3c. above - NCSS sampling error - readily explains the random variations. Given the current sample sizes on NCSS, changes of 50 percent or more in the casualty rates from one model year to the next can be well within the bounds of probability (especially for the fatality rate and for the oldest and newest cars, where the NCSS sample is smallest).

The second feature that can be detected on Figure H-1 is a downward trend in all three graphs: newer cars, on the average, do appear to have lower casualty rates. The reduction is presumably due to a combination of Factor 1 (real crashworthiness improvments), Factor 2 (changing vehicle and exposure mix) and Factor 3a (reporting bias of older cars). But the relatively small number of data points and the overwhelming random fluctuation due to the small sample sizes precludes, at this time, a statistical analysis to identify the relative impacts of the various factors. For example, even the effect of Standard 214 that was observed in this report (e.g. 18 percent AIS $\geqslant$ 2 reduction in sidedoor impacts, which means 10 percent AIS $\geqslant$ 2 reduction in all side impacts) would easily be submerged by the random year-to-year fluctuations (on the order of 50 percent) and probably could not be detected on the graphs. Less far-reaching safety improvements have even less chance of detection.

FIGURE H-3

AIS ≥ 3 INJURY RATES IN SIDE IMPACTS
BY MODEL YEAR
TREND LINE AND OBSERVED RATES
(NCSS)



The most meaningful analysis that can be performed at this time is a simple weighted* least squares regression to determine the slope of the downward trend and to test if the slope is significantly different from zero. The regression lines and observed casualty rates are shown in Figures H-2 (for AIS $\geqslant$ 2 injury), H-3 (for AIS $\geqslant$ 3 injury) and H-4 (for fatalities). All of the regression lines have a negative slope, confirming the trend toward lower casualty rates in newer cars. But the slope is significantly lower than zero only for the fatality rates ($p=.002$), not for AIS $\geqslant$ 2 ($p=.17$) or AIS $\geqslant$ 3 ($p=.06$). The lack of statistical significance for the latter trends is primarily due to the random year-to-year scatter of the casualty rates, as is readily noticeable in Figures H-2 and H-3. The scatter should decrease as the NCSS sample size increases.

The slopes correspond to an average year-to-year decrease of 2 percent in the AIS $\geqslant$ 2 rate, 3 percent in the AIS $\geqslant$ 3 rate, and 6 percent in the fatality rate. These rates of decrease reflect the combined effects of safety standards, other crashworthiness improvements, changes in the vehicle mix, reduced severity of accidents involving new cars and reporting biases.

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* Weighting of the data points is necessary because the casualty rates in some model years are based on substantially larger samples than in others.

FIGURE H-4

FATALITY RATES IN SIDE IMPACTS BY MODEL YEAR

TREND LINE AND OBSERVED RATES (NCSS)