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**National Highway
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Administration**

Evaluation of the Effectiveness of Occupant Protection

Federal Motor Vehicle Safety Standard 208

INTERIM REPORT

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HIGHLIGHTS OF FINDINGS

Automatic occupant protection, state belt laws, and greater voluntary belt use amount to a 'winning combination' that saves lives and reduces injury severity. Safety Standard 208 combines a nationwide effort to increase belt use through state belt laws, enforcement and education, and a requirement that automatic occupant protection, such as air bags or automatic belts, be phased into passenger cars (1987-90) and light trucks (1995-98). Air bags plus manual belts will be required in all cars in 1997 and light trucks in 1998.

This interim report, evaluating the effectiveness of occupant protection, based on data available in May 1992, is issued in response to the exceptional public interest in the occupant protection program. Although there are not enough data for statistically significant results on every evaluation question, it is already clear that the occupant protection program is saving thousands of lives:

- In 1983, the "baseline" year just before the occupant protection program began, national belt use was 14 percent, and no states had belt laws. By the end of 1991, 42 states and the District of Columbia had belt laws, and belt use had climbed to 59 percent or more.

- Motorized automatic shoulder belts without a disconnect feature have a use rate of 97 percent; motorized belts with a disconnect, 91 percent. The use rate for automatic non-motorized 3-point belts is 64 percent; for manual 3-point belts in air bag-equipped cars, 57 percent; and for manual belts in cars without automatic protection, 56 percent.

- The high use of motorized belts, however, is partially offset by low use of the manual lap belt accompanying the motorized system: 29 percent.

- Fatality risk of occupants in cars equipped with air bags plus manual belts (at 1991 use rates) is 23 percent lower than in "baseline" cars with manual belts at 1983 use rates. The risk in cars with motorized 2-point belts (without disconnect) is 16 percent lower than baseline; in cars with non-motorized 3-point automatic belts, 10 percent lower than baseline. All three are statistically significant fatality reductions relative to baseline, but there are not yet enough data for a definitive rank-ordering of the automatic systems.

- The overall fatality risk in 1991 cars at 1991 belt use rates is 16 percent lower than the baseline of manual-belt cars at 1983 use rates, with confidence bounds of 11 to 21 percent.

- Cars equipped with motorized 2-point belts (without disconnect) have significantly lower occupant ejection rates than cars with any other type of occupant protection. Cars with automatic 3-point belts have significantly lower ejection rates than cars with manual belts.

- Automatic occupant protection, when used, significantly reduces the risk of moderate and serious injuries.

SUMMARY

Federal Motor Vehicle Safety Standard 208 ("Occupant Crash Protection"), as amended on July 17, 1984, defined the National Highway Traffic Safety Administration's (NHTSA) occupant protection program. It consisted of two components: an immediate - and continuing - nationwide effort to increase belt use, through encouragement of State buckle-up laws, enforcement and public education, and a rule requiring that automatic occupant protection, such as air bags or automatic belts, be phased into passenger cars during 1987-90.

Manual safety belts are highly effective in reducing fatalities and serious injuries in crashes, but only if occupants take the time to buckle them. In 1983, the year before Standard 208 was promulgated, manual safety belts were used by 14 percent of the general driver population. NHTSA's occupant protection program attacks the problem of low belt use from two directions. Buckle-up laws, enforcement and public education directly address the deficiency of belt use. Automatic occupant protection, such as air bags or automatic belts, provides a level of safety in crashes even without any buckling-up action by the occupants. (Some types of automatic protection, such as air bags and motorized belts, are accompanied by a manual belt; NHTSA strongly recommends buckling the manual belts and using them in combination with the automatic system.)

The two components of NHTSA's occupant protection program always have reinforced one another. The Standard 208 regulation, by offering a choice between automatic protection and belt laws, was the catalyst that broke the logjam on belt laws in the States. No States had buckle-up laws in 1983; as of May 1992, 42 States plus the District of Columbia and Puerto Rico have enacted them. Propitiously, a public trend toward safety-awareness began during the 1980's, and the buckle-up laws and educational programs nurtured it. By 1989, the public did not want to choose between belt laws and automatic protection: they wanted both, and they were willing to pay extra for the best protection.

Belt use by the driving population increased to nearly 59 percent in late 1991. The increase in belt use enables the combination of air bags and manual belts to approach its full life-saving potential, and it has made air bags, plus manual belts, the first choice of consumers. Conversely, as motorists have acquired the motivation and habit of buckling up, the "automatic" feature of automatic belt systems became relatively less important, and those systems lost market share to air bags.

Standard 208's phase-in requirement for automatic occupant protection was 10 percent of passenger cars in model year 1987, 25 percent in model year 1988, 40 percent in model year 1989, and all cars manufactured after September 1, 1989 (model year 1990). To encourage the installation of air bags (which initially evolved for drivers only and later for passengers), Standard 208 exempts the right front passenger position from automatic protection until September 1, 1993, if an air bag (or other non-belt technology) is installed for the driver; thereafter, automatic protection is required at both positions in all cars. The Intermodal Surface Transportation Efficiency Act of 1991 requires all passenger cars manufactured after September 1, 1997 to have

driver and passenger air bags, plus manual lap and shoulder belts.

In 1991, NHTSA extended the automatic occupant protection requirements to light trucks and vans, on a phased-in basis (model years 1995-98). The Intermodal Surface Transportation Efficiency Act of 1991 requires NHTSA to amend this rule to require these vehicles to have driver and passenger air bags, plus manual lap and shoulder belts, by September 1, 1998.

The 1987-90 phase-in of automatic occupant protection was completed on schedule. Manufacturers met or exceeded the yearly production targets and sold the cars. Six distinct types of automatic protection are currently available, including two configurations using air bags and four types of automatic belts:

(1) Driver air bag plus manual 3 point (lap/shoulder) belts for the driver and the right front passenger. Mercedes, in late 1985, was the first to make driver air bags standard; Chrysler was the first to make them standard on all domestic cars (1988-90). A rapid market shift from automatic belts to air bags followed: by 1991, driver air bags were the automatic system with the highest market share.

(2) Driver and right-front passenger air bags with manual 3 point belts. Initially in Porsche and Lincoln, passenger air bags were still produced in small quantities through 1991, the last model year for which data are available for this report.

(3) Motorized 2 point (torso) belts without disconnect, plus manual lap belts - the motors automatically move the torso belts into place when the ignition is turned on; the belts can be loosened but not disconnected in emergency egress situations (Ford, Toyota, et al.)

(4) Motorized 2 point belts with disconnect, plus manual lap belts - they resemble the preceding type, but they can be disconnected rather than just loosened (Nissan, Mazda, Subaru et al.)

(5) Nonmotorized 3 point (lap/shoulder) belts with disconnect - the door-mounted belts automatically move into place when the doors close; they can be disconnected (GM, Honda, et al.)

(6) Nonmotorized 2 point belts - the door-mounted belts automatically move into place when the doors close - plus manual lap belts and/or a knee bolster; most can be disconnected (VW, Hyundai, et al.)

Executive Order 12291 (February 1981) requires Federal agencies to evaluate their existing regulations and programs. The objectives of an evaluation are to determine the actual benefits - lives saved, injuries prevented, damages avoided - and costs of programs. NHTSA published an evaluation plan for its occupant protection program in the Federal Register on January 17, 1990. It describes analyses scheduled through 1994. The Intermodal Surface Transportation Efficiency Act of 1991 requires periodic evaluations of the effectiveness of occupant protection, beginning in 1992.

The objective of NHTSA's evaluation is to measure the total effect of the occupant protection program - the combination of automatic protection and a nationwide effort to increase belt use: the actual reduction of fatalities and injuries for current automatic protection given current belt use rates, relative to a baseline of cars with manual belts at 1983 use rates. NHTSA is also interested in the potential fatality and injury reduction for automatic protection systems given 100 percent belt use. Other objectives are to assess the operational performance, sales, utilization and costs of automatic occupant protection.

NHTSA's usual procedure is to wait until a standard has been in place for several years and then evaluate its overall effect in a single report. Because of the exceptional public interest in the occupant protection program, and in response to the Intermodal Surface Transportation Efficiency Act of 1991, NHTSA is issuing this interim report, evaluating the benefits of the program, based on information available in May 1992. One problem with issuing interim reports is that there may not be enough data for statistically meaningful results on all of the questions. The six types of automatic protection differ widely in sales and exposure; as a consequence, effectiveness estimates vary in their precision and statistical significance. The analyses and tabulations that follow are in many cases accompanied by assessments of their statistical precision; the assessments are an integral part of the results and the numbers could be misleading without them.

Belt use

The agency sponsored a survey of automatic (and manual) belt use in 19 metropolitan areas throughout the United States, annually, during 1983-91. Trained observers looked into cars stopped at intersections and noted the actual belt use by drivers. The impact of the occupant protection program is evidenced by the persistent gains in overall belt use (manual and automatic belt cars of all ages, combined) in the 19 cities during those years:

	Belt Use in 19 Cities
1983	14 percent
1984	14
1985	21
1986	30
1987	42
1988	46
1989	46
1990	49
1991	51*

*Based on State surveys, nationwide belt use was 59 percent in late 1991.

During calendar year 1991, use of automatic belts in model year 1987 and later cars in the 19 cities was:

	Automatic Belt Use in 19 Cities, 1991
Motorized 2 point belts (without disconnect)	97 percent
Motorized 2 point belts (with disconnect)	91
Nonmotorized 3 point belts (with disconnect)	64
Nonmotorized 2 point belts	74

For comparison purposes, belt use in cars of the same age (model year 1987 and later) with manual belts only was approximately 56 percent during 1991. Manual belt use in cars with air bags was approximately 57 percent.

In other words, the two types of motorized automatic belts had a much larger increment of use relative to manual belts than did the two types of nonmotorized automatic belts. Motorized belts without disconnect had the highest use rates in 1991.

While use of motorized automatic torso belts is high, the advantage is partially offset by low use of the manual lap belt which accompanies the motorized system. According to a 1989-90 observational survey in North Carolina, only 29 percent of the drivers in cars with motorized torso belts buckled the manual lap belt. In other words, although 91 to 97 percent of drivers in cars with motorized belts obtain the protection of a torso belt, only 29 percent obtain the additional protection offered by a combination of a torso and a lap belt - a smaller percentage than in cars with manual or automatic three-point belts.

All of the preceding statistics are based on observations of drivers at intersections during daylight hours. Belt use by persons involved in crashes is not necessarily the same; in severe crashes, it may be substantially lower.

Effectiveness

There are two separate measures of the effectiveness of an occupant protection system in reducing fatalities or injuries: the actual and the potential effectiveness. In some studies, these measures have been called "effectiveness as used" and "effectiveness when used."

The actual effectiveness of an automatic protection system is the difference in fatality or injury risk with this system, at current (1991) belt use rates, and the baseline fatality or injury risk of cars with manual belts at 1983 use rates (before Standard 208). It measures the net total benefit of the occupant protection program: improvements in occupant protection technology plus increases in the use of the systems. For example, the fatality risk for all drivers of cars with air bags (some of whom currently use the manual belts provided in air bag cars, some of whom do not) is compared to the risk for all drivers of similar cars with manual belts only, at 1983 use rates. As belt use rises, actual effectiveness increases.

The potential effectiveness of an occupant protection system is the difference in fatality or injury risk of a person who uses this system and the baseline fatality risk of an unrestrained person. It measures the maximum benefit that can theoretically be obtained from a specific protection technology. For example, the injury risk of a belted driver of an air bag car is compared to the risk of an unrestrained driver of a similar car without air bags. The potential effectiveness is higher than the actual effectiveness and will not vary in response to changes in manual or automatic belt use. At this time, there are sufficient data for estimating the actual reduction of fatalities and ejections and the potential reduction of nonfatal injuries.

Actual fatality reduction

"Best estimates" of fatality reduction for each type of automatic protection, relative to the baseline of manual belts at 1983 use rates, were obtained by combining the results of three or more statistical analysis procedures using Fatal Accident Reporting System data and vehicle registration data. Also, the overall actual effectiveness of the occupant protection program is estimated by taking a sales-weighted average of the results for various types of automatic protection, based on sales of model year 1991 cars. The estimate for air bags is for drivers only, while the estimates for automatic belts are for drivers and right-front passengers.

	Fatality Reduction (%) Relative to Manual Belts at 1983 Use Rates		
		Approx. Confidence Bounds	
Cars Equipped with	**Best Estimate**	Lower	Upper
Driver air bags with manual 3 point belts	**23**	13	33
Motorized 2 point belts (without disconnect)	**16**	9	23
Motorized 2 point belts (with disconnect)	**7***	- 6	20
Nonmotorized 3 point belts (with disconnect)	**10**	3	17
Nonmotorized 2 point belts	**8***	- 5	21
1991 SALES-WEIGHTED AVERAGE	**16**	11	21

[* - not a statistically significant reduction]

It is clear that the occupant protection program, as outlined in Safety Standard 208 - the automatic protection requirement in combination with a nationwide effort to increase belt use - has reduced the likelihood of a fatality, given a crash. The fatality risk in 1991 cars at 1991 belt use rates is 16 percent lower than the baseline of manual-belt cars at 1983 use rates, with confidence bounds of 11 to 21 percent.

Moreover, each individual type of automatic protection has a positive "best estimate" of actual fatality reduction. Three of these reductions are statistically significant, as evidenced by the positive lower confidence bounds: air bags with manual belts, motorized 2 point belts (<u>without</u> disconnect) and nonmotorized 3 point belts.

It is too early for a definitive rank-ordering of the systems. While there is already strong evidence that air bags and motorized 2 point belts (<u>without</u> disconnect) are the most effective automatic systems, the overlap in the confidence bounds for the various types is still substantial.

As stated above, all of these estimates of <u>actual</u> effectiveness can change over time if there are changes in the use of the automatic belts, the manual 3-point belts supplied with air bags, or the manual lap belts supplied with automatic 2-point belts. If belt use increases, effectiveness will rise. Also, in future model years, as the market share for air bags increases toward 100 percent, the sales-weighted average will rise and approach the estimate for air bags.

<u>Effect of automatic belts on the risk of occupant ejection</u>

A pressing question about the performance of automatic occupant protection concerns the effect of automatic belts on occupant ejection. In 1990, 17 percent of front outboard occupant fatalities in cars equipped with manual belts were completely ejected from the vehicle during the crash. On the one hand, the higher use of automatic than manual belts creates a hope that ejections will be reduced. On the other hand, there are fears that door-mounted nonmotorized automatic belts might lose efficacy if doors are forced open during a crash. This is not a problem with motorized automatic belts (which are not door-mounted), but their benefits could be undermined by low use of the accompanying manual lap belt.

Rates of occupant ejections per 100 persons involved in fatal crashes are computed for cars with automatic belts and cars with manual belts, based on Fatal Accident Reporting System data. Ejection rates are adjusted for body type (2-door vs. 4-door) and crash mode (rollover vs. nonrollover).

Cars Equipped with	**Ejections per 100 Occupants Involved in Fatal Crashes**
Motorized 2-point belts (<u>without</u> disconnect)	7.6
Motorized 2-point belts (<u>with</u> disconnect)	9.7
Nonmotorized 3-point belts (with disconnect)	8.7
Nonmotorized 2-point belts	10.0
Manual belts	10.2

Cars equipped with motorized 2-point belts (<u>without</u> disconnect) have significantly lower ejection risk than cars with any of the other automatic belt systems or with manual belts only. Cars with nonmotorized 3-point belts have significantly lower ejection risk than cars with manual belts only.

The findings are preliminary evidence that automatic belts did not increase the risk of ejection; in fact, two types of automatic belts significantly reduced it. It is still premature to conclude that motorized 2-point belts (<u>with</u> disconnect) and nonmotorized 2-point belts reduced the risk of ejection compared with manual belt-equipped cars.

<u>Case-by-case review of crashes involving automatic occupant protection</u>

NHTSA crashworthiness research teams reviewed hard-copy cases from the Fatal Accident Reporting System (FARS) and the National Accident Sampling System (NASS) which involved cars with automatic occupant protection. The review comprised a sample of 240 FARS cases, 81 NASS fatality cases (all fatal cases available in the 1988-90 NASS files), and 117 NASS serious injury cases (all such cases available in the 1988-90 NASS files).

The FARS case reviewers found that the automatic protection systems appeared to be working as expected, but identified several areas of interest to be examined in the more detailed NASS cases: occupant compartment intrusion, occupant ejection, rollover, side impact, complex crash kinematics (multiple impact events), unsurvivable crashes (e.g., very high speeds, or occupant-compartment invasion by trains, heavy trucks, bridge piers), air bag-related injuries, belt-related injuries, and other possible patterns, such as injuries affected by the age or size of the occupant.

The objective was to evaluate the general technical performance of automatic protection in terms of any unexpected problems. The objective was <u>not</u> to fully evaluate individual automatic systems nor to compare systems. **<u>NOTE</u>: the reviewers were examining only fatal and serious injury cases, and thus problems were more likely to be observed than successes. Also this review was of unweighted NASS cases and was not extrapolated to nationally representative statistics.**

The major finding was that FMVSS 208 automatic crash protection systems, when properly and <u>fully</u> used, generally appear to be working as expected in crashes. "Full" use means buckling up the manual 3-point belts in an air-bag car and buckling up the manual lap belts in a car with automatic 2-point belts. There did not appear to be any patterns of unexpected problems either with air bag or automatic belt systems when fully used.

Other findings were that belts either were not used at all, or not fully used, in half the fatal NASS cases. Similarly, in serious-injury NASS cases, belts were not used at all or not fully used in nearly half the cases. Manual lap belts were not used in nearly half the two-point automatic fatal cases. This suggested the need for greater attention to the importance of lap belt use, especially in preventing ejection in rollover crashes. Four fatal and three serious-injury cases involved 1987-89 cars equipped with an automatic 2-point belt but no lap belt (they meet Standard 208, having a knee bolster instead of a lap belt; since 1990, all cars with automatic 2-point belts have lap belts).

Occupant compartment intrusion was noted to be a major factor in nearly half the fatal and serious injury NASS cases. One-third of the fatal NASS cases were rated as unsurvivable, regardless of the availability or use of any current restraint system.

<u>Potential injury reduction for automatic protection</u>

The preceding analyses of actual fatality and ejection reduction compared all occupants of cars equipped with automatic protection to all occupants of cars equipped with manual belts. The following analysis attempts to assess the <u>potential</u>, or "when used" effectiveness of automatic protection. Specifically, the analysis compares the injury outcome of vehicle occupants who used their crash protection system with the outcome of those who were unrestrained. The estimated effectiveness represents the potential reduction in the risk of injury for each automatic system at 100 percent use.

For this analysis, it is necessary to have accident data with accurate reporting of occupants' use of automatic or manual belt systems. Data from the National Accident Sampling System were used, because they have the most accurate belt-use reporting of any NHTSA files. Nevertheless, there is evidence that belt use may be slightly overreported, even in NASS. It is believed that this slight overreporting will not significantly bias the effectiveness estimates.

The analysis of potential effectiveness was attempted using two statistical models to account for the presence of differential rates of crash type involvement, occupant age and sex, and other crash characteristics. While the data encompassed moderate and greater injuries - level 2 or higher on the Abbreviated Injury Scale (AIS) - approximately 75 percent of the cases were moderate injury. Model 1 contains delta-V, a measure of crash severity defined as a vehicle's velocity change during a collision; model 2 does not. The advantage of model 1 is that the presence of delta-V results in a much better model fit, while the advantage of model 2 is that it is based on approximately twice as many cases, since cases with unknown delta-V can be included. The table below presents the effectiveness estimates for each model.

	Potential Reduction (%) of Moderate and Greater Injuries	
	Model 1	**Model 2**
Air bag with manual belt	77	68
Air bag without manual belt	insufficient data	
2-point auto belt with manual lap belt	56	68
2-point auto belt without manual lap belt	45*	44
3-point auto belt	60	59
Manual lap and shoulder belt	45	60

[* - not a statistically significant reduction]

Each type of occupant protection, when fully used, results in significantly lower likelihood of moderate and greater injury compared with being unrestrained. However, the observed differences between any two types of occupant protection are not statistically significant at this time - the estimates are based on limited data samples and there are still an insufficient number of data to rank-order the systems.

The findings are evidence that automatic occupant protection, when fully used, and manual belts, when used, significantly reduce the risk of moderate and greater injury. It is still premature to conclude that one system performs better or worse than another. Effectiveness estimates will be recomputed as more data become available.

Conclusions

- Standard 208 resulted in an occupant protection program that saves lives. The combination of automatic protection - especially air bags - and the nationwide effort to increase belt use has significantly reduced actual fatality risk and is saving thousands of lives a year.
- Air bags (when used in combination with manual belts) and automatic belts also significantly reduce injury risk.
- Automatic belts have reduced the actual risk of occupant ejection in crashes.

CHAPTER 1

SUMMARY OF SALES AND FATALITIES BY TYPE OF AUTOMATIC PROTECTION

Federal Motor Vehicle Safety Standard (FMVSS) No. 208, Occupant Crash Protection, was amended on July 17, 1984[1] to require manufacturers to provide automatic occupant protection systems in passenger cars on a gradual phase-in basis beginning September 1, 1986. The amendment specified that 10 percent of all passenger cars manufactured during the model year beginning after September 1, 1986 have automatic occupant protection systems. This percentage was to increase gradually, ending with automatic occupant protection systems available in all passenger cars manufactured after September 1, 1989. The percentage required for the passenger car fleet by model year is shown below.

Percentage of Manufacturer's Passenger Car Fleet
Required to be Equipped with Automatic Systems, by Model Year

Model Year	Percent
1987	10%
1988	25%
1989	40%
1990	100%

Automatic occupant protection is provided to the consumer with several types of systems. A number of passenger car models are available with air bags. An air bag remains folded and stowed until the vehicle is involved in a moderate to high speed frontal crash. Such a crash will inflate the bag within a split second after impact, thus protecting the occupant from hitting the steering wheel or other vehicle components. Most passenger cars equipped with air bags contain this protection for the driver only while the right front passenger is provided with a manual lap and shoulder belt under a special provision of Standard 208 that expires on September 1, 1993. A few passenger car models are available with full front-seat air bags, thereby providing additional protection for both the driver and right-front passenger. All 1987-1991 vehicles equipped with air bags also have a manual lap and shoulder belt system for the driver and passenger (or, in rare cases, manual belts for the driver and an automatic belt system for the passenger). Drivers of vehicles equipped with air bags must use the manual lap and shoulder belt system for the greatest possible crash protection.

The remaining categories of automatic occupant protection systems are automatic safety belts, as no action is required by occupants to engage these belt systems. For some systems, however, the greatest possible protection can only be achieved by additional use of the manual lap belt. Automatic safety belts may be classified as motorized or nonmotorized. Motorized belts are 2-point (shoulder) belts anchored to electric motors in the vehicle's door frame. With this type of system, the belt moves into place around the occupant when the vehicle's ignition is turned on. All motorized 2-point belts are accompanied by manual lap belts that are an integral part of the occupant protection system. A further distinction that may be made between motorized belts are those that can be disconnected by the consumer vs. those which remain permanently connected (and allow egress in emergency situations by a spool-out feature). Nonmotorized belts are anchored to the vehicle door. These belts move into position around the occupant once the vehicle door is closed. Most of these belts are 3-point (combination lap and shoulder) belts. This type of automatic occupant protection system is shown as "nonmotorized 3-pt. belts" in Tables 1-1 through 1-4. Other nonmotorized belt systems are equipped with an automatic 2-point (shoulder) belt plus manual lap belt and/or knee bolster. This type of automatic occupant protection system is shown as "nonmotorized 2-pt. belts" in Tables 1-1 through 1-4. The manual lap belt is an important part of the 2-point system and must be used in vehicles equipped with these systems for the greatest possible crash protection.

Sales of passenger cars with automatic occupant protection systems have increased substantially during the period 1987-1990. Data on new vehicle registrations from R. L. Polk and Company, used as a surrogate for sales of cars with automatic occupant protection systems, by model year (MY) are shown in Table 1-1.[2] Data for vehicles with manual belts only are shown for comparison purposes. Model year 1990 vehicles shown as equipped with manual belts are those vehicles manufactured in advance of September 1, 1989, after which all vehicles were required to be equipped with automatic occupant protection systems.

As can be seen in Table 1-1, the majority of model year 1987 passenger cars registered were equipped with manual systems, followed by 3-point and motorized 2-point systems without disconnect. Although the Porsche 944 offered full front seat air bags as an option in 1987, it is not possible to determine from the Vehicle Identification Number which cars were so equipped. The counts for these cars are therefore included in the unknowns. By model year 1989, the proportion of new passenger cars registered with manual systems had declined 35 percent from 1987, while registrations for cars equipped with 3-point belts and driver air bags had increased by almost 200 percent each. Table 1-2 shows the cumulative number of passenger cars registered with automatic occupant protection systems, beginning with model year 1987 vehicles.[3]

As can be seen in Table 1-2, approximately 5.8 million passenger cars with driver air bags have been registered through September 1, 1991, the most recent data available from R. L. Polk. An additional 239,000 vehicles equipped with full front-seat air bags were registered during the same period. Through September 1, 1991, vehicles equipped with automatic safety belt systems, such as motorized 2-point belts without disconnect and nonmotorized 3-point belts, represent a larger portion of the total new passenger car fleet.

Table 1-3 indicates the cumulative exposure, in vehicle years, for vehicles equipped with automatic occupant protection systems after September 1, 1986,

TABLE 1-1

REGISTRATIONS OF NEW PASSENGER CARS BY TYPE OF OCCUPANT PROTECTION

(model year 1987 - 1991)

	MY 1987	MY 1988	MY 1989	MY 1990	MY 1991
Driver air bags	134,414	201,873	441,269	2,358,075	2,654,097
Full front-seat air bags	0	2,168	63,029	143,554	29,964
Motorized 2Pt. belts (w/o disconnect)	513,277	949,383	1,154,319	1,113,505	1,167,338
Motorized 2Pt. belts (w/ disconnect)	162,423	256,369	504,014	1,609,891	1,303,815
Nonmotorized 3Pt. belts	528,583	1,380,127	1,850,085	2,826,216	2,448,403
Nonmotorized 2Pt. belts	121,804	206,741	119,244	551,925	546,096
Manual belts only	8,930,491	7,555,876	5,764,735	89,225	0
Unknown type	2,931	10,040	5,995	12,764	3,462
TOTALS	10,393,923	10,562,577	9,902,690	8,705,155	8,153,175

TABLE 1-2

CUMULATIVE REGISTRATIONS OF NEW PASSENGER CARS
BY TYPE OF OCCUPANT PROTECTION, 1987-91

	Number Registered through				
	9/1/87	9/1/88	9/1/89	9/1/90	9/1/91
Driver air bags	92,930	265,236	678,966	3,017,702	5,789,728
Full front-seat air bags	0	1,135	47,065	196,172	238,715
Motorized 2Pt. belts (w/o disconnect)	378,597	1,233,347	2,443,312	3,645,197	4,987,822
Motorized 2Pt. belts (w/ disconnect)	100,908	341,302	830,442	2,156,328	3,836,512
Nonmotorized 3Pt. belts	380,691	1,640,340	3,423,250	6,218,149	9,033,414
Nonmotorized 2Pt. belts	63,566	287,847	402,157	972,839	1,545,810
Manual belts only	7,194,317	14,838,324	20,991,326	22,315,096	22,340,327
Unknown type	1,610	5,494	17,865	27,588	35,192
TOTALS	8,212,619	18,613,025	28,834,383	38,549,071	47,807,520

TABLE 1-3

CUMULATIVE EXPOSURE FOR PASSENGER CARS
BY TYPE OF OCCUPANT PROTECTION, IN VEHICLE YEARS

	Exposure (Vehicle Years) through				
	9/1/87	9/1/88	9/1/89	9/1/90	9/1/91
Driver air bags	37,491	201,596	656,924	2,157,074	6,465,392
Full front-seat air bags	0	440	18,324	141,086	358,983
Motorized 2Pt. belts (w/o disconnect)	126,934	902,189	2,689,625	5,703,078	9,925,356
Motorized 2Pt. belts (w/ disconnect)	32,898	243,881	784,692	2,195,503	5,040,136
Nonmotorized 3Pt. belts	97,205	970,140	3,417,183	8,103,093	15,642,427
Nonmotorized 2Pt. belts	15,314	190,545	538,581	1,122,653	2,366,256
Manual belts only	3,082,182	14,179,921	32,189,338	49,254,919	76,403,048
Unknown type	763	6,233	27,393	70,791	99,150

when the FMVSS No. 208 phase-in requirement became effective.[4]

As the number of vehicles available with various types of automatic occupant protection systems increase, i.e., the exposure of these vehicles increases, the fatality sample sizes also increase. Vehicles equipped with automatic systems represent a larger portion of the total vehicle population, and as a consequence, more occupant fatalities in these vehicles can be expected.

Table 1-4 shows the number of front-seat occupant fatalities, i.e., driver and right-front passengers combined, that occurred in vehicles with the various automatic occupant protection system types, based upon actual data from the Fatal Accident Reporting System (FARS). Fatalities involving front-seat occupants were used as a measure of the involvement of automatic systems in fatal crashes as these represent the occurrences most likely to be impacted by the use and presence of automatic occupant protection systems. Right-front passenger fatalities that occurred in vehicles equipped with driver air bags are shown as separate entries on line 2 of Table 1-4. These occupants would typically have had only a manual lap and shoulder belt available, while the driver would have had the manual system in addition to the air bag available for use.[5]

The availability of passenger cars with driver air bags varies by make and model type between manufacturers. Table 1-5 shows the types of vehicles available for model year 1991 equipped with driver air bags for selected automotive manufacturers. As can be seen in Table 1-5, for model year 1991, there were over 60 models equipped with air bags available to consumers. All models shown, with a few exceptions, are equipped with driver air bags. The Lincoln Continental and Town Car of Ford Motor Company, and Acura Legend LS are equipped with full front-seat air bags as standard equipment. All models of Porsche are also equipped with full front-seat air bags. The 1991 Mercedes-Benz 300SL and 500SL convertibles, 420SEL, 560SEC and 560SEL are equipped with full front-seat air bags, while other Mercedes-Benz models have this system as an option.

The models equipped with air bags for model year 1991 are predominately four-door vehicles. The trend in vehicles equipped with air bags available to consumers varies among automotive manufacturers. Mercedes-Benz, considered a manufacturer of luxury vehicles, was the first to make air bags available to consumers. The Chrysler Corporation has a range of vehicles available to consumers, from economy models such as the Plymouth Acclaim to luxury models such as the Chrysler New Yorker 5th Avenue. The General Motors Corporation emphasizes "sporty" and luxury vehicles with air bag availability, such as the Chevrolet Camaro, Corvette and Geo Storm and Buick Riviera and Cadillac Deville. The Ford Motor Company has air bags available on family-type models, such as the Ford Taurus and Mercury Sable and luxury models, such as the Lincoln Mark VII and Town Car.

TABLE 1-4

CUMULATIVE FRONT-SEAT OCCUPANT FATALITIES IN PASSENGER CARS
BY TYPE OF OCCUPANT PROTECTION

(model year 1987 - 1991)

	Fatalities through				
Cars with	9/1/87	9/1/88	9/1/89	9/1/90	9/1/91*
Driver air bags					
Driver fatals	3	19	58	222	809*
Passenger fatals	2	12	31	112	270*
Full front-seat air bags	0	3	5	15	33*
Motorized 2Pt. belts (w/o disconnect)	19	162	501	1087	1943*
Motorized 2Pt. belts (w/ disconnect)	17	67	197	474	1011*
Nonmotorized 3Pt. belts	25	206	650	1451	2669*
Nonmotorized 2Pt. belts	11	45	107	245	532*
Manual belts only	765	3204	6679	10,422	14,693*
Unknown type	22	95	216	369	773*

* Fatalities in crashes which occurred before 9/1/91 and were logged into the Fatal Accident Reporting System by May 1992. (There is a lag time between the accident event and the entry of the accident case into FARS.) Totals in this table do not match those in the analyses of Chapter 3, which are based on FARS data available as of March 1992 (an earlier version with fewer accident cases).

TABLE 1-5

MAKE/MODELS EQUIPPED WITH AIR BAGS IN MODEL YEAR 1991

(standard or optional)

Manufacturer	Make	Model(s) With Air Bags
General Motors	Buick	Riviera, Reatta, Park Avenue, Roadmaster Estate
	Cadillac	Deville, Seville, Eldorado, Allante, Fleetwood
	Chevrolet	Camaro, Corvette, Beretta, Corsica, Caprice
	Geo	Storm, Metro
	Oldsmobile	Toronado, 88, 98
	Pontiac	Firebird
Chrysler	Chrysler	All Models
	Dodge	Daytona, Dynasty, Shadow, Colt Vista, Spirit, Stealth
	Plymouth	Acclaim, Horizon, Sundance
Ford	Ford	Crown Victoria, Mustang, Taurus, Tempo
	Lincoln	All Models
	Mercury	Grand Marquis, Sable, Capri, Topaz
Nissan	Infiniti	M30, Q45
	Nissan	Pulsar NX, 300ZX
Toyota	Toyota	Celica, Supra, MR2
	Lexus	All Models
Honda	Acura	Legend, NSX
	Honda	Accord
BMW		All Models
Isuzu		All Models
Jaguar		XJS
Mazda		Miata, RX-7
Mercedes-Benz		All Models
Mitsubishi		3000GT
Porsche		All Models
Saab		All Models
Volkswagen	Volkswagen	Cabriolet
	Audi	All Models
Volvo		All Models

FOOTNOTES FOR CHAPTER 1

1) The amendment to FMVSS No. 208, Occupant Crash Protection, is contained in The Federal Register, July 17, 1984, p. 28962.

2) Data in Table 1-1 are from the R. L. Polk & Company's National New Car Registrations. This file contains data on all vehicles registered, by model year for this purposes of this report, as of August 31, 1991. The Vehicle Identification Number (VIN) was used in most cases to determine the type of occupant protection for each vehicle. (See Footnote 3.) This data was used to represent sales of all new passenger cars by model year. While in most cases a vehicle is registered at the time of sale or in anticipation of sale, often vehicles may be registered by dealers but are not actually sold.

3) Data shown as unknown represent vehicles for which the VIN was not specific enough so that a determination of system type could be made. Vehicles were also included as unknown if, in the absence of specific information in the VIN, it was not possible to corroborate system type by matching with data from the Fatal Accident Reporting System (FARS), for vehicles involved in fatal crashes. FARS is the agency's system through which data from a complete census of all traffic crashes resulting in a fatality are gathered every year. In addition, a number of vehicles were identified by VIN as being equipped with automatic belt systems; however, it was not possible to determine which specific system type. These vehicles are included as unknown in Table 1-2.

4) The exposure is based upon the actual number of vehicles registered by model year with the automatic occupant protection system type specified and the number of months per year each vehicle was in use. New vehicles registered in a given month were assumed to average one-half month exposure or use for that month. For example, all vehicles registered in January 1990 would be assumed to have 1/2 month exposure for January and 11 months for the rest of 1990, for a total of 11-1/2 months exposure.

5) Fatalities are shown as unknown if occurring in vehicles for which data was not adequate for a determination of system type. A significant portion of these fatalities occurred in vehicles with automatic belt systems, however, it was not possible to determine the specific system type.

CHAPTER 2

BELT USE IN THE 19 CITY STUDY

For the past several years the National Highway Traffic Safety Administration (NHTSA) has contracted for periodic observational studies of safety belt and child safety seat use by passenger car occupants in 19 metropolitan areas throughout the United States. These studies have enabled the agency to track use rate index trends within these geographic areas over time. Also, data collected on the sex, estimated age and seating position of occupants along with vehicle-related information have been used for more detailed analyses of key issues of interest.

The 19 City Index of shoulder belt use by drivers of passenger cars is obtained by observing all vehicles in the traffic stream, including both those with manual belts and those with automatic occupant protection. The index is formed by a simple non-weighted average of all of the observations made in the 19 cities. The study in its present form was conducted from 1983 through 1991. The increases in the index over time, from 14 percent in 1983 to 51 percent in 1991, can be mainly attributed to the advent of state belt use laws and the increased percentage of vehicles in the traffic population that have automatic belts. Table 2-1 shows the 19 City Index by calendar year. The "19 City Index" number for 1991 is a year-round average for just those 19 cities and is directly comparable to the indices for earlier years, as shown in Table 2-1. However, based on a compendium of State surveys, NHTSA estimates that nationwide belt use was 59 percent in late 1991.

After the introduction of automatic occupant protection in the 1987 model year, additional efforts were undertaken to collect safety belt use rates in cars equipped with these new systems. During 1987, 10 percent of all new cars were equipped with automatic occupant protection, which increased to 25 percent in 1988, 40 percent in 1989 and 100 percent in 1990 and later model years. Automatic occupant protection systems alternatives include three-point systems, two-point motorized belt systems, two-point nonmotorized belt systems and air bags.

Table 2-2 shows observed driver use of the four types of automatic belt systems for each year since the introduction of these systems in 1987. During calendar year 1991, shoulder belts were used by 97 percent of drivers in cars with motorized two-point belts without disconnect, 91 percent in cars with motorized two-point belts with disconnect, 64 percent in cars with nonmotorized three-point belts and 74 percent in cars with nonmotorized two-point belts. According to Table 2-2, the use rates of both types of nonmotorized systems and the motorized 2-point system with disconnect fell off substantially between 1987 and 1990, although the 2-point systems made partial recoveries in 1991.

Table 2-3 shows observed driver use of the four automatic belt systems as a function of model year for the data collected during 1991 in the 19 City Study. It is noteworthy that use of the motorized belts without disconnect has remained 95 percent or higher, whereas use of motorized belts with disconnect declines gradually from 93 percent for new (model year 1991) cars

TABLE 2-1

19 CITY INDEX OF BELT USE BY DRIVERS, 1983-91

Calendar Year	**Driver Belt Use (%)**
1983	14
1984	14
1985	21
1986	30
1987	42
1988	46
1989	46
1990	49
1991	51*

*Based on State surveys, nationwide belt use was 59 percent in late 1991.

TABLE 2-2

19 CITY AUTOMATIC BELT USE, BY CALENDAR YEAR

Cars Equipped with	Driver Belt Use (%) by Calendar Year				
	1987	1988	1989	1990	1991
Motorized 2 point belts (without disconnect)	99	98	98	97	97
Motorized 2 point belts (with disconnect)	95	92	90	86	91
Nonmotorized 3 point belts (with disconnect)	77	77	74	65	64
Nonmotorized 2 point belts	83	80	75	65	74

TABLE 2-3

USE OF AUTOMATIC BELT SYSTEMS, BY MODEL YEAR, DURING 1991

(VIN-decoded observations in 5 of the 19 cities)

Model Year	2 Point Motorized: Without Disconnect		2 Point Motorized: With Disconnect		3 Point Nonmotorized		2 Point Nonmotorized	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**
1991	350	95	480	93	498	61	111	79
1990	470	97	710	92	937	55	239	71
1989	438	98	186	86	628	57	42	64
1988	359	98	105	88	447	55	54	72
1987	221	98	68	84	142	59	40	63

Notes: N = Number of passenger cars observed
% = Percentage of drivers using the automatic belt

to 84 percent for four-year-old (1987) cars. Two-point nonmotorized belts show a similar decline in use as vehicle age increases, whereas three-point nonmotorized belts start out with the lowest use rate, but show little decline in use during the first five years of a car's life span.[1]

The data in Table 2-3 are a "VIN-decoded" subset of the 19 City data that are contained in Table 2-2. The VIN-decoding process consists of recording the license plate number, using it to obtain the Vehicle Identification Number from State registration files, and decoding the VIN to determine the model year and double-check the type of occupant protection seen by the observer. In 1991, the process was performed on observations from 5 of the 19 cities, comprising approximately 18 percent of the vehicles observed in the 19 city study.[2]

Table 2-4 shows observed driver shoulder belt use by general type of occupant protection (manual belts only, automatic belts, manual belts with air bag), by calendar year, for vehicles manufactured since the 1987 model year in the 19 City Study. Table 2-4 suggests that, year after year, manual belt use in cars with air bags is about the same as in cars of comparable age (model years 1987-91) with manual belts only. The data set used to create the table includes only VIN-decoded data from each year. The VIN-decoded data are a subsample of the observations, and they are a different subsample each year; thus the data are not directly comparable from one year to the next.

Specifically, during 1991, belt use in the VIN-decoded subsample (5 cities) was substantially lower than in the other 14. It is estimated that, for the 19 cities as a whole, manual belt use was 56 percent in 1987-91 cars with manual belts only and 57 percent in cars with air bags[3] - use rates that approach the 64 percent for nonmotorized three-point automatic belts.

While use of motorized automatic torso belts is high, the advantage is partially offset by low use of the manual lap belt which accompanies the motorized system. According to a 1989-90 observational survey in North Carolina, only 29 percent of the drivers in cars with motorized torso belts buckled the manual lap belt.[4] In other words, although 91 to 97 percent of drivers in cars with motorized belts obtain the protection of a torso belt, only 29 percent obtain the full protection offered by a combination of a torso and a lap belt - a smaller percentage than in cars with manual three-point belts. Nonmotorized two-point torso belts have lower use rates than motorized belts and they have low lap belt use; some 1987-89 cars with nonmotorized two-point belts do not come equipped with manual lap belts.

TABLE 2-4

DRIVER BELT USE BY TYPE OF OCCUPANT PROTECTION AND CALENDAR YEAR

(VIN-decoded observation subsample of 19 city survey)

	Calendar Year					
	1989		1990		1991	
Cars Equipped with	**N**	**%**	**N**	**%**	**N**	**%**
Manual belts only	21,102	53	15,096	52	12,053	48
Automatic belts	2,086	78	21,950	78	6,564	77
Air bags plus manual belts	276	58	1,580	50	2,451	49

Notes: N = Number of passenger cars observed
% = Percentage of drivers using the automatic belt

FOOTNOTES FOR CHAPTER 2

1) Use rates for different model years may not be directly comparable, since the make/models equipped with a specific type of automatic belts changed from year to year.

2) The five cities with VIN-decoded data in 1991 (Birmingham, Fargo-Moorhead, New Orleans, New York and Seattle) had significantly lower belt use than the remainder of the 19 cities. For example, use of nonmotorized 3 point belts was 56.7 percent in the five cities ("VIN-decoded" observations) and 63.5 percent in the 19 cities as a whole - an 8 percent difference.

3) As stated in footnote 2, use of nonmotorized 3 point belts was 56.7 percent in the five cities ("VIN-decoded" observations) and 63.5 percent in the 19 cities as a whole - an 8 percent difference. Thus, since manual belt use in 1987-90 cars is 48.4 percent in the five cities, it estimated to have been 56 percent in the 19 cities as a whole during 1991. Since manual belt use in air-bag cars is 49.4 percent in the five cities, it estimated to have been 57 percent in the 19 cities as a whole during 1991.

4) Hunter, William W., et al., Analysis of Occupant Restraint Issues from State Accident Data, Highway Safety Research Center, Chapel Hill, 1990, Chapter 6.

CHAPTER 3

FATALITY REDUCTION

The agency's occupant protection program, as outlined in Safety Standard 208 (July 1984), consists of two components: a requirement to install automatic protection, such as air bags or automatic belts, to be phased in during 1987-90, and an immediate nationwide effort to increase belt use, through State laws, enforcement and education. Both components share the goal of reducing fatalities and injuries. They work together inextricably; e.g., the benefits of an air bag/manual belt system increase significantly if manual belt use increases.

The starting point (baseline) for the evaluation is the safety environment that existed in 1983, the year before Standard 208 was promulgated. At that time, manual belts were used by only 14 percent of the general population of drivers and right-front (RF) passengers, and an even lower 7.2 percent of drivers and RF passengers involved in potentially fatal crashes.[1,2] An occupant protection system has positive "<u>actual effectiveness</u>," or is "<u>effective as [currently] used</u>" if cars with this system, at current (1/1/91) belt use rates, have lower fatality risk than manual-belt equipped cars at 1983 use rates.

The analyses of this chapter all measure the <u>actual</u> (or "as used") effectiveness of manual and various types of automatic occupant protection.[3] For example, the fatality rate for all drivers of cars with air bags (some of whom currently use the manual belts provided in air bag cars, some not) is compared to the rate for all drivers of comparable cars with manual belts only, at 1983 use rates (i.e., 7.2 percent in potentially fatal crashes). <u>Actual</u> effectiveness represents the <u>total</u> benefits of the occupant protection program, as outlined by Standard 208: the lives saved by increases in manual belt use since 1983, <u>plus</u> the supplemental benefit for equipping cars with air bags. <u>Actual</u> effectiveness can change over time if belt use changes: the higher the belt use, the more lives saved, relative to the 1983 baseline.

<u>Data sources and analysis overview</u>

The Fatal Accident Reporting System (FARS) provides a census of fatalities in the United States, including drivers and right front passengers of cars with air bags or automatic belts. As of March 1992, the FARS file is essentially complete through the first half of 1991 and nearing completion for the second half of 1991, as well. Whereas the FARS file reports "occupant belt use," this data element, which is not based on direct observations, is suspected of being inaccurately reported in States with belt use laws. Thus, the effectiveness analyses should not rely directly on the belt use variable as reported in FARS.[4]

R. L. Polk furnishes NHTSA with monthly vehicle registration counts by make/model, etc. As of March 1992, this file is complete for model years 1987-91 through June 1991. Registration data for model years 1985-86 are obtained from Polk's annual National Vehicle Population Profile. FARS and Polk data are combined to compute fatality rates per million vehicle exposure years, by type of occupant protection, car size, body style, and other variables.[5]

The evaluation of the actual effectiveness of manual belts (as currently used) is carried out in a single step. NHTSA has already developed a method for estimating the lives saved by safety belts and belt use laws since 1983 - based on the trend of the actual, observed belt use in the driving population (19 city survey) and certain assumptions about manual belt effectiveness and belt use in fatal crashes vs. the general driving population.[2] As will be described below, this method is applied to 1983 and 1991 manual-belt cars, to obtain an estimate of actual manual belt effectiveness.

The evaluation of the actual effectiveness of air bags and automatic belts is carried out in two analysis steps. First, the effectiveness of an automatic system, at current belt use rates, is estimated relative to a manual belt system, at current use rates. Next, this incremental fatality reduction is added to the benefits of 1983-91 increases in manual belt use, to estimate the benefits of automatic systems, as currently used, relative to the baseline of manual-belt cars at 1983 belt use rates. The two-step approach is necessitated by the data and analysis methods used in the evaluation.

Fatality reduction for 1983-91 increase in manual belt use

The agency has developed a general method for estimating the number of lives saved by safety belts.[2] This method does not rely on current belt use reporting in FARS, which may be inaccurate in States with belt use laws. Instead, it is based on an empirical relationship between U1, the belt use of the general driver and RF passenger population, which can be accurately observed in NHTSA's 19 City Survey or a State belt use survey, and U2, the belt use of fatally injured drivers and RF passengers. U2 is much lower than U1 for two reasons: (1) the types of people who get involved in severe crashes (e.g., drunk drivers) are less likely to buckle up than the general population; (2) belts save lives, so an even smaller percentage of the fatalities than the survivors of severe crashes are belted.

U2, belt use of fatally injured occupants, is no longer accurately reported on FARS, but it was considered accurate prior to belt use laws. Before belt use laws, the empirical relationship between U1, general belt use, and U2, fatality belt use was

$$U2 = .43\ U1 - .019$$

In 1983, the baseline year, belt use on the road was 14 percent in the 19 city study and 4 percent among fatally injured persons. In 1991, overall belt use on the road was 51 percent in the 19 city study. However, by mid-1991, approximately 17 million of the 144 million passenger cars on the road were equipped with automatic belts, which have higher use rates than manual belts. If all the cars on the road had been equipped with manual belts, overall use would have been lower than 51 percent. It is estimated that an all-manual belt fleet would have had 48 percent use in the 19 cities during 1991.[6] Based on the above empirical formula, 48 percent manual belt use in the 19 city study corresponds to 19.7 percent belt use among fatally injured persons in cars equipped with manual belts.

The fatality reduction attributable to the increase in manual belt use can be inferred from the increase in belt use among fatally injured occupants. Since the fatality risk of an occupant protected by manual belts is 45 percent lower than the fatality risk of an unrestrained occupant[7], every 55 belted fatalities imply the existence of an additional 45 belted persons, involved in potentially fatal crashes (i.e., fatal for an unrestrained occupant), but saved by the belt. It is possible to define U3, the manual belt use rate in "potentially fatal" crashes, from U2, as follows:

$$U3 = [U2 + (.45/.55)\ U2] \ / \ [1 + (.45/.55)\ U2]$$

U3 was 7.2 percent in 1983 and would have reached 29.5 percent in 1991 if all cars had manual belts. Since the fatality risk of a person using manual belts is 45 percent lower than the risk for an unrestrained person, the fatality reduction attributable to the increase in manual belt use during 1983-91 is

$$1 - [(1 - U3_{1991} + .55\ U3_{1991}) \ / \ (1 - U3_{1983} + .55\ U3_{1983})] =$$

$$1 - [(1 - .295 + .55x.295) \ / \ (1 - .072 + .55x.072)] = \textbf{10.4 percent}$$

Fatality reduction for driver air bags

As of March 1992, the Fatal Accident Reporting System (FARS) contained records of 790 occupant fatalities in model year 1985-91 passenger cars at seating positions equipped with air bags (777 drivers and 13 right front passengers). While this is not a vast sample, 790 fatalities are enough for statistically meaningful preliminary analyses.

At first, air bags were not installed in the "typical" car. Many of the early installations were in luxury cars such as Mercedes and BMW; luxury cars still account for large proportion of the cumulative on-the-road experience with air bags. Chrysler made them standard on all domestic cars in 1988-90. At that time, also, air bags became standard equipment on sporty cars such as Daytona, Mustang, Camaro, Miata, etc. Subsequently, they began to appear on typical "family" cars such as Taurus and Corsica.

As stated above, the objective is to compare fatality rates in cars with driver air bags to rates in comparable cars with manual belts. It would not be fair to compare fatality rates in Mercedes with air bags to those in Chevettes with manual belts. It would be equally unfair to compare fatality rates in Mazda Miatas with air bags to those in Lincoln Town Cars with manual belts.[8] The principal task of the analysis is finding control groups of truly comparable cars or persons with manual belts.

One unique factor in the phase-in process for Standard 208 has a windfall of aiding Step 1 of the effectiveness analysis (air bags vs. manual belts at current use rates). The regulation allows cars with driver air bags to have manual belts for right front passengers until 9/1/93 and, as of mid-1991, over

90 percent of cars with air bags have them only for the driver.

In cars with manual belts, driver and right front passenger fatality risk are nearly equal (when both seats are occupied).[9] In other words, the right front passenger is a "control group" for the driver of a car with driver air bags. The ratio of driver to right front passenger fatalities in cars with driver air bags (where both seats are occupied) is a very good way to measure the effectiveness of a seat position equipped with air bags plus manual belts (at current use rates) vs. a seat position equipped only with manual belts (at current use rates). A disadvantage is that the analysis has to be limited to cars where both seats are occupied (about 1/3 of the fatality data sample), but an offsetting advantage is that exposure (Polk) data are not needed and FARS cases from the last half of 1991 can be included.

Table 3-1 shows that there were 811 driver fatalities and 835 right front passenger fatalities in control group cars with manual belts (model year 1988-89 cars weighing at least 2500 pounds, driver and right front seats both occupied).[10] But in cars with driver air bags with both seats occupied, there were only 263 driver fatalities (with air bags) as opposed to 304 right front passenger fatalities (without air bags). That is an 11 percent fatality reduction for driver air bags relative to manual belts at current use rates (not statistically significant[11]: chi-square for Table 3-1 is 1.407) - corresponding to a **20 percent fatality reduction for driver air bags relative to the baseline of manual belts at 1983 use rates.**[12]

Another unique characteristic of air bags, which can lead to a second method for estimating effectiveness, is that they are primarily designed for action in frontal crashes. With an appropriately inclusive definition of "frontal" crashes, it is assumed [perhaps incorrectly] that air bags have little effect, relative to manual-belt cars at current use rates, in the remaining "nonfrontal" crashes. The nonfrontal fatalities are a control group and the reduction of frontal relative to nonfrontal fatalities is computed in air bag cars relative to manual-belt cars, at current belt use rates. This analysis has the disadvantage of relying on an unproven assumption but the advantage that all air bag fatalities can be included, regardless of occupancy of the right-front seat.

Table 3-2 provides results for three definitions of "frontal" crashes. In the first, most restrictive definition, a frontal crash is one in which the primary impact point was the front of the car and there was no subsequent rollover.[13] Table 3-2 shows that there were 1009 frontal driver fatalities and 1164 nonfrontal driver fatalities in control group cars with manual belts (model year 1988-89 cars weighing at least 2500 pounds). But in cars with air bags, there were only 291 frontal driver fatalities as opposed to 460 nonfrontal driver fatalities. That is a 27 percent reduction of frontal fatalities for air bags (i.e., the ratio of frontal to nonfrontal fatalities is 27 percent lower in the air bag cars than in the control group) - amounting to a 13 percent overall fatality reduction for air bags relative to manual belts at current use rates (statistically significant: chi-square for the first contingency table in Table 3-2 is 13.349).[11,14] That corresponds to a **22 percent fatality reduction for driver air bags relative to the baseline of manual belts at 1983 use rates.**[12]

TABLE 3-1

EFFECTIVENESS OF DRIVER AIR BAGS BASED ON REDUCTION OF
DRIVER FATALITIES RELATIVE TO RIGHT FRONT PASSENGER FATALITIES

(both seats occupied)

	Driver Fatalities	Right Front Fatalities	Risk Factor	Percent Reduction
Cars w. manual belts only (current use rates)	811	835	.971	
Cars w. driver air bags	263	304	.865	11

(not a statistically significant difference: chi-square = 1.407)

Fatality reduction for air bag cars at current belt use rates relative to manual-belt cars at 1983 use rates: 20 percent

TABLE 3-2

EFFECTIVENESS OF DRIVER AIR BAGS BASED ON REDUCTION OF FRONTAL FATALITIES RELATIVE TO NONFRONTAL FATALITIES

	Frontal Driver Fatalities	Nonfrontal Driver Fatalities	Air Bag Effectiveness In "Frontals"	Air Bag Effectiveness Over-all
(definition of "frontal" #1: frontal damage w/o subsequent rollover)[13]				
Cars w. manual belts only (current use rates)	1009	1164		
Cars w. driver air bags	291	460	27	13
(statistically significant difference: chi-square = 13.349)				
(definition of "frontal" #2: any crash with frontal damage)[15]				
Cars w. manual belts only (current use rates)	1158	1015		
Cars w. driver air bags	347	404	25	13
(statistically significant difference: chi-square = 11.217)				
(definition of "frontal" #3: any frontal or front-side damage)[16]				
Cars w. manual belts only (current use rates)	1285	888		
Cars w. driver air bags	400	351	21	13
(statistically significant difference: chi-square = 7.882)				

Fatality reduction for air bag cars at current belt use rates relative to manual-belt cars at 1983 use rates: 22 percent

The second part of Table 3-2 uses a broader definition of "frontal" crashes, viz. any crash in which the primary impact point was the front of the car (with or without subsequent rollover).[15] Again, there is a statistically significant reduction of frontal relative to nonfrontal fatalities (chi-square is 11.217). Although the reduction of "frontal" fatalities is only 25 percent here, the frontals are a larger proportion of all crashes than in the first contingency table. Thus, the overall effectiveness of air bags is the same: a 13 percent overall fatality reduction for air bags relative to manual belts at current use rates, and a **22 percent fatality reduction for driver air bags relative to the baseline of manual belts at 1983 use rates.**[12]

The last part of Table 3-2 further expands the definition of "frontal" crashes to include cars with front-side as well as frontal damage.[16] In this broad class of "frontals," the "frontal" fatality reduction for air bags is 21 percent (statistically significant: chi-square is 7.882) - amounting, again, to a 13 percent overall fatality reduction for air bags relative to manual belts at current use rates, and a **22 percent fatality reduction for driver air bags relative to the baseline of manual belts at 1983 use rates.**[12]

A third method for estimating air bag effectiveness is based on driver fatality rates per million vehicle exposure years, derived from FARS and R. L. Polk data. Data are complete through the first half of 1991; there are 485 driver fatalities in model year 1985-90 cars with air bags, which accumulated 5.417 million exposure years - a fatality rate of 89.54.

This fatality rate cannot fairly be compared to the actual fatality rate for all cars with only manual belts, since the typical car with air bags is larger, more luxurious and has older drivers than the average car with manual belts. It would have a lower fatality rate even without the air bags.

For a fair comparison, it is necessary to predict the fatality rate that would have occurred in the air bag cars, if they did not have air bags, but only manual belts, at current use rates. This is accomplished by using the data on cars with manual belts to calibrate a regression model predicting the rate of driver fatalities per million years as a function of a car's mass, market class (2 door vs. 4 door; luxury, sporty or neither), age, manufacturer-nameplate (9 domestic and 7 import groups), driver age and sex (percent of fatals who are males under 30 years) and calendar year.[17] For the fleet of air bag cars, based on their distribution of mass, market class, etc., the model predicts a fatality rate of 108.48 (if they did not have air bags, but only manual belts, at current use rates). Since the actual fatality rate with the air bags is 89.54, this is a 17 percent fatality reduction for air bags relative to manual belts at current use rates, and a **26 percent fatality reduction for driver air bags relative to the baseline of manual belts at 1983 use rates.**[12]

In summary, three rather different methods are used for computing the actual fatality reduction for driver air bags (relative to the baseline of manual-belt cars at 1983 use rates), yielding a total of five estimates: 20, 22, 22, 22 and 26 percent. The statistical significance of the three results based on comparison of frontal and nonfrontal crashes and the close agreement among all five estimates are highly encouraging evidence that the combination of air bags and programs to increase belt use are saving many lives.

Fatality reduction for automatic belts

Three methods are used to estimate fatality reductions for each of the major types of automatic belts at current use rates, relative to manual-belt cars, at current belt use rates. Each method is based on fatality rates per million vehicle years, as calculated from FARS and Polk data. These reductions are added to the benefits of 1983-91 increases in manual belt use, to obtain effectiveness estimates for automatic belts, as currently used, relative to the baseline of manual belts at 1983 use rates. Each method is applied twice, once to model year 1985-90 cars with automatic belts and once to model year 1985-89 cars, yielding a total of six effectiveness estimates. The goal is to average the six estimates, each of which may have its own sampling errors and biases, to obtain a single "best" estimate for each type of automatic protection.

The first method is essentially the same as was used for air bags. The actual fatality rate per million vehicle exposure years is computed for all model year 1985-90 cars with a particular type of belts, based on FARS and Polk data through June 1991. Right front passenger as well as driver fatalities are included in the fatality rate (since automatic belts, unlike driver air bags, are installed at both positions). The analysis excludes model year 1991 cars, because the Polk data are incomplete and there are some uncertainties about computing partial exposure years.

The actual fatality rates are compared to the rates that would have been expected if the cars did not have automatic belts, but only had manual belts, at current use rates. The expected rates are derived from a regression model, calibrated from data on 1985-89 cars without automatic protection, predicting the rate of driver plus right front passenger fatalities per million years as a function of a car's mass, market class, age, manufacturer/nameplate, driver age and sex, and calendar year.[18]

Table 3-3a shows that cars with manual belts, at current use rates, had actual and expected front seat fatality rates of 173 per million car years. Cars with motorized 2 point belts (without disconnect) had a lower actual fatality rate of 166.80. However, these cars, even without the automatic belts, would have been expected to perform slightly better than the average manual belt car - their expected fatality rate is 169.33. Thus, the actual fatality rate of 166.80 is 2 percent lower than would be expected for manual belt cars at current use rates. It is **12 percent lower than would be expected for comparable manual-belt cars at 1983 use rates.**[12] Motorized 2 point belts (with disconnect) have a fatality rate 12 percent lower than the expected baseline rate. Nonmotorized 3 point belts (with disconnect) have 16 percent lower than baseline fatalities; nonmotorized 2 point systems, 7 percent lower.

Table 3-3b repeats the analysis of Table 3-3a, but limits the data to model year 1985-89 cars with automatic belts. It has the advantage that the automatic and manual-belt cars are more directly comparable (same model years), but sample sizes are reduced by 25-50 percent. Here, the effectiveness estimates range from 12 percent for nonmotorized 3 point belts to 16 percent for nonmotorized 2 point belts.

TABLE 3-3a

ACTUAL VS. EXPECTED* FATALITY RATES FOR AUTOMATIC BELTS[18]

(model years 1985-90 in 1/86-6/91 FARS and Polk files)

Type of Belts	Fatalities	Exposure (10^6 Car Years)	Fatality Rate: Actual	Fatality Rate: Expected*	Fatality Reduction (%) Rel. to Manual Belts: At Current Use	Fatality Reduction (%) Rel. to Manual Belts: At 1983 Use
Manual, at current use rates	32053	185.67	172.63	172.63	-	**10**
Motorized 2 point (without disconnect)	1544	9.26	166.80	169.33	2	**12**
Motorized 2 point (with disconnect)	565	3.35	168.67	172.39	2	**12**
Nonmotorized 3 point (with disconnect)	2058	12.69	162.15	173.72	7	**16**
Nonmotorized 2 point	421	1.97	213.51	206.19	- 4	**7**

*Expected for comparable manual-belt cars at current belt use rates

TABLE 3-3b

ACTUAL VS. EXPECTED* FATALITY RATES FOR AUTOMATIC BELTS[18]

(model years 1985-89 in 1/86-6/91 FARS and Polk files)

Type of Belts	Fata-lities	Exposure (10^6 Car Years)	Fatality Rate Actual	Fatality Rate Expected*	Fatality Reduction (%) Rel. to Manual Belts: At Current Use	Fatality Reduction (%) Rel. to Manual Belts: **At 1983 Use**
Manual, at current use rates	32014	185.52	172.57	172.60	-	**10**
Motorized 2 point (<u>without</u> disconnect)	1286	8.00	160.81	167.02	4	**14**
Motorized 2 point (<u>with</u> disconnect)	286	1.73	165.18	174.27	5	**15**
Nonmotorized 3 point (with disconnect)	1599	9.60	166.51	169.31	2	**12**
Nonmotorized 2 point	299	1.47	203.57	216.31	6	**16**

*Expected for comparable manual-belt cars at current belt use rates

The second method for estimating effectiveness is based only on actual fatality rates. The actual fatality rate for cars with a particular type of automatic belt is compared to the actual rate for cars of the same makes and models with manual belts. The analysis is facilitated by another unique characteristic of the implementation process for Standard 208: automatic protection was gradually phased in during 1987-90 and coexisted with manual belts until as late as 1989. Cars with a particular type of automatic belt have counterparts of the same makes and models, with manual belts, that are about the same age.

The approach is to identify groups of make/models which began the transition from manual belts to a specific type of automatic belt some time during 1987-90. For example, the group that got motorized 2 point belts (without disconnect) includes Escort/Lynx, Tempo/Topaz, Thunderbird/Cougar, Isuzu Impulse and Toyota Camry. Models which had such belts before 1987 (Toyota Cressida) are excluded. Within each group of make/models, the actual fatality rates of the 1987-90 cars with automatic belts are compared to the actual rates of the 1985-89 cars without automatic belts. However, to keep the sample sizes "balanced" between manual and automatic-belt cars, only the 1987-88 manual-belt cars are used in the comparison with models that got automatic belts in 1989, and only the 1989 manual belt cars are used in the comparison with models that got automatic belts in 1990.[19]

Table 3-4a shows that the group of make/models which switched from manual to motorized 2 point belts (without disconnect) had a fatality rate of 183.60 with the manual belts and 172.29 with the automatic belts. That is a 6 percent reduction for motorized 2 point belts (without disconnect) relative to manual-belt cars at current use rates, corresponding to a **16 percent fatality reduction relative to manual-belt cars at 1983 use rates.**[12] The other three automatic belt systems had effectiveness estimates lower than 10 percent.

Table 3-4b repeats the analysis of Table 3-4a, but limits the data to model year 1985-**89** cars from make/models that got automatic belts during 1987-**89**. That reduces the automatic-belt sample sizes by as much as 30 percent (but the manual-belt sample sizes stay about the same or grow, because the requirement for "balanced" samples is not imposed). Here, too, the effectiveness estimate for motorized 2 point belts (without disconnect), 17 percent, is substantially higher than for the other types of automatic belts.

The third procedure for estimating effectiveness is a synthesis of the two preceding methods. In the groups of make/models which switched from manual belts to a specific type of automatic protection during 1987-90, the difference in actual fatality rates of the 1987-90 cars with automatic protection and the 1985-89 cars with manual belts is measured relative to the difference in expected rates, as derived from the regression equation.

TABLE 3-4a

ACTUAL FATALITY RATES FOR GROUPS OF MAKE/MODELS[19]
WHICH SWITCHED FROM MANUAL TO AUTOMATIC BELTS IN 1987-90

(model years 1985-90 in 1/86-6/91 FARS and Polk files)

Make/Models Switching from Manual to	Belt Type	Fatalities	Exposure (10^6 Car Years)	Actual Fatality Rate	Fatality Reduction (%) Rel. to Manual Belts: At Current Use	**At 1983 Use**
Motorized 2 point (without disconnect)	manual	2547	13.87	183.60		
	auto	1497	8.69	172.29	6	**16**
Motorized 2 point (with disconnect)	manual	1259	8.11	155.22		
	auto	396	2.34	168.91	- 9	**2**
Nonmotorized 3 point (with disconnect)	manual	2759	17.98	153.42		
	auto	1579	9.73	162.30	- 6	**5**
Nonmotorized 2 point	manual	1417	7.31	193.78		
	auto	387	1.85	208.91	- 8	**3**

TABLE 3-4b

ACTUAL FATALITY RATES FOR GROUPS OF MAKE/MODELS[19]
WHICH SWITCHED FROM MANUAL TO AUTOMATIC BELTS IN 1987-89

(model years 1985-89 in 1/86-6/91 FARS and Polk files)

Make/Models Switching from Manual to	Belt Type	Fata-lities	Exposure (10^6 Car Years)	Actual Fatality Rate	**Fatality Reduction (%) Rel. to Manual Belts** At Current Use	**At 1983 Use**
Motorized 2 point						
(without disconnect)	manual	2908	16.00	181.75		
	auto	1229	7.31	168.09	8	**17**
Motorized 2 point						
(with disconnect)	manual	1539	9.64	159.60		
	auto	276	1.66	166.74	- 4	**6**
Nonmotorized 3 point						
(with disconnect)	manual	2257	14.31	157.75		
	auto	1553	9.27	167.53	- 6	**5**
Nonmotorized 2 point						
	manual	1598	8.61	185.54		
	auto	299	1.47	203.57	-10	**2**

Table 3-5a carries out the estimation for each type of automatic belt. For example, the group of make/models which switched from manual to motorized 2 point belts (<u>without</u> disconnect) had an actual fatality rate of 183.60 with the manual belts and 172.29 with the automatic belts. But the <u>expected</u> fatality rate barely changed, from 177.83 to 176.12, because the mix of cars with automatic belts was about the same as the counterparts with manual belts. The actual fatality rate decreased while the expected stayed almost the same; the reduction in the actual relative to the expected is 5 percent,[20] corresponding to a **15 percent fatality reduction relative to manual-belt cars at 1983 use rates.**[12] By this method, the fatality reductions for the other three types of automatic belts range from 6 to 15 percent, relative to manual-belt cars at 1983 use rates.

Table 3-5b repeats the analysis of Table 3-4a, but limits the data to model year 1985-89 cars from make/models that got automatic belts during 1987-89. Here, too, the effectiveness estimate for motorized 2 point belts (<u>without</u> disconnect), 19 percent, substantially exceeds the estimates for the other types of automatic belts.

In summary, six rather interrelated estimates of fatality reduction are computed for each type of automatic belt. The six estimates for motorized 2 point belts (<u>without</u> disconnect) are all greater than 10 percent and in close agreement with one another: 12, 14, 16, 17, 15 and 19 percent. That is fairly strong evidence that this type of automatic belt is saving many lives, relative to the baseline of manual-belt cars at 1983 use rates. The eighteen estimates for the other three types of automatic belts are <u>all</u> positive, although not consistently greater than 10 percent.

<u>"Best" estimates of effectiveness</u>

The various individual estimates of actual fatality reduction are averaged[21] to derive preliminary "best" estimates, with approximate confidence bounds[22], for five types of automatic occupant protection, relative to cars with manual belts, at 1983 use rates. For example, five estimates of fatality reduction were obtained for driver air bags (20, 22, 22, 22 and 26 percent) and they average out to 23 percent.

Also, the overall effectiveness of the occupant protection program, as outlined in Standard 208, is estimated by taking a sales-weighted average of the five individual estimates, based on sales of model year 1991 cars through June 1991 (which were approximately 40 percent air bags, 15 percent motorized 2 point belts <u>without</u> disconnect, 15 percent motorized 2 point belts <u>with</u> disconnect, 25 percent nonmotorized 3 point belts and 5 percent nonmotorized 2 point belts). The sales-weighted average represents the difference between the actual fatality rate in 1991 cars, at 1991 belt use, and the fatality rate that would occur in those cars if they were equipped only with manual belts, at 1983 use rates.

TABLE 3-5a

ACTUAL VS. EXPECTED FATALITY RATES[20] FOR GROUPS OF MAKE/MODELS WHICH SWITCHED FROM MANUAL TO AUTOMATIC BELTS IN 1987-90

(model years 1985-90 in 1/86-6/91 FARS and Polk files)

Make/Models Switching from Manual to	Belt Type	Fatality Rates At Current Use: Actual	Fatality Rates At Current Use: Expected	Red. (%) Actual Rel. to Expected	**Fat. Red. (%) Rel. to Manual Belts At 1983 Use**
Motorized 2 point (<u>without</u> disconnect)	manual	183.60	177.83		
	auto	172.29	176.12	5	**15**
Motorized 2 point (<u>with</u> disconnect)	manual	155.22	162.34		
	auto	168.91	167.94	- 5	**6**
Nonmotorized 3 point (with disconnect)	manual	153.42	159.57		
	auto	162.30	177.77	5	**15**
Nonmotorized 2 point	manual	193.78	196.82		
	auto	208.91	205.81	- 3	**8**

TABLE 3-5b

ACTUAL VS. EXPECTED FATALITY RATES[20] FOR GROUPS OF MAKE/MODELS WHICH SWITCHED FROM MANUAL TO AUTOMATIC BELTS IN 1987-89

(model years 1985-89 in 1/86-6/91 FARS and Polk files)

Make/Models Switching from Manual to	Belt Type	Fatality Rates At Current Use: Actual	Fatality Rates At Current Use: Expected	Red. (%) Actual Rel. to Expected	**Fat. Red. (%) Rel. to Manual Belts At 1983 Use**
Motorized 2 point (<u>without</u> disconnect)	manual	181.75	172.05		
	auto	168.09	175.09	9	**19**
Motorized 2 point (<u>with</u> disconnect)	manual	159.60	173.31		
	auto	166.74	172.64	- 5	**6**
Nonmotorized 3 point (with disconnect)	manual	157.75	166.56		
	auto	167.53	170.91	- 3	**7**
Nonmotorized 2 point	manual	185.54	201.13		
	auto	203.57	216.31	- 2	**9**

Cars Equipped with	Fatality Reduction (%) Relative to Manual Belts at 1983 Use Rates Best Estimate	Approx. Confidence Bounds Lower	Upper
Driver air bags with manual 3 point belts	23	13	33
Motorized 2 point belts (without disconnect)	16	9	23
Motorized 2 point belts (with disconnect)	7	- 6	20
Nonmotorized 3 point belts (with disconnect)	10	3	17
Nonmotorized 2 point belts	8	- 5	21
1991 SALES-WEIGHTED AVERAGE	16	11	21

It is clear that the occupant protection program, as outlined in Safety Standard 208 - the automatic protection requirement in combination with a nationwide effort to increase belt use - has reduced fatality risk. The average fatality reduction for 1991 cars at 1991 belt use rates is 16 percent relative to the baseline of manual-belt cars at 1983 use rates, with confidence bounds of 11 to 21 percent.

Moreover, each of the five individual types of automatic protection has a positive "best estimate" of fatality reduction relative to the baseline. Three of the systems - air bags with manual belts, motorized 2 point belts (without disconnect) and nonmotorized 3 point belts - have a statistically significant reduction relative to the baseline, as evidenced by the positive lower confidence bounds.

It is too early for a definitive rank-ordering of the systems. While there is already strong evidence that air bags and motorized 2 point belts (without disconnect) are the most effective automatic systems, the overlap in the confidence bounds for the various types is still substantial.

As stated above, all of the estimates represent actual effectiveness of automatic systems, as currently used, and can change over time if there are changes in the use of the automatic belts, the manual 3-point belts supplied with air bags, or the manual lap belts supplied with automatic 2-point belts. If belt use increases, "actual" effectiveness will rise. Also, the sales-weighted average for all automatic systems is based on 1991 sales. In the future, as the market share for air bags increases toward 100 percent, the sales-weighted average will rise and approach the estimate for air bags.

FOOTNOTES FOR CHAPTER 3

1) Perkins, David D., Cynecki, Michael J., and Goryl, Michael E, Restraint System Usage in the Traffic Population, 1983 Annual Report, Report No. DOT HS 806 582, NHTSA, 1984.

2) Partyka, Susan C., Lives Saved by Seat Belts from 1983 through 1987, NHTSA Technical Report No. DOT HS 807 324, NHTSA, 1988.

3) There is another way to define effectiveness: potential (or "when used") effectiveness - i.e., the difference in fatality or injury risk of an individual who uses a particular type of automatic protection and an individual who is unrestrained. Potential effectiveness represents gross benefits if the automatic system is used by every individual. It is typically higher than actual (or "as used") effectiveness and will not change over time as manual or automatic belt use changes.

Actual effectiveness is of primary interest to the evaluator or planner, who wishes to know the actual benefits of the occupant protection program relative to the automobile fleet that existed in 1983, prior to the programs outlined in Standard 208. Potential effectiveness may be a more useful concept to the engineer, who wants to know how well automatic protection functions if it is properly used.

A problem in calculating potential effectiveness is that the accident data must have accurate reporting of belt use - and it is believed that belt use has been consistently overreported in FARS ever since belt use laws took effect. By contrast, actual effectiveness is based on a comparison of all persons in cars with automatic protection vs. all persons in cars with manual belts, regardless of belt use; it is unnecessary to know which of the occupants used belts. Only the actual fatality reduction is estimated in this chapter.

The effectiveness of automatic protection by crash mode is another issue of great interest but requiring accident samples well beyond those available for this preliminary evaluation. Effectiveness estimates by crash mode, when they become available, may provide insights on why certain types of automatic protection are more effective than others.

4) FARS data for calendar years 1986-91 were used (the 1991 data to the extent they were available as of 3/92). For each record of a model year 1985-91 passenger car, the make/model, the type of occupant protection and the body style (number of doors) were decoded from the VIN by a program developed especially for this project. The type of occupant protection suggested by the VIN was compared to a list of valid codes by make-model-model year, obtained from NHTSA's contractor for the 19 city study (observation of belt use). Nonvalid occupant protection codes in the VIN were corrected, based on this list, or the cases were deleted. References: Fatal Accident Reporting System, 1990 Coding and Validation Manual (NHTSA, National Center for Statistics and Analysis, Report No. DOT HS 807 359) and Fatal Accident Reporting System, 1991 Coding and Validation Manual (NHTSA, National Center for Statistics and Analysis).

5) Monthly Polk files include a 3 digit make/model identifier, the body style, and various codes to indicate type of occupant protection. With the help of the NHTSA contractor's list of valid occupant protection types (Paul Guzek [Goodell-Grivas, Inc.], letter to Robert Schweitz [NHTSA], October 30, 1990), these latter codes were unambiguously mapped to specific types of automatic or manual protection (except for a few models, such as the 1987 Nissan Maxima and 1990 Nissan Sentra, which were deleted from the fatality analyses). Polk's National Vehicle Population Profile for 1987 gives essentially complete registration totals for model years 1985-86, but has no information on type of occupant protection. However, only a few 1985 Mercedes models can have more than one type of occupant protection (almost all other cars have manual protection) - these Mercedes models are deleted from the fatality analysis. The merging of Polk and FARS data is based on the 3 digit make/model identifier, which is present in both FARS and Polk; when it is coded unknown in the original FARS data, the code is filled in by decoding the VIN.

Fatality counts and exposure totals shown in this chapter differ from those in Tables 1-1 - 1-4 of Chapter 1 because the time spans of FARS and Polk data collection are not the same. Also, in this chapter, make-models in those model years where <u>either</u> the FARS data <u>or</u> the Polk data did not allow an unambiguous classification of the type of occupant protection which was installed in the car (e.g., the 1987 Maxima and the 1990 Sentra) were excluded from <u>both</u> the fatality and exposure totals. In Chapter 1, they were only excluded from those tables where there was ambiguity (e.g., only the fatality tables, if the exposure data were unambiguous). Thus, the data in Chapter 1 should not be used for estimating fatality rates per million exposure years.

6) As of June 30, 1991, 17 million of the 144 million passenger cars on the road, i.e., 12 percent of the fleet, were equipped with some kind of automatic belts (based on the Polk files described in footnote 5). Aggregate belt use for all types of cars with automatic belts was 80 percent in the 19 city study during 1991. Belt use in <u>manual</u>-belt equipped cars of comparable age (model years 1987-90) was 48.4 percent in <u>five</u> of the 19 cities in which belt use was not only observed but also "VIN-decoded" (i.e., the license plate numbers were checked with State registration files to obtain the exact model year and make/model from the VIN). However, these five cities had significantly lower belt use than the remainder of the 19 cities. For example, use of nonmotorized 3 point belts was 56.7 percent in the five cities ("VIN-decoded" observations) and 63.5 percent in the 19 cities as a whole - an 8 percent difference. Thus, since <u>manual</u> belt use in 1987-90 cars is 48.4 percent in the five cities, it estimated to have been <u>56 percent</u> in the 19 cities as a whole during 1991. (This is the estimated manual belt use rate in relatively <u>new</u> cars. It is higher than the use rate in cars of all ages, since belt use decreases as cars get older.)

In summary, cars with automatic belts, which constituted 12 percent of all passenger cars during 1991, had 80 percent belt use. If these relatively new cars had been equipped with manual belts, use would have been approximately 56 percent. Thus, belt use in <u>all</u> passenger cars, which was 51 percent in the 19 cities during 1991, would have been

$$51 - .12(80 - 56) = \underline{48 \text{ percent}}$$

if all cars on the road had been equipped with manual belts during 1991.

7) Final Regulatory Impact Analysis, Amendment to Federal Motor Vehicle Safety Standard 208, Passenger Car Front Seat Occupant Protection, pp. IV-1 - IV-16, Report No. DOT HS 806 572, NHTSA, 1984.

8) Of course, the Mercedes and the Lincoln have the advantage of greater mass and bulk but an even more important factor, in the context of fatality rates per million exposure years, is that the types of people who drive Mercedes and Lincoln are far less likely to engage in the type of driving that results in severe crashes than the types of people who drive Chevettes and Miatas.

The technique of explicit or implicit "control groups" is used throughout the chapter. It should be noted that none of them are "perfect" or "designed" control groups in the sense of a planned laboratory experiment. Rather, they are "post hoc" groups of crashes involving cars with manual belts which match the groups of crashes with automatic protection as closely as possible, given what can be deduced from the data. The match is not necessarily perfect, because some driver or exposure factors cannot be deduced from accident files such as FARS. For example, if drivers of air bag cars are more "cautious" than average, they might have fewer frontal crashes than drivers in the control group of manual belt cars of the same size and age.

9) Evans, L. and Frick, M. C., "Seating Position in Cars and Fatality Risk," Publication No. GMR-5911, GM Research Laboratories, Warren, MI, 1987, p. 5 shows 15,880 right front passenger fatalities and 15,793 driver fatalities, when both seats are occupied, over 11 years of FARS data.

10) Additional discussion of driver vs. right front passenger fatality risk may be found in An Evaluation of Occupant Protection in Frontal Interior Impact for Unrestrained Front Seat Occupants of Cars and Light Trucks (NHTSA Report No. DOT HS 807 203, 1/88). The control group of cars weighing 2500 pounds or more is selected to correspond to air bag cars, most of which weigh 2500 pounds (the weight of a Ford Tempo) or more.

11) Chi-square has to be at least 3.841 for statistical significance (p less than .05).

12) The effectiveness of manual belts as currently used relative to manual belts at 1983 baseline use is 10.4 percent. If the effectiveness of an automatic system at current belt use levels, relative to manual-belt cars at current use levels is E, the effectiveness of the automatic system at current belt use levels, relative to the baseline of manual-belt cars at 1983 use levels, is

$$1 - [(1 - .104)(1 - E)]$$

13) "Frontal" is defined to include the following FARS cases: Most Harmful Event cannot be 1 (rollover), 2-6 (fire, explosion, immersion, gas

inhalation, fell from vehicle, injured in vehicle) while Principal Impact Point has to be 11, 12, or 1 o'clock. Note that this definition could include some cases with subsequent rollover, as long as it is not the "most harmful event." Reference: Fatal Accident Reporting System, 1990 Coding and Validation Manual (NHTSA, National Center for Statistics and Analysis, Report No. DOT HS 807 359).

14) Effectiveness in frontal crashes is estimated by

$$1 - [(291/460) / (1009/1164)]$$

while overall fatality reduction (relative to manual-belt cars at current use levels) is estimated by

$$[1 - [(291/460) / (1009/1164)]] [1009/(1009+1164)]$$

15) "Frontal" is defined to include the following FARS cases: Most Harmful Event cannot be 2-6 (fire, explosion, immersion, gas inhalation, fell from vehicle, injured in vehicle) while Principal Impact Point has to be 11, 12, or 1 o'clock.

16) "Frontal" is defined to include the following FARS cases: Most Harmful Event cannot be 2-6 (fire, explosion, immersion, gas inhalation, fell from vehicle, injured in vehicle) while Principal Impact Point has to be 10, 11, 12, 1, or 2 o'clock.

17) The regression model for driver fatality rates, as well as all other regression models in this chapter, is based on log-linear regression with aggregate data. In other words, the data (fatalities and exposure of 1985-89 manual belt cars) are split up into cells (according to values of discrete independent variables or class intervals of continuous independent variables) and a fatality rate is calculated in each cell. The data points for the regressions are the cells and the dependent variable is the log of the fatality rate in each cell.

The analysis is carried out in three stages. The first stage is a regression in which the dependent variable is the log of the fatality rate, based on the actual fatalities and exposure in each cell. One independent variable is the log of the vehicle weight (split into 4 class intervals for the regression, but intended for use as a continuous variable when the regression equation is used to predict fatality rates; the source of the vehicle weight data is Polk NVPP files or Automotive News Almanacs; the average weight for a given make/model during 1985-91 is used, unless there were major restylings, in which case separate weights are used for before/after the restyling). Another independent variable is the proportion of the fatalities who were men aged 30 or less (also split into 4 class intervals but intended for use as a continuous variable; data are entered on a make/model basis, based on FARS; the variable had to be based on fatalities only because exposure is not classified by driver age on Polk). The number of doors (2,4) and vehicle age (0,1,2,3,4,5) are discrete linear variables. An additional, dichotomous variable indicates if the car was less than 1 year old. Calendar year is a categorical variable (86,87,88,89,90,91). Certain make/models are designated "luxury" (Lincoln, Cadillac, BMW 500-700, Acura, Mercedes, Volvo, Nissan Maxima, Toyota Cressida and some others) while others are designated "sporty" (Omni-Charger, Mustang, Camaro, Firebird, Corvette, Fiero, Nissan 300ZX, Honda CRX, Porsche, Toyota Supra and some others); dichotomous variables flag the luxury and sporty cars. The fatality and exposure data are tabulated across the various combinations of the independent variables, creating the cells. Then the dependent variable (log of the fatality rate) is calculated in each cell. The regression is weighted by the amount of exposure in each cell.

Each of the independent variables was significant in the first stage regression. Although the above factors are helpful in predicting fatality rates, there is still residual variation between makes and models. For example, the model overpredicts the fatality rates of Pontiacs while underpredicting the rates of Chevrolets that are essentially the same vehicle designs as the Pontiacs, even after controlling for driver age, etc. Essentially, some nameplates attract less risky groups of drivers than others and these differences cannot be explained by demographic variables such as age and sex. There are 30 year old males who drive Volvos and 30 year old males who drive Corvettes, but the first group undoubtedly takes fewer risks in their driving than the second. To account for these differences, a second stage of the regression analysis included an independent variable denoting the nameplate/origin of the car (with 16 categories - Chrysler, Ford, Lincoln, Mercury, Buick, Cadillac, Chevrolet, Oldsmobile, Pontiac, captive Asian import, Nissan, Honda, Toyota, other Japanese car, Hyundai, European). If this new variable were added to all the earlier independent variables, there would be too many small cells and it would not be possible to compute meaningful fatality rates in the cells. The number of cells is reduced by collapsing them across vehicle age and calendar year and incorporating the [relatively small] stage 1 effects of vehicle age and calendar year into the data by adjusting the exposure according to the stage 1 coefficients for those variables. For example, if the stage 1 regression says CY 87 adds .162 to the log of the fatality rate, all CY 87 exposure is adjusted upwards by exp(.162) in the stage 2 regression.

Each of the independent variables was significant in the second stage regression. The regression equation does an excellent job predicting the fatality rates by make and model, for cars without automatic protection - within ±10 percent for most makes and models.

R squared is .64 in the first stage regression and .84 in the second stage regression. R squared is not a particularly meaningful measure of fit in regressions with aggregate data, since it is highly sensitive to the level of aggregation of the data (size of the class intervals of the independent variables). However, these are average or better values of R squared, compared to similar regressions on FARS data in other NHTSA evaluations.

The third stage of the analysis is to apply the regression equation, by make and model, to all the exposure of cars without automatic protection on the Polk files, yielding an expected number of fatalities. Because of various computational errors built into regression models, this may over or underpredict the actual number of fatalities by up to 3 percent. The fatality rate given by the regression equation is multiplied by a constant: the ratio of actual to predicted fatalities as calculated above (i.e., for all cars without automatic protection, combined).

The regression equation is now ready for predicting the fatality rate that would occur in any group of cars (e.g., the cars with driver air bags) if they did not have automatic protection.

18) Same approach as footnote 17, except that right front passenger as well as driver fatalities are included in the fatality rates.

19) The group of make/models switching from manual to motorized 2 point belts (<u>without</u> disconnect) during 1987-90 consists of Ford Escort, Tempo, Thunderbird, Probe and Festiva; Mercury Lynx, Topaz, Cougar and Tracer; Merkur Scorpio; Isuzu Impulse; and Toyota Camry.

The group of make/models switching from manual to motorized 2 point belts (<u>with</u> disconnect) during 1987-90 consists of Chrysler/Dodge/Plymouth Conquest; Dodge/Plymouth Colt (except Vista); Dodge Shadow; Plymouth Sundance; Eagle Premier; Pontiac LeMans; Nissan Maxima, Stanza and Pulsar; Jaguar; Mazda; Saab 900; Subaru DL/GL and XT; Mitsubishi Starion and Mirage; Daihatsu Charade; and Sterling.

The group of make/models switching from manual to nonmotorized 3 point belts (with disconnect) during 1987-90 consists of Buick LeSabre, Electra Somerset/Skylark, Century and Regal (W body); Cadillac Fleetwood Brougham; Chevrolet Beretta/Corsica, Cavalier, Celebrity and Caprice; Oldsmobile 88, 98, Calais, Ciera and Supreme (W); Pontiac Bonneville, Grand Am, Sunbird, 6000 and Grand Prix (W); Honda Accord (not all years), Prelude and CRX; Renault Alliance; and Subaru Justy;

The group of make/models switching from manual to nonmotorized 2 point belts during 1987-90 consists of Chrysler LeBaron (excluding GTS); Dodge Daytona; VW Jetta, Golf and Fox; Peugeot 505; Toyota Corolla and Tercel; Mitsubishi Precis (through 89); Yugo; and Hyundai (through 89).

Some of the preceding make/models were subsequently equipped with air bags or were available with optional air bags. <u>The air bag cars are excluded from the analysis</u>.

20) The effectiveness formula is

1 - [(actual auto/actual manual) / (expected auto/expected manual)]

21) The procedure for averaging the effectiveness estimates is not a straight arithmetic average. Each estimate is logarithmically transformed - e.g., 17 percent becomes log(1 - .17). The three air bag effectiveness measurements based on performance in frontal vs. nonfrontal crashes were based on nearly the same data and procedure; they produced identical estimates of 22 percent; they are treated, in the computation of the average, as a single estimate of 22 percent. The automatic belt results based on the change in actual relative to expected risk for switchover groups of make/models are weighted double

in computing the average, because they are considered less prone to bias than the other procedures for automatic belts. The average of the logs is then transformed back to a percent effectiveness.

22) These confidence bounds are only approximate rather than rigorous and are intentionally wide to allow for biases as well as sampling error. They are derived as follows: the analyses for air bags are based on 790 actual fatalities, but given that air bags reduce fatalities by 23 percent, the "expected" number of fatalities is 1026; the standard deviation of a Poisson variate with mean 1026 is 32 and ± <u>three</u> standard deviations are close to 10 percent of the mean.

The analyses for motorized 2 point belts (<u>without</u> disconnect) are based on approximately 1500 fatalities (in FARS), but given that the belts reduce fatalities by 16 percent, the "expected" number of fatalities is 1786; the standard deviation of a Poisson variate with mean 1786 is 42.3 and ±3 standard deviations are close to 7 percent of the mean.

The analyses for nonmotorized 3 point belts are based on approximately 2000 fatalities, but given that the belts reduce fatalities by 10 percent, the "expected" number of fatalities is 2222; the standard deviation of a Poisson variate with mean 2222 is 47.1 and ±3 standard deviations are slightly under 7 percent of the mean. The analyses of the other automatic belt systems are based on about 500 fatalities, but since the effectiveness is 7-8 percent, the "expected" number of fatalities is 537; the standard deviation of a Poisson variate with mean 537 is 23.2 and ±3 standard deviations are close to 13 percent of the mean.

Whereas each of the effectiveness estimates is based on multiple analyses of the data (5 for air bags, 6 for automatic belts), each of these procedures basically reuses the same data, so the repetitions cannot be expected to reduce sampling error. The purpose of multiple analysis procedures is to minimize the nonsampling error and cancel out the biases that may be inherent in any single procedure.

The confidence bounds for the sales-weighted average are obtained by treating this average as a linear combination of five normal, independent variates (i.e., a weighted sum of the estimates for the five individual types of automatic protection).

CHAPTER 4

THE RISK OF EJECTION WITH AUTOMATIC OCCUPANT PROTECTION

One of the NHTSA's objectives in the plan to evaluate automatic occupant protection[1] was "... to observe the operational performance of automatic occupant protection systems and their effectiveness in specific crash situations." That includes, specifically, an assessment of the degree to which occupants of vehicles equipped with automatic occupant protection systems are ejected during crashes, and the circumstances under which these ejections might occur.

It is not clear if cars equipped with automatic systems may be expected to have lower or higher occupant ejection rates than cars equipped with manual belts. The higher use rate of automatic systems offers the expectation that ejection may be reduced. On the other hand, it is not known if automatic systems, when used, are as effective in preventing ejection as a manual belt system, when used. Individual systems may vary. For example, the 2-point automatic belt can be worn without the manual lap belt, resulting in unknown consequences for ejection risk.

In police-reported towaway accidents, fewer than one percent of front outboard passenger car occupants are completely ejected. Looking at fatalities only, about 18 percent of such fatalities are ejected. Over 97 percent of those that are ejected are unrestrained, whether the accident is a towaway only, or involves serious injury or fatality.[2]

Factors such as ejection portal and type of accident are related to the assessment of ejection risk. The ejection portal is of particular interest when examining two-door vs. four-door vehicles. Typically, ejection rates are greater for two-door vehicles, which have a heavier door and a larger sized opening per door, than for four-door vehicles. In all crashes, the most common ejection routes are the near-side door and the near-side window. Front outboard occupants have the door next to them open less than two percent of the time. The most common types of accidents leading to door openings are rollovers and near-side crashes. Overall, when a near-side door does open, 25 percent of such occupants are ejected out the door. When the accident is a rollover, 48 percent are ejected out the door.

An assessment of ejection risk was performed by the agency in 1990 in response to a petition concerning door-mounted automatic belts. In that study, NHTSA examined ejection rates for specific General Motors vehicles with such 3-point automatic occupant protection systems to determine if rates for vehicles with these systems, as used, were different from the rates for these vehicles before the introduction of automatic protection (i.e., when equipped with manual belts). Ejection rates for fatal crash-involved drivers and right front-seat passengers were computed for selected body platforms using a total of forty months of FARS data for each model year. For each vehicle model year, the calendar year of the model year plus four months in the previous year and two full years following the calendar year were used in FARS, beginning with model year 1987 vehicles.

The rates were examined by body platform, as it is believed that vehicles belonging to the same body platform would respond similarly under certain crash conditions, particularly in ejections. Body platform is used to describe vehicles with generally similar structures across a manufacturer's makes and models. For example, Buick LeSabre, Oldsmobile Delta 88, and Pontiac Bonneville all have the H-body platform. In addition, demographic characteristics are believed to be similar for individuals purchasing vehicles belonging to the same body platform.

Ejection rates for two-door vs. four-door vehicles within body platform were examined as well, since the number of doors per vehicle determines the size of the possible ejection portal and the weight of the doors, and therefore is an issue in studying ejection. A study of these rates indicated that while the proportion of ejected drivers and right-front passengers (combined) appears greater for two-door vehicles than for four-door vehicles, the rates for manual vs. 3-point automatic systems, within body platform, appear similar. Ejection rates are shown in Table 4-1, along with values of the t-statistic testing the statistical significance of the differences between rates for manual and 3-point automatic systems. As seen in Table 4-1, the ejection rate for L-body, four-door vehicles equipped with 3-point automatic belts is less than the rate for the same type vehicles with manual systems at a statistically significant level ($p < 0.05$). Interpretation of this finding, however, must keep in mind the small number of cases [n=135] for occupants involved in these vehicles. None of the other differences shown in Table 4-1 were statistically significant.

When the FARS data from the 40-month period represented above are aggregated, the ejection rates for manual vs. 3-point automatic systems are similar, as can be seen in Table 4-2. Data from Table 4-1 above was aggregated across body platforms, for all vehicles with two doors vs. those with four doors. Rates for four-door vehicles are lower than the rates for two-door vehicles; however, the rates are comparable between manual systems and 3-point automatic systems. Neither of the differences between rates for 3-point vs. manual systems were found to be statistically significant.

With results from the efforts discussed above as background, an analysis of FARS data was undertaken to obtain a general assessment of automatic systems and ejection risk. To assess the differences in ejection risk for all vehicles equipped with automatic occupant protection systems, data from FARS through December 1991 were examined. The data represents a total of 64 months of FARS data, i.e., September 1986 - December 1991.

Table 4-3 presents ejection rates for front-seat occupants involved in fatal crashes beginning with 1987 model year two-door and four-door vehicles, for five automatic system types and manual belts. Vehicles that either had full front-seat air bags or were station wagons are not included in further tables or analyses. During the 64 months of data, fewer than 115 vehicles with full front-seat air bags were included in the FARS file, which is too small a number for these purposes. Similarly, only about 1,800 station wagons are included, and about 75 percent of these had manual belts. This leaves too few involvements for each type of automatic restraint to be of statistical interest. Ejection rates are shown for occupants in all vehicles combined, and for two-door and four-door vehicles separately. Drivers and passengers of vehicles equipped with driver air bags are shown separately, as the passengers

TABLE 4-1

EJECTION RATES PER 100 PERSONS INVOLVED IN FATAL CRASHES
FOR SELECTED GENERAL MOTORS VEHICLES

(drivers and right-front passengers, combined)

	Ejections per 100 Occupants		
Body Platform/No. of Doors	Manual Belts	3-Pt Auto(1)	t-test
H-Body, 4-Door (LeSabre, Delta 88, Bonneville)	2.4 [n=334]	4.1 [n=611]	1.466
L-Body, 2-Door (Beretta)	14.6 [n=260]	18.0 [n=266]	1.057
L-Body, 4-Door (Corsica)	10.5 [n=286]	5.2 [n=135]	-2.012*
N-Body, 2-Door (Skylark, Calais, Grand Am)	9.5 [n=524]	9.6 [n=500]	0.054
N-Body, 4-Door (Skylark, Calais, Grand Am)	6.6 [n=258]	5.7 [n=244]	-0.420

(1) Vehicles equipped with 3-point automatic belt systems contain non-motorized lap and shoulder combination belts (with disconnect) anchored to the vehicle door.

* Statistically significant, $p < 0.05$.

TABLE 4-2

EJECTION RATES FOR TWO-DOOR VS. FOUR-DOOR GENERAL MOTORS VEHICLES

(drivers and right-front passengers, combined)

	Ejections per 100 Occupants		
Number of Doors	Manual Belts	3 Pt. Auto(1)	t-test
Two Door	11.0 [n=2761]	12.5 [n=840]	1.186
Four Door	4.8 [n=7004]	4.6 [n=1121]	-0.255

(1) Vehicles equipped with 3-point automatic belt systems contain non-motorized lap and shoulder combination belts (with disconnect) anchored to the vehicle door.

TABLE 4-3

EJECTIONS PER 100 FRONT-SEAT OCCUPANTS INVOLVED IN FATAL CRASHES
BY TYPE OF OCCUPANT PROTECTION

(model year 1987 - 1991 vehicles)

Cars Equipped with	All Cars	Two-Door	Four-Door
	Ejections per 100 Occupants		
Driver air bags			
Drivers	12.5* [n= 2092]	20.1* [n= 955]	6.2* [n= 1137]
Passengers	12.2* [n= 772]	20.1* [n= 349]	5.7* [n= 423]
Motorized 2 pt. belts (w/o disconnect)	8.7 [n= 4532]	12.6 [n= 2205]	4.9 [n= 2327]
Motorized 2 pt. belts (w/ disconnect)	10.3 [n= 2390]	13.3 [n= 1162]	7.5 [n= 1228]
Nonmotorized 3 pt. belts	9.0 [n= 6607]	13.2 [n= 3448]	4.4 [n= 3159]
Nonmotorized 2 pt. belts	11.7 [n= 1193]	11.8 [n= 526]	11.7 [n= 667]
Manual belts only	10.2 [n=31822]	14.5 [n=15731]	6.0 [n=16091]

* The result is obtained from fatal crashes and may be magnified, since non-ejectees who are "saved" by the air bag are not entered into FARS if the crash does not involve another occupant who was fatally injured.

would have had only the manual lap and shoulder belt as occupant protection.

Overall ejection rates as shown in Table 4-3 range from 8.7 percent of front-seat occupants involved in fatal crashes in vehicles equipped with motorized 2 point systems without the disconnect feature, to 12.5 percent of drivers in driver air bag-equipped vehicles. Marked differences in ejection rates emerge when involvements are separated for two-door vs. four-door vehicles. Ejection rates for front-seat occupants involved in fatal crashes of four-door vehicles appear considerably lower than that for two-door vehicles. Ejection rates for four-door vehicles range from 4.4 percent for 3-point systems to 11.7 percent for non-motorized 2-point systems. Rates for two-door vehicles range from a low of 11.8 percent for persons involved in vehicles equipped with nonmotorized 2-point belts to 20.1 percent of all involved front-seat occupants of driver air bag-equipped vehicles.

These ejection rates may be misleading. They are obtained from fatal crashes and may be somewhat exaggerated, since non-ejectees who are "saved" by their restraint systems are not entered into FARS if the crash does not involve another occupant who was fatally injured. This is especially true for air bag equipped vehicles.

Comparing the raw data on the rate of ejection by system type may be misleading, due to confounding factors such as the proportion of two-door vs. four-door vehicles for each system type and the degree to which rollover occurs for each system type. For example, in fatal crashes, 17 percent of front-seat occupants in vehicles equipped with manual systems were involved in a rollover crash, while 22 percent of front-seat occupants in vehicles equipped with non-motorized 2-point systems were involved in crashes with rollover. A comparison of ejection rates for each type of automatic system, adjusted for the degree to which these factors are present for vehicles equipped with manual systems, could eliminate these differences, thereby yielding adjusted rates more readily comparable to the experience of vehicles equipped with manual systems.

A comparison of the ejection rates for automatic systems, based on the experience of manual systems, was examined to assess the magnitude of the differences in rates, as these systems are used, seen in Table 4-3. Front-seat involved occupants of model year 1987-1991 vehicles equipped with manual belts and automatic systems were identified in FARS beginning with September 1986. These data, classified according to whether the fatal crash involved rollover and the number of doors in the vehicle involved, are shown in Table 4-4. The proportion of crashes occurring for each combination (rollovers of two-door and four-door vehicles and non-rollovers of two-door and four-door vehicles) represents the degree to which these factors contributing to ejection exist for manual belts.

As can be seen in Table 4-4, for vehicles equipped with manual belts, 10.8 percent of front-seat occupants involved in fatal crashes were in two-door vehicles in rollovers, while 5.9 percent of front-seat occupants involved in fatal crashes were in four-door vehicles in rollovers. By comparison, the proportion of front-seat occupants involved in fatal crashes with rollover is greater for all automatic four-door vehicles, with the exception of that for nonmotorized 3-point belts. This means that for the other automatic systems, the degree of rollover is greater than that experienced in vehicles equipped

TABLE 4-4

DISTRIBUTION OF FATAL CRASH INVOLVEMENTS
BY TYPE OF OCCUPANT PROTECTION, ROLLOVER AND NUMBER OF DOORS

(front seat occupants of model year 1987-91 cars)

	Percent of Occupant Involvements			
	Rollover		**Nonrollover**	
Cars Equipped with	**2 Door**	**4 Door**	**2 Door**	**4 Door**
Driver air bags				
Drivers	13.1	5.9	32.6	48.4
Passengers	13.3	8.4	31.9	46.4
Motorized 2-point belts (w/o disconnect)	12.9	7.6	35.8	43.8
Motorized 2-point belts (with disconnect)	11.5	7.5	37.2	43.8
Nonmotorized 3-point belts	11.7	5.6	40.5	42.2
Nonmotorized 2-point belts	10.4	11.8	33.7	44.1
Manual belts only	10.8	5.9	38.6	44.6

with manual belts, perhaps creating a bias toward more ejections for these vehicles. This bias may be due to other factors not related to system effectiveness, e.g., a greater proportion of small cars among the population of vehicles with automatic protection.

Ejection rates, without an adjustment to compensate for these differences, would not accurately reflect the degree to which automatic systems are related to reducing ejections. Therefore, the relative exposure to rollover by number of doors, of vehicles equipped with manual belts shown at the bottom of Table 4-4 was used to compute adjusted ejection rates for automatic systems based upon the experience of vehicles equipped with manual systems. The rates after adjustment, by system type, are shown in Table 4-5.[3]

The number of occupants varies considerably by restraint type. There are more than 30,000 occupants in vehicles equipped with manual belts, and fewer than 1200 with nonmotorized 2-point belts. Also, the number of vehicles equipped with driver air bags is relatively small, and this is made even smaller by the necessity of separating drivers and right-front passengers because of different restraint availability. Therefore, standard errors were calculated for the adjusted ejection rate for each type of restraint system. A confidence interval for the ejection rate would be approximately twice the standard error added to and subtracted from the ejection rate. For example, drivers in vehicles with driver air bags were ejected at an adjusted rate of 11.9 percent, with a standard error of 0.64. The confidence interval would then be 11.9 plus or minus (1.96 x 0.64), or 10.6 to 13.2 percent.

T-tests were conducted to compare manual belts to each type of automatic restraint, using the adjusted ejection rates. Ejection rates for right front passengers in vehicles with driver air bags, as well as occupants with motorized 2-point belts with disconnect and nonmotorized 2-point belts were not significantly different from those with manual belts. Motorized 2-point belts without disconnect and 3-point belts had significantly lower ejection rates than did manual belts. Drivers in vehicles with driver air bags show a significantly higher ejection rate. For this last result, however, it must be kept in mind the relatively small sample size involved, and noted that the result is rather close to the significance level of 1.96. Also, the result is obtained from fatal crashes and may be somewhat exaggerated, since non-ejectees who are "saved" by the air bag are not entered into FARS if the crash does not involve another occupant who was fatally injured.

TABLE 4-5

EJECTIONS PER 100 FRONT-SEAT OCCUPANTS INVOLVED IN FATAL CRASHES BY TYPE OF OCCUPANT PROTECTION, ADJUSTED FOR ROLLOVER AND NUMBER OF DOORS

(model year 1987 - 1991 vehicles)

Cars Equipped with	**Ejections per 100 Occupants** **Unadjusted**	**Adjusted**	**Adjusted Standard Error**	**t Value*** **
Driver air bags				
Drivers	12.5* [n= 2092]	11.9*	0.64	2.56**
Passengers	12.2* [n= 772]	11.4*	1.07	1.07
Motorized 2 pt. belts (w/o disconnect)	8.7 [n= 4532]	7.6	0.33	-7.10**
Motorized 2 pt. belts (w/ disconnect)	10.3 [n= 2390]	9.7	0.55	-0.83
Nonmotorized 3 pt. belts	9.0 [n= 6607]	8.7	0.31	-4.56**
Nonmotorized 2 pt. belts	11.7 [n= 1193]	10.0	0.78	-0.24
Manual belts only				
Drivers + passengers	10.2 [n=31844]	10.2	0.15	
Drivers	10.3 [n=22652]			
Passengers	10.1 [n= 9170]			

* The result is obtained from fatal crashes and may be magnified, since non-ejectees who are "saved" by the air bag are not entered into FARS if the crash does not involve another occupant who was fatally injured.

** Statistically significant at 0.05 level.

*** t value for the difference of the adjusted rates for this system and manual belts.

Original ejection rates for automatic systems were adjusted using the distribution of persons involved in fatal crashes in vehicles equipped with manual belts shown in Table 4-4.

FOOTNOTES FOR CHAPTER 4

1) Federal Register, January 17, 1990, p. 1586.

2) Partyka, Susan C., Occupant Ejections from Light Passenger Vehicles, Office of Vehicle Safety Standards, Rulemaking, National Highway Traffic Safety Administration, 1991.

3) Adjusted ejection rates for all automatic systems were computed, using the distribution of front-seat occupants involved in fatal crashes for vehicles equipped with manual belts shown in Table 4-4. For each automatic occupant protection system type, the adjusted ejection rates were computed using the ejection rate in each cell of the 2x2 matrix (rollover vs. number of doors) and weighting the cell rates by the manual belt exposure in Table 4-4. These adjusted rates are shown along with the original ejection rates from Table 4-3 in Table 4-5.

CHAPTER 5

TECHNICAL REVIEW OF CRASHES INVOLVING AUTOMATIC OCCUPANT PROTECTION

A series of accident cases from the Fatal Accident Reporting System (FARS) and the National Accident Sampling System (NASS) which involved cars with automatic occupant protection were reviewed. The review comprised a sample of 240 FARS cases, 81 NASS fatality cases (all fatal cases available in the 1988-90 NASS files), and 117 NASS serious injury cases (all such cases available in the 1988-90 NASS files).

Review protocol

In Phase I, a group of seven NHTSA crashworthiness researchers performed a technical review of a sample of 240 FARS Police Accident Reports (PARs) involving vehicles identified, by VIN in FARS, as being equipped with automatic occupant protection. The reviewers found that the automatic occupant protection systems generally appear to be working as intended. Phase I also identified areas of special interest to be addressed using the more detailed information available in NASS files. These areas were: intrusion, ejection, rollover, side impact, complex crash kinematics, crash survivability (was it a catastrophic crash?), high-speed crashes, AIS ≥ 3 injuries related to belts (level 3 or higher on the Abbreviated Injury Scale), belt-related neck injuries, air-bag related injuries, head impacts, belt failure, and injuries affected by the size or age of the occupant.

In Phase II, NASS hard copy cases were reviewed. A group of fifteen crashworthiness researchers performed a technical review of NASS cases involving vehicles identified, by VIN, as being equipped with automatic occupant protection. Cases available from 1988-1990 calendar year NASS files were reviewed. Eighty-one (81) cases were reviewed in which a fatality was recorded as having occurred in a seating position equipped with automatic protection; 117 were cases in which a serious (AIS ≥ 3) injury occurred.

The reviewers were grouped in five teams to examine cases categorized into five automatic system types: air bags, 2 point motorized belts <u>without</u> disconnect, 2 point motorized belts <u>with</u> disconnect, 3 point door-mounted belts (nonmotorized - with disconnect), and 2 point door-mounted (nonmotorized) belts.

The technical reviewers were looking for indications of whether or not automatic occupant protection systems generally were operating as would be expected, recognizing that a substantial number of fatalities and serious injuries would still occur with systems projected to be approximately 30-50 percent effective. **NOTE: This review consisted only of serious injury and fatality cases. As such, problems or "failures" are more likely than successes to be observed.** Non-injury, minor injury, and moderate injury cases were not examined. This report reviewed unweighted NASS cases, and does not extrapolate to statistically represent the national experience. Moreover, this unweighted case review does not attempt to compare different types of automatic protection.

The objective was to evaluate the general technical performance of automatic occupant protection systems. The objective was not to evaluate the various individual systems, and not to evaluate one category of automatic protection in comparison with any other type of automatic protection. Some limitations of this review can be appreciated by recalling that there are about 120 new car models each year. While there are five generally similar automatic occupant protection systems, there are many specific differences in the systems by make, model, and model year. Technical reviews of this limited number of cases are useful and necessary, for general assessment purposes, but not sufficient for dispositive judgements on any particular system.

Findings

This technical review indicates that automatic crash protection systems, when properly and fully used, generally appear to have worked as expected in the examined crashes. However, certain injury patterns were noted:

Belts: Belts were either not used, improperly used or unavailable in nearly half the fatal cases reviewed (41 of 81 cases). This included automatic belts disconnected, manual lap belts not connected, manual lap belts unavailable, three-point manual belts not worn in the air bag seating position, and loosely or otherwise improperly worn belts.

Manual lap belts were not used in one-half of the fatal cases involving automatic 2-point belts (27 of 53 cases). In four of these cases a manual lap belt was not available.

In 44 percent of the serious injury cases, belts were not used, not fully used, improperly used, or unavailable (51 of 117 cases). Automatic belts were not used in 30 percent of serious injury cases (32 of 107). Manual belts were not used in 5 of 10 air-bag cases. Manual lap belts were not used in 41 percent of cases involving cars with automatic 2-point belts (22 of 54). In three of these cases, the manual lap belt was unavailable.

Ejection: Ejection, especially when belts were either not worn or worn improperly, e.g. manual lap belt not used, occurred in 16 of the 81 fatal cases reviewed.

Intrusion: Intrusion was a major factor in more than half the fatal cases (43 of 81 cases) and in nearly half of the serious injury cases (50 of 117). In many instances the reports contained information showing that massive damage and intrusion were involved where air bag and belt-restrained fatalities and serious injuries occurred. One-third of the fatal cases reviewed were judged unsurvivable (28 of 81 cases).

Complex Kinematics: It was noted that 12 of 81 fatal cases and 14 of 117 serious injury cases had the characteristic of complex vehicle and/or occupant kinematics (e.g., multiple impact events).

Occupant Age and Size: In 15 of the 81 fatal crashes and in 10 of the 117 serious injury cases, occupant age/size effects were noted. Many of these 25 cases involved elderly occupants.

Rollover: High speed, off-the-road rollovers were a common pattern in fatal crashes - often resulting in ejection, especially when belts were not properly worn.

Side Impact Fatalities and Injuries: Fatalities and serious injuries of occupants in near-side impacts was another recurring phenomenon both in air-bag and in automatic-belt equipped vehicles.

CHAPTER 6

INJURY REDUCTION

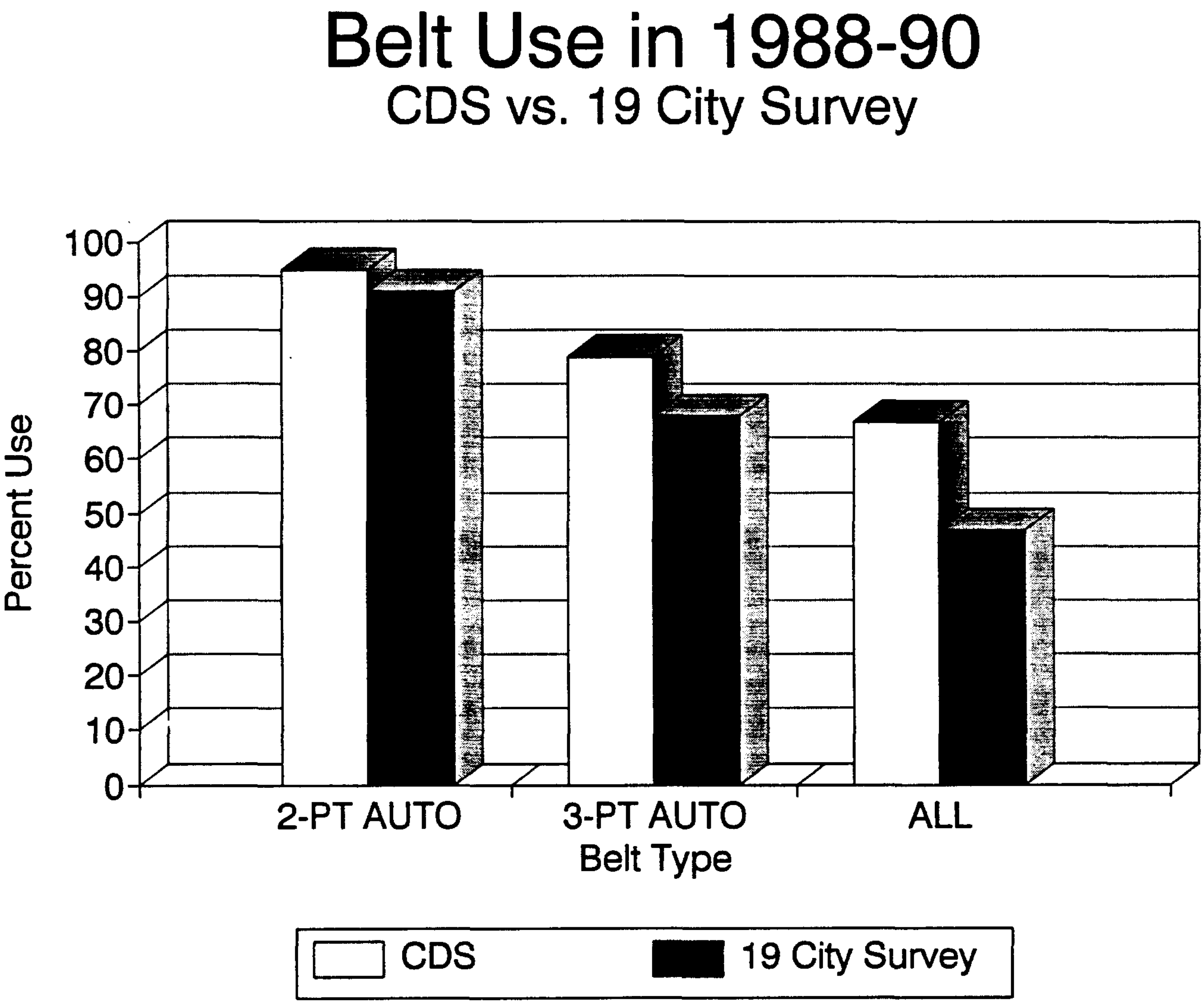
The preceding analyses of actual fatality and ejection reduction compared all occupants of cars equipped with automatic protection to all occupants of cars equipped with manual belts. The following analysis attempts to assess the potential, or "when used" effectiveness of automatic protection. Specifically, the analysis compares the injury outcome of passenger car occupants who were reported to have used their occupant protection system with the outcome of those who reportedly did not. The estimated effectiveness represents the potential reduction in the global risk of injury for each automatic system at 100 percent use.

For this analysis, it is necessary to have crash data with accurate reporting of occupants' use of automatic or manual belt systems. Data from the National Accident Sampling System (NASS) were used because they have the most accurate belt use reporting of any NHTSA file. This is due to the fact that the assessment of belt use used in the current analysis is based on the judgment of trained professional accident investigators, after having reviewed the police accident report, vehicle inspections, injury patterns based on hospital records, and interviews with crash-involved parties. Even so, reported belt use in NASS is higher than the observed belt use of drivers on the road, especially for manual lap belts that accompany motorized 2-point automatic belts. Many crashes investigated by the NASS teams are of sufficiently low severity and low injury to vehicle occupants to provide little in the way of hard evidence of belt use, necessitating the NASS investigators to rely primarily on self-reporting of belt use by the involved parties. While this pattern of higher use rates in NASS could result in inflated estimates of the "when used" effectiveness of these systems, it is believed that this will not significantly influence the effectiveness estimates relative to one another.

Figure 6-1 presents estimates of belt use for two sources of data: the NASS Crashworthiness Data System (CDS) and NHTSA's 19 city survey. The data have been collapsed into three categories for consistency between the two sources: 2-point automatic belts (motorized, nonmotorized, with and without manual lap belts), 3-point automatic belts, and the total (consisting mostly of manual lap and shoulder belt systems). From this figure it can be seen that reported belt use in crashes is higher than that observed in the general driving public. This situation is generally considered counterintuitive since the risk-taking behavior associated with the nonuse of belts would be consistent with higher crash involvement and injury rates, and hence, lower belt use in crashes.

Several contrasts with the previous analyses of <u>actual</u> effectiveness should be noted. First, while the previously documented analyses focused on fatal crashes, the current analysis of when used effectiveness focuses on moderate and greater injury - i.e., level 2 or more on the Abbreviated Injury Scale (AIS). This was necessitated by the fact that there are far too few cases of fatal injury investigated by the NASS teams to conduct such an analysis. AIS level 2 and greater was selected for this analysis for consistency with previously published reports addressing the fatal and injury reducing

Figure 6-1



Belt Use in 1988-90
CDS vs. 19 City Survey
Percent Use
100
90
80
70
60
50
40
30
20
10
0
2-PT AUTO
3-PT AUTO
ALL
Belt Type
CDS
19 City Survey

effectiveness of occupant protection systems.

Second, the previous analyses of actual effectiveness documented in this report used data from the Fatal Accident Reporting System, while the current analysis of potential effectiveness used data from the NASS Crashworthiness Data System, for the period 1988 through June 1991.

As mentioned earlier, these estimates of actual effectiveness did not require that belt use be known. Implicitly, the estimates of actual effectiveness consist of the combined effect of two components: the "when used" effectiveness of individual systems (at 100 percent use) and the actual use rate of these systems. However, in the "when used" analysis, it is necessary to know precisely whether the system was used and in what specific combination (i.e., 2-point automatic belts with vs. without the manual lap belt).

The occupant protection systems investigated for potential effectiveness differ slightly from the previous categorization of actual effectiveness for several reasons. First, it is not necessary to distinguish between 2-point automatic belts with vs. without the disconnect feature, since if it were known that the system was in use, it clearly was not disconnected. Therefore, these systems were combined to form the 2-point automatic belt group; however, it was still necessary to distinguish between the use of a 2-point automatic belt without manual lap belt use and one in which the manual lap belt was used. The second reason for combining systems was to assure sufficient sample sizes for estimating effectiveness for as many systems as possible. Thus, motorized and nonmotorized 2-point automatic belts were also combined into one group.

Lastly, the current analysis contrasts the injury outcome of restrained front outboard occupants with those who were unrestrained. This is in contrast to the estimates of actual effectiveness, wherein the comparison is drawn between front outboard occupants of vehicles equipped with automatic protection vs. the same occupants of vehicles equipped with manual protection systems and does not consider whether the occupant protection system is used or not. In the when used analysis, the estimates represent the reduction in the likelihood of moderate and greater injury (AIS $\geq$ 2) resulting from the use of the individual system; these estimates should be greater in magnitude than the actual effectiveness estimates, and closer to the traditional estimates of effectiveness presented in the literature.

Thus, there are a number of differences between the current analysis of potential effectiveness and the previously discussed estimates of actual effectiveness. It is important to avoid confusing the two sets of estimates, since they should differ in magnitude.

Methodology

The analysis that follows investigates the injury experience of front outboard occupants at least 5 years old of passenger cars of model years 1985 and later. The analysis uses a statistical model to estimate the effectiveness of specific occupant protection systems accounting for various crash, vehicle and person characteristics. Some of these characteristics include delta-v, a measure of crash severity which has been shown to be a significant factor in determining injury severity, vehicle damage location, whether or not the vehicle rolled over, occupant age and sex. The results of two models are presented. The first uses delta-v as a predictor of moderate and greater injury; however, there is a price to pay for using this important variable. Approximately one-half of the cases are lost when delta-v is missing, and for vehicles that rolled over. The second model avoids the use of delta-v and doubles the number of cases available for analysis; however, the final model does not provide as good a fit as the model that includes delta-v. These issues are discussed in more detail below.

The specific cases used in this analysis cover the period January 1988 through June 1991 and included:

- passenger cars,
- model years 1985 and later,
- drivers and right front passengers (front outboard),
- occupant at least 5 year old (no child safety seats),
- occupant protection system could be determined from inspection of the Vehicle Identification Number (VIN), and
- belt use could be determined from the NASS team investigator-reported use variable.

Belt effectiveness has traditionally been defined for a given occupant protection system as

$$100(1 - P_i/P_0)$$

where P_i = proportion of occupants receiving MAIS (Maximum AIS) 2-5 injuries or killed for <u>occupant protection system i</u>

P_0 = proportion of occupants receiving MAIS 2-5 injuries or killed for <u>unrestrained occupants</u>

The ratio P_i/P_0 is also known as the relative risk.

Another useful measure of belt effectiveness is the odds ratio, defined as

$$[P_i/P_0] \times [(1-P_0)/(1-P_i)]$$

Note that when $(1-P_0)/(1-P_i)$ is approximately equal 1, the odds ratio and relative risk will be approximately equal. This will occur when both P_0 and P_i are small. However, for the current file of unrestrained occupants, $P_0 = .16$ (that is, the moderate injury rate is 16 percent) so this approximate equality does not hold. The meaning of the odds ratio is "how much less likely are moderate and greater injury for an occupant using a specific occupant protection system than for an unrestrained occupant." For example, if the odds ratio is .5 and the system used was manual lap and shoulder belts, the odds of serious injury or fatality are one-half what they would be if the occupant were unrestrained.

When calculating the odds ratio, it is desirable to control for other variables that may affect whether the specific occupant was injured. To illustrate, if the odds ratio were .25 for occupants using both air bag and manual belts, the comparison should be made with unrestrained occupants holding crash, vehicle, and occupant characteristics constant, so that the effect of the air bag and manual belt can be isolated and measured separately from such other variables as crash severity, damage location and whether or not a rollover occurred. This was accomplished by the use of a statistical model. In the current instance the model employed is a logistic regression model[1]. Besides controlling for other variables, this approach allows one to estimate the odds ratios for different occupant protection systems easily, since the regression coefficient for each occupant protection system indicator variable is equal to the log of the odds ratio for that system. By exponentiating and using the standard errors provided by the software package, confidence intervals can be obtained on each odds ratio.

The following occupant protection system/use groupings were created using the VIN, occupant seating position and CDS "use" variables. The six groupings based on the VIN are

- air bag with manual belt
- air bag without manual belt
- 2-point automatic belt with manual lap belt
- 2-point automatic belt without manual lap belt
- 3-point automatic belt
- manual lap and shoulder belt

The percentage of missing data in the analysis data set of 13,930 occupants is given below for each variable.

- deformation location: 15%
- injury level: 0.4%
- occupant protection system indicator (VIN): 6%
- seat position: 0%
- rollover indicator: 1%
- vehicle curb weight: 2.6%
- occupant sex: 0%
- occupant age: 0%
- total delta-v: 60%
- intrusion indicator: 2%

For this analysis, elimination of observations with missing data resulted in 5,031 complete cases (occupants) to fit the model containing occupant protection system indicator, seat position, deformation location, total delta-v, passenger compartment intrusion indicator, sex and age.

The use of delta-v in estimating effectiveness is believed to result in more accurate estimates. This is due to the fact that delta-v is known to be a very influential factor in determining injury severity, and accounting for it should allow one to isolate occupant protection system effectiveness. However, delta-v is not reported for all or even the majority of vehicles in NASS; approximately 50 percent of the vehicles involved in NASS-investigated crashes will have no recorded delta-v.

Moreover, delta-v is not missing at random. For example, total delta-v is not calculated for vehicles that rolled over. It is also not calculated for vehicles for which inspection could not be made or sufficient data could not be gathered. This may be more likely in crashes resulting in little or no injury and damage to the vehicle, or in catastrophic crashes where damage is so great that measurements cannot be made. For this reason a separate model was also fit for all cases including those where total delta-v was missing. This model was based on 9,483 cases and includes occupant protection system indicator, seat position, deformation location, passenger compartment intrusion indicator, sex, age, rollover indicator, and vehicle curb weight.

Figure 6-2 presents the distribution of occupants at various injury levels (MAIS = maximum AIS level) for two sets of data: those cases where delta-v was known and those with delta-v missing. Two points are worth noting. First, there is little difference between the two injury distributions for AIS 2 and greater injury whether considering cases with delta-v missing or those cases with delta-v known. Second, over 70 percent of the occupants receiving moderate and greater injury received moderate injury. Thus, the analysis of potential effectiveness is driven, to a great extent, by the effectiveness of occupant protection in reducing moderate injury.

One might also inquire about the distribution of damage locations between the two groups of data (delta-v known vs. delta-v missing). Figure 6-3 presents these distributions for nonrollover crashes (since vehicles that rolled over would not be amenable to measurement of delta-v). There is little difference in the distributions of damage location for those cases where delta-v was known vs. missing. Thus, by estimating a model for those cases where delta-v was known, one does not obtain a sample that omits, for example, a majority of side-impact crashes. However, occupants of vehicles that rolled over will not be represented in the models using delta-v.

Since occupant ejection occurs more frequently in rollover crashes, and safety belts traditionally have been considered very effective in preventing ejection (when they are used), one might expect differences in the effectiveness estimates between the two sets of models. However, occupants of vehicles that rolled over constitute approximately 6 percent of the crash-involved occupants of towed vehicles nationally, and thus, their absence should not have a large effect on the resulting estimates.

Table 6-1 presents the sample sizes for the two models to be estimated: the model including delta-v and the model without delta-v. The sample sizes for air bags <u>without</u> manual lap and shoulder belts are clearly insufficient for computing effectiveness estimates at this time.

The model estimation began by fitting as many variables at once as the 640K memory limitation of the software package[2] would allow, then fitting the reduced model after eliminating variables not significant at $\alpha = .05$. The criteria used to judge the adequacy of each model was the percentage of MAIS 2+ cases correctly predicted by the model. The approach was to first fit a model for cases with total delta-v reported (called the "nonrollovers"). For this analysis the $\alpha = .05$ criteria resulted in elimination of curb weight (curb weight is believed to be correlated with delta-v; this result has been observed previously in an analysis of NASS data on the issue of vehicle weight and injury occurrence) and occupant's weight. In addition, the indicator variable for air bag without manual belt was not significant ($p = .18$) because

Figure 6-2

Distribution of Occupants by MAIS

Source: CDS 1988-90, Jan-June 1991

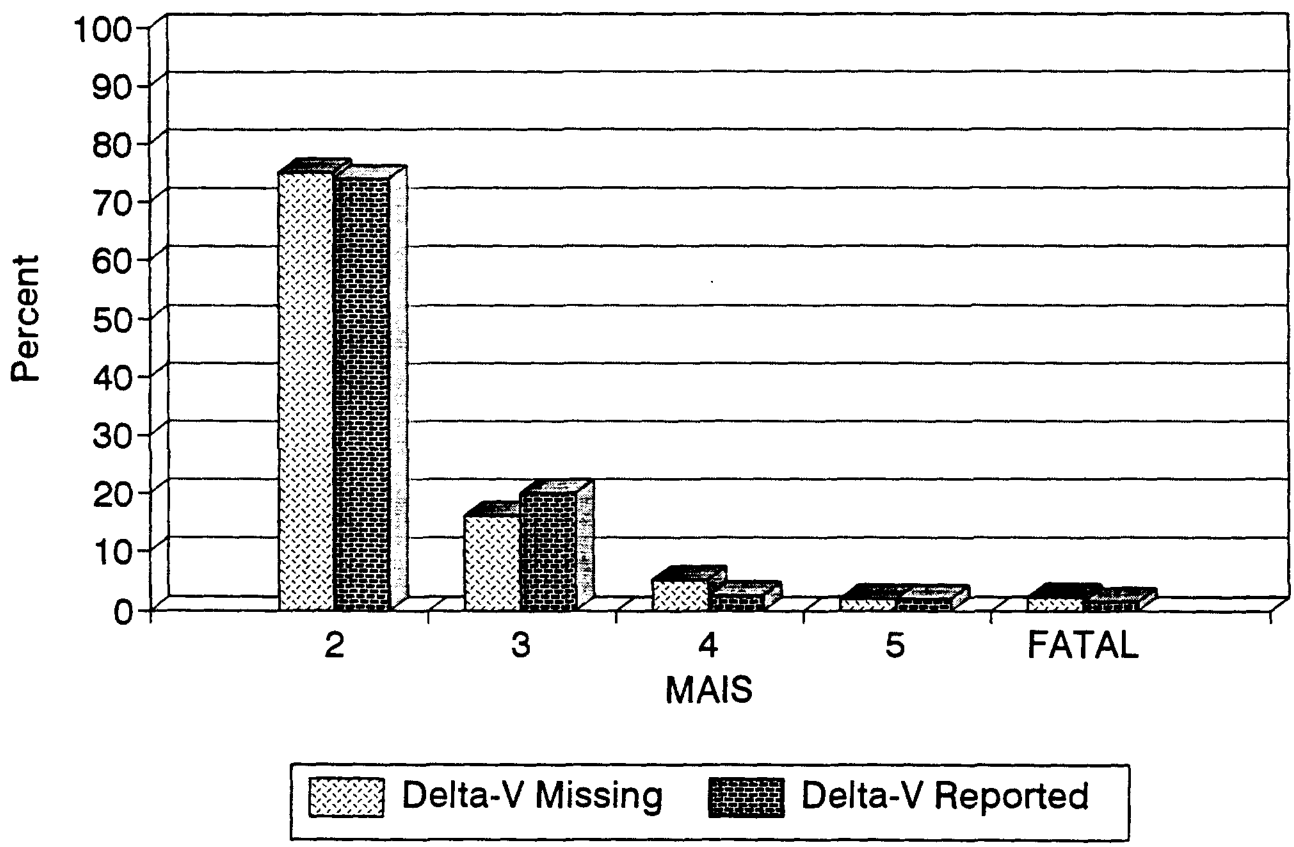


Figure 6-3

Distribution of Occupants by Crash Mode

Source: CDS 1988-90, Jan-June 1991

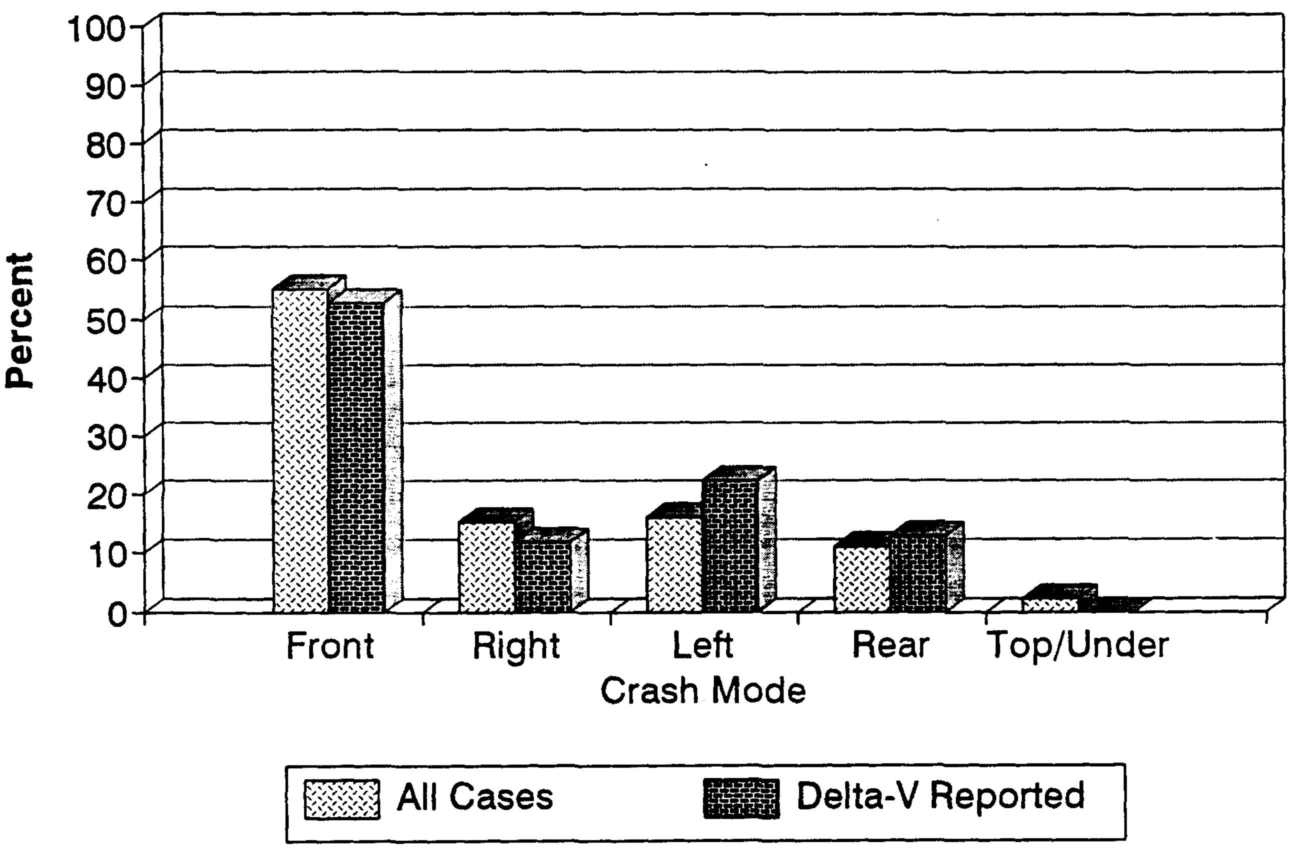


TABLE 6-1

TABLE OF SAMPLE SIZES

Type of Occupant Protection	Number of Accident Cases Model 1 (with delta-v)	Model 2 (without delta-v)
Air bag plus manual lap and shoulder belt	89	165
Air bag without manual lap and shoulder belt	20	47
2-point automatic belt plus manual lap belt	254	512
2-point automatic belt without manual lap belt	148	299
3-point automatic belt	280	490
Manual lap and shoulder belt	2,536	4,688
Unrestrained	1,704	3,282
TOTAL	5,031	9,483

of its extremely large standard error (there are only 20 such cases in the analysis file). The variables contained in the final version of this model are occupant protection system indicator, a seat position by deformation location indicator interaction term, sex, delta-v, age, and intrusion indicator.[3]

For comparison, a model containing a rollover indicator and curb weight in addition to the other variables but excluding total delta-v was fit to the entire data set in order to include both the rollovers and other cases where total delta-v is missing. For this model n = 9,483 cases are available. Rollover is highly significant at p = .001 and curb weight is significant at p = .09, but this model is a poorer predictor of moderate and greater injury than the model containing delta-v. This is probably because rollover and intrusion by themselves are not adequate indicators of crash severity for the entire data set; only six percent of the occupants in the analysis data set were involved in a rollover crash. One measure of crash severity, the crush profile (in inches), is missing when total delta-v is missing.

Thus, including crush profile would amount to again excluding rollover crashes from the analysis. The extent zone is not an appropriate variable to use, because of its different meaning for different size and model cars.

<u>Results</u>

Table 6-2 presents the estimates of effectiveness[4] for the two models, with 95 percent lower and upper confidence intervals.

Each type of occupant protection results in significantly lower likelihood of moderate and greater injury compared with being <u>unrestrained</u>. However, the observed differences between any two types of occupant protection are not statistically significant at this time (as NASS collects more information, new estimates will be developed which will likely have smaller confidence intervals). The estimates are based on a limited number of cases and there are still insufficient data to rank order these occupant protection systems.

The overall goodness of fit tests indicate that the models fit; however, close examination of the residuals by type of occupant protection and by injury severity reveals a degree of lack of fit, especially for the lower injury severity categories. Table 6-3 and Figure 6-4 shows the percentage of occupants, at each actual MAIS level, which the model predicts as having MAIS 2+.

The inability of the models to fit the lower injury severity cases well may also be due the small proportion of moderate-to-fatally injured occupants in the input data set. For example, of the approximately 5,300 occupants used in the model including delta-v, 9 percent (using the NASS probabilistic weighting scheme) were killed or had MAIS in the 2 to 6 range. It is clear that the model containing delta-v provides a much more accurate prediction of the occurrence of moderate and greater injury than does the model without delta-v, as evidenced by the percentage of correct predictions in Table 6-3. However, there are good reasons for presenting the results of both models, since the model without delta-v contains occupants of vehicles that rolled over and also

TABLE 6-2

EFFECTIVENESS ESTIMATES WITH 95% CONFIDENCE INTERVALS

(NASS CDS data for 1988-90 and January-June 1991)

Type of Occupant Protection	Effectiveness Estimate [Confidence Interval] Model 1* (with delta-v)	Effectiveness Estimate [Confidence Interval] Model 2** (without delta-v)
Air bag <u>plus</u> manual lap and shoulder belt	.77 [.54, .99]	.68 [.45, .90]
Air bag <u>without</u> manual lap and shoulder belt	insufficient data	insufficient data
2-point automatic belt <u>plus</u> manual lap belt	.56 [.36, .77]	.68 [.52, .83]
2-point automatic belt <u>without</u> manual lap belt	.45*** [.02, .89]	.44 [.09, .80]
3-point automatic belt	.60 [.34, .86]	.59 [.34, .84]
Manual lap and shoulder belt	.45 [.29, .61]	.60 [.51, .69]

* Model 1 contains occupant protection system indicator, **total delta-v**, age, sex, intrusion indicator, and seat position by deformation location interaction term

** Model 2 contains occupant protection system indicator, curb weight, rollover indicator, age, sex, intrusion indicator, and seat position by deformation location interaction term

*** parameter estimate not statistically significant

NOTE: NONE OF THESE EFFECTIVENESS ESTIMATES ARE SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER, BASED ON STATISTICAL TESTS OF SIGNIFICANCE.

TABLE 6-3

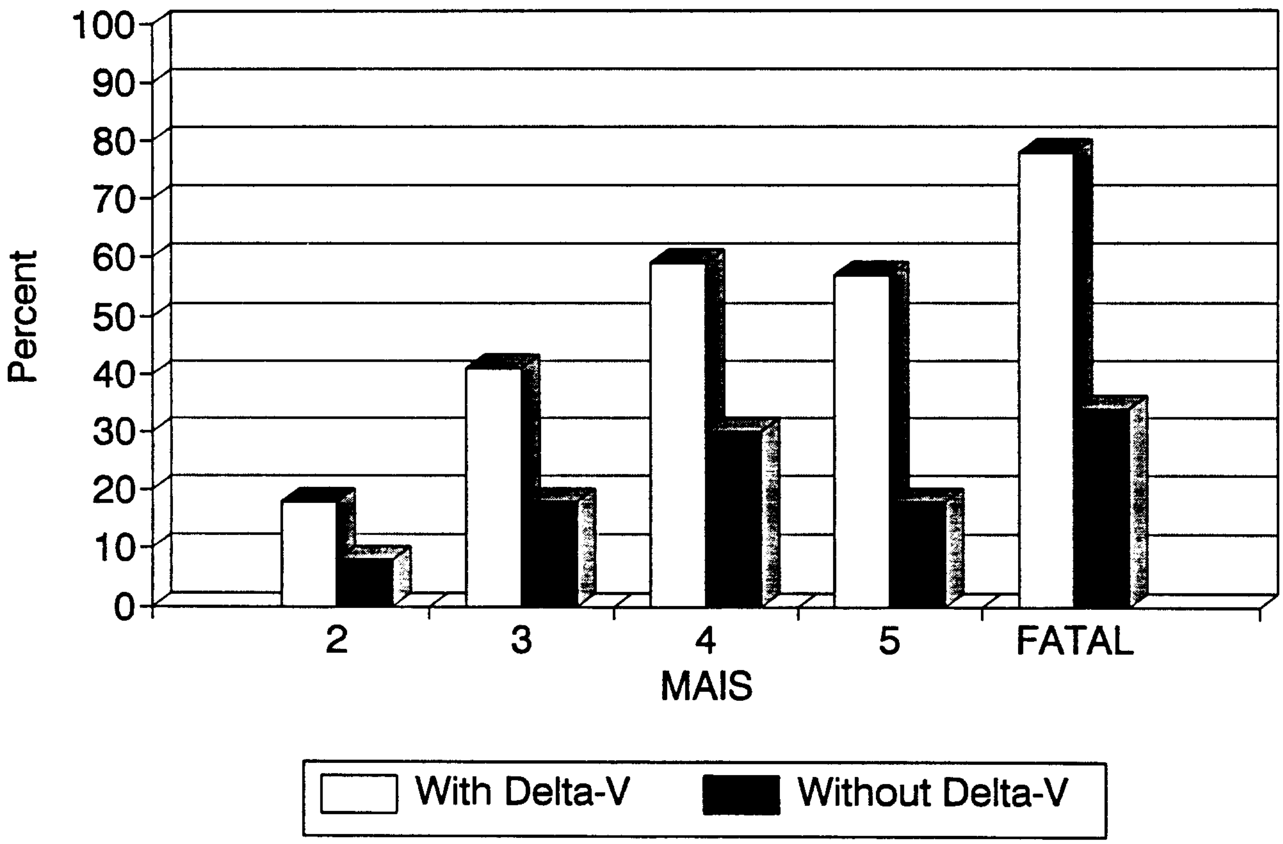
PERCENTAGE OF MAIS 2+ INJURED OCCUPANTS CORRECTLY PREDICTED
BY THE TWO STATISTICAL MODELS

	Percentage Correctly Predicted as MAIS 2+	
Actual Injury Level	**Model with delta-v**	**Model without delta-v**
MAIS 2	18	8
MAIS 3	41	18
MAIS 4	59	30
MAIS 5	57	18
FATAL	78	34

Figure 6-4

Percent Fatalities & MAIS 2-5 Occupants

Correctly Predicted for Two Models



contains approximately twice the number of cases.

Tables 6-4 and 6-5 present the logistic regression coefficients for the two models, i.e., with and without delta-V, along with the odds ratios derived from them. Confidence intervals at the 95% confidence level are also presented for the odds ratios.

In conclusion, the findings are evidence that automatic occupant protection and manual belts, when used, significantly reduce the risk of moderate and greater injury. It is still premature to conclude that one system performs better or worse than another. As more data become available, new estimates of effectiveness will be computed.

TABLE 6-4

MODEL CONTAINING OCCUPANT PROTECTION SYSTEM INDICATORS, INTRUSION INDICATOR, SEAT POSITION BY DEFORMATION LOCATION INTERACTION, SEX, AGE, AND TOTAL DELTA-V, USING UNRESTRAINED OCCUPANTS AS THE REFERENCE GROUP AND **VIN** FOR OCCUPANT PROTECTION SYSTEM CODING

Variable		β_j	**SE**(β_j)	**Odds Ratio**	**95% CI for Odds Ratio**
Intercept	j=0	-3.56977	.513237		
Air bag w/ Manual Belt	j=1	-1.56088	.393534	.21	[.083, .53]
Air bag w/o Manual Belt**	j=2	-1.14591	.701629	.32	[.035, 2.90]
2-Point Automatic Shoulder Belt Only**	j=3	- .90872	.285800	.40	[.25, .66]
2-Point Automatic Lap & Shoulder	j=4	- .67420	.491823	.51	[.21, 1.27]
3-Point Automatic	j=5	-1.00255	.326139	.37	[.18, .75]
Manual Lap & Shoulder	j=6	- .66163	.120946	.52	[.38, .71]
Seat Position Driver vs. Passenger for:	j=7				
Front**		- .16283	.161377	.85	[.61, 1.18]
Right Side		- .43643	.203694	.65	[.42, .98]
Left Side**		- .19604	.171551	.82	[.58, 1.17]
Rear		-1.5228	.306941	.22	[.12, .41]
Top/Undercarriage		.79922	.170023	2.22	[1.57, 3.16]
Sex Male vs. Female	j=8	- .51665	.153127	.56	[.44, .79]
Total Delta V	j=9	.15976	.010869	1.17	[1.15, 1.21]
Age	j=10	.02322	.004024	1.02	[1.01, 1.04]
Intrusion Yes vs. No	j=11	.98419	.158232	2.68	[1.93, 3.71]

**** - not statistically significant**

TABLE 6-5

MODEL CONTAINING OCCUPANT PROTECTION SYSTEM INDICATORS, CURB WEIGHT, SEX, AGE, ROLLOVER INDICATOR, INTRUSION INDICATOR, AND SEAT POSITION BY DEFORMATION LOCATION INTERACTION USING UNRESTRAINED OCCUPANTS AS THE REFERENCE GROUP AND VIN FOR OCCUPANT PROTECTION SYSTEM CODING

Variable		β_j	SE(β_j)	**Odds Ratio**	**95% CI for Odds Ratio**
Intercept	j=0	2.70505	.452610		
Air bag w/ Manual Belt	j=1	-1.25550	.370381	.28	[.13, .61]
Air bag w/o Manual Belt**	j=2	- .61880	.408533	.54	[.23, 1.25]
2-Point Automatic Shoulder Belt Only	j=3	- .66905	.325192	.51	[.26, 1.00]
2-Point Automatic Lap & Shoulder	j=4	-1.25461	.203452	.29	[.19, .43]
3-Point Automatic	j=5	-1.00739	.272853	.37	[.21, .64]
Manual Belts n=4688	j=6	-1.03280	.115166	.36	[.28, .45]
Seat Position Driver vs. Passenger for:	j=11				
Front**		.00913	.119055	1.01	[.79, 1.29]
Right Side		- .45300	.126422	.64	[.49, .83]
Left Side		- .42500	.138626	.65	[.49, .87]
Rear		- .89737	.217862	.41	[.26, .64]
Top/Undercarriage		- .94132	.203693	.39	[.26, .59]
Sex Male vs. Female	j=12	- .30624	.115166	.74	[.58, .93]
Vehicle Curb Weight	j=13	- .02362	.013211	.98	[.95, 1.00]
Age	j=14	.01917	.002506	1.02	[1.01, 1.03]
Rollover Yes vs. No	j=15	.72544	.200606	2.07	[1.37, 3.12]
Intrusion Yes vs. No	j=16	1.78586	.132611	6.0	[4.54, 7.84]

**** - not statistically significant**

FOOTNOTES FOR CHAPTER 6

1) Logistic regression is appropriate for the situation where the dependent variable takes on only two values, such as Y = 1 (moderate to fatal injury) or Y = 0 (minor/no injuries), and the probability of the outcome, P(Y = 1), is approximately estimated by the logistic function

$$p(Y=1)=\frac{e^{\beta_0+\beta_1 X_1+\ldots\beta_k X_k}}{1+e^{\beta_0+\beta_1 X_1+\ldots\beta_k X_k}}.$$

The X_i's are the independent variables, e.g., total delta-v, age, sex, type of occupant protection, etc. If there were only one independent variable X, the plot of P(Y = 1) vs. X should be approximately the S-shaped logistic curve, which levels off at P(Y = 0) and P(Y = 1). By transforming P(Y = 1) using the logit transformation, we get

$$\ln\left(\frac{P}{1-P}\right)=\beta_0+\beta_1 X_1+\ldots\beta_k X_k.$$

The model is now linear in the parameters so the β's can be easily estimated. If we consider six types of occupant protection vs. being unrestrained, the six occupant protection systems would be coded as indicator variables X_1 through X_6 with X_i = 1 meaning "system i present and used" and X_i = 0 meaning "system i not available or not used". The unrestrained occupants are the "reference group" to which the likelihood of injury to a restrained occupant is compared, and would have $X_1 = X_2 = \ldots X_6 = 0$. The odds ratio for system i would be e^{β_i}.

Reference: Hosmer and Lemeshow, Applied Logistic Regression, 1989, Wiley & Sons

2) A PC version of Research Triangle Institute's SUDAAN software package was used for the logistic regression in order to take the unequal weighting, stratification, and clustering of the CDS sample design into account. Without taking account of both the sample design and the weights, the standard errors of the regression coefficients will be incorrect, hence inferences about variables to be included in the model based on p-values may be incorrect. Clustering in particular, which occurs in CDS in the selection of PSU's and police jurisdictions, usually increases standard errors compared to what they would be if simple random sampling were used. Therefore packages such as SAS and BMDP should not be used except possibly for preliminary analysis. SUDAAN uses the Iterative Reweighted Least Squares algorithm to solve the maximum likelihood equations for the regression coefficients. It produces the correct standard errors for the regression coefficients using the Taylor Series Method (Linearization Method) of variance estimation. The overall goodness-of-fit statistics produced are the

Satterthwaite-Adjusted F and the Wald F.

Reference: Wolter, Introduction to Variance Estimation, 1985, Springer-Verlag

3) Ejection is an excellent predictor of serious injury/fatality (in fact it is almost synonymous with the outcome variable Y), but it is not used because it is desired to include the ability of a system to prevent ejection as part of its effectiveness estimate.

A model with the addition of a total delta-v^2 term was fit because of graphical evidence that the relationship between total delta v and $\ln\{P/(1-P)\}$ is nonlinear, where P is the probability of moderate-to-fatal injury. This squared term had a p-value of .06. The effect of including total delta- v^2 is to dampen slightly the effectiveness estimates of the various occupant protection systems at high values of delta-v. However, inclusion of this term had virtually no effect on the ability of the model to predict serious injury/fatality or on the estimated regression coefficients, so it was omitted. The functional form of the relationship between $P(Y = 1)$ and the other continuous variables (age and curb weight) was not investigated in such detail.

Reference: Skinner, Holt, and Smith, Analysis of Complex Surveys, 1989, Wiley & Sons

4) To obtain effectiveness estimates, the estimated logits (the logit is defined in footnote 1) were averaged for the unrestrained occupants; this average logit was then solved for P_0, the probability of moderate-to-fatal injury for the unrestrained occupants. (Equivalently, but less conveniently, P_0 could also be obtained by evaluating the model at the average value for each independent variable for the unrestrained occupants.) By substituting for P_0 in the odds ratio expression defined on footnote 1 and setting the expression equal to the estimated odds ratio (see Tables 6-2 and 6-3) for occupant protection system i, one can solve for P_i. The relative risk is then easily obtained. Variances of the effectiveness estimates were computed using a replication technique called jackknifing (see reference for footnote 2).