Fatality Reduction by Automatic Occupant Protection in the United States

Charles J. Kahane
National Highway Traffic Safety Administration
United States

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ABSTRACT

Automatic occupant protection, state belt laws, and greater voluntary belt use amount to a 'winning combination' that saves lives. Federal Motor Vehicle Safety Standard 208, as amended on July 17, 1984, combined 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 and light trucks. The effectiveness of automatic occupant protection is measured by statistical analysis of fatal crashes involving model year 1985-93 passenger cars, based on FARS data from 1986 through mid-1993.

Fatality risk of occupants in cars equipped with air bags plus manual belts (at 1993 use rates) is 23 percent lower than in "baseline" cars with manual belts at 1983 use rates. In similar comparisons, the fatality reductions for the four types of automatic belts range from 11 to 19 percent. All reductions are statistically significant. In the 1993 model-year mix of cars with air bags or automatic belts, at 1993 belt use rates, the average fatality risk is 20 percent lower than for baseline, manual-belt cars at 1983 use rates.

INTRODUCTION

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.[1] It consisted of two components: an immediate, nationwide effort to increase belt use, through encouragement of State buckle-up laws, enforcement and public education, and a rule requiring that <u>automatic occupant protection</u>, such as air bags or automatic belts, be phased into passenger cars during 1987-90. Based on fatal accident data collected between January 1986 and June 1993, this paper estimates the fatality reduction associated with increased manual belt use, driver air bags, and four generic types of automatic belts for front-seat occupants of passenger cars in the United States.

OVERVIEW OF THE OCCUPANT PROTECTION PROGRAM

Manual safety belts are highly effective in reducing fatalities and serious injuries in crashes, but only if occupants take the time to buckle them. Numerous research studies indicate that, when used, manual lap and shoulder belts reduce the risk of fatal injury to front-seat passenger-car occupants by 45 percent.[2] In 1983, the year before FMVSS 208 was promulgated, manual safety belts were used by 14 percent of the general driver population.[3] 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 FMVSS 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 September 1993, 45 States plus the District of Columbia and Puerto Rico have enacted them. In the United States, public consciousness of health and safety issues generally increased during the 1980's. Buckle-up laws and educational programs nurtured the public's awareness of auto safety issues. 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. Although the FMVSS 208 provisions relating to belt use laws expired on April 1, 1989, the nationwide effort to encourage State buckle-up laws and to increase belt use has continued.

Belt use by the driving population increased to 62 percent in late 1992 and reached 66 percent in 1993.[4] The agency estimates that safety belts saved about 5,226 lives in 1992 in passenger cars and light trucks.[5] 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.

FMVSS 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), FMVSS 208 exempted 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.

In 1991, NHTSA extended the automatic occupant protection requirements to light trucks and vans, on a phased-in basis: 20 percent in model year 1995, 50 percent in model year 1996, 90 percent in model year 1997 and all light trucks and vans manufactured after September 1, 1997 (model year 1998).

The Intermodal Surface Transportation Efficiency Act of 1991 requires all passenger cars manufactured after September 1, 1997 and all light trucks and vans manufactured after September 1, 1998 to have driver and passenger air bags, plus lap and shoulder belts.

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 have been offered, 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 in this study. It is anticipated, however, that this will become the dominant type of occupant protection after September 1, 1993, when the passenger seat will no longer be exempted from automatic protection in cars with driver air bags.

(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. Motorized belts without disconnect were first installed in the 1981 Toyota Cressida, and subsequently were installed on certain Fords, Toyotas, and other cars.

(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 (VW, Hyundai, some Toyotas, et al.). Most can be disconnected. Beginning in 1990, all of them included manual lap belts, but some 1987-89 systems had knee bolsters instead of lap belts.

EVALUATION GOALS

NHTSA periodically evaluates the effectiveness of the occupant protection program in accordance with a plan published in 1990[6] and in response to Executive Order 12866 [7] and the Intermodal Surface Transportation Efficiency Act of 1991. NHTSA issued an Interim Evaluation Report in June 1992, based on information available at that time.[8] The Insurance Institute for Highway Safety published an analysis of the fatality reduction for driver air bags in October 1991.[9] These studies showed that the occupant protection program, as a whole, was significantly reducing fatality risk in passenger cars in 1991, and that cars with air bags plus manual belts had significantly lower fatality risk than cars with manual belts alone.

There are two separate measures of the effectiveness of the overall occupant protection program or of any specific type of 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 (1993) belt use rates, and the baseline fatality or injury risk of cars with manual belts at 1983 use rates (before FMVSS 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.

NHTSA is also interested in the potential effectiveness of an occupant protection system, which is the difference in fatality or injury risk of a person who fully and properly uses this system and the fatality risk of a completely unrestrained person. 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.

This paper, however, does not address the potential effectiveness of occupant protection. Its goal is to produce six estimates of actual fatality reduction:

(1) **Manual** belts at 1993 use rates vs. manual belts at 1983 use rates
(2) Driver **air bags** plus manual belts at 1993 use rates vs. manual belts at 1983 use rates
(3) **Motorized** 2-point belts **without** disconnect plus manual lap belts at 1993 use rates vs. manual belts at 1983 use rates
(4) **Motorized** 2-point belts **with** disconnect plus manual lap belts at 1993 use rates vs. manual belts at 1983 use rates
(5) **Nonmotorized 3-point** automatic belts at 1993 use rates vs. manual belts at 1983 use rates
(6) **Nonmotorized 2-point** automatic belts at 1993 use rates vs. manual belts at 1983 use rates

As of mid-1993, there was insufficient accident experience with dual air bags for estimating the fatality reduction for the right-front passenger. The other types of automatic protection differ widely in sales and exposure; as a consequence, the estimates of fatality reduction vary in their precision and statistical significance. Assessments of statistical precision or significance are an integral part of the results and the effectiveness estimates could be misleading without them.

DATA SOURCES AND ANALYSIS OVERVIEW

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.[10] As of March 1994, the FARS file is essentially complete through the first half of 1993. The study is based on FARS records of model year 1985-93 passenger cars involved in fatal crashes between January 1986 and June 1993. Make-models were identified by analyzing the Vehicle Identification Number and the type of occupant protection was identified from the VIN, based on various sources in the literature.[11] Whereas the FARS file reports "occupant belt use," this data element is not needed for the analyses of actual effectiveness.

Beginning with model year 1987, R. L. Polk has furnished NHTSA with monthly car registration counts by make-model, subseries, body style and type of occupant protection. Registration data for model years 1985-86 are obtained from Polk's annual National Vehicle Population Profile. These new-car registration data, in combination with vehicle survival probabilities,[12] are used to calculate the exposure, in vehicle years, for cars of a given make-model and model year in a given calendar year - e.g., 1989 Ford Mustang in 1992. FARS and Polk data are merged to allow computation of fatality rates per million vehicle exposure years, by calendar year, make-model, model year, body style and type of occupant protection.

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.[13] As will be described below, this method is applied to 1983 and 1993 manual-belt cars, to obtain an estimate of actual manual belt effectiveness.

The evaluation of the actual effectiveness of air bags or 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 1983-93 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.[13] This method does not rely on belt use reporting in FARS (whose accuracy in some States with belt use laws has been a matter of debate), but is based on an empirical relationship between U1, the belt use of the general driver and right-front passenger population, which can be accurately observed in NHTSA's 19 City Survey[3] or a State belt use survey, and U2, the belt use of fatally injured drivers and right-front 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, although perhaps inaccurately reported on FARS in States with belt use laws, was always 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[3] and 4 percent among fatally injured persons. In 1993, overall belt use on the road was estimated to be 66 percent in the United States.[4] However, this overall figure includes cars with automatic belts, which have higher use rates than cars with manual belts and which, by mid-1993, constituted approximately 18 percent of the passenger cars on the road. It is estimated that use of manual belts during 1993 was 63 percent.[14] Based on the above empirical formula, 63 percent manual belt use on the road corresponds to 25.2 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[2], 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 7.25 percent in 1983 and would have reached 38.0 percent in 1993 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 1983-93 is

$$1 - [(1 - U3_{1993} + .55\,U3_{1993}) \,/\, (1 - U3_{1983} + .55\,U3_{1983})]$$

$$= 1 - [(1 - .38 + .55 \times .38) \,/\, (1 - .0725 + .55 \times .0725)]$$

$$= 14.3 \text{ percent}$$

FATALITY REDUCTION FOR DRIVER AIR BAGS

As of March 1994, the Fatal Accident Reporting System (FARS) contained records of 2107 occupant fatalities in model year 1985-93 passenger cars at seating positions equipped with air bags (2069 drivers and 38 right-front passengers). That is almost three times as many fatal cases as were on file two years ago, consistent with the large increases in the sales of cars equipped with air bags. There are enough accident cases for meaningful statistical analyses.

At first, air bags were not installed in make-models with high sales volumes. Many of the early installations were in luxury cars such as Mercedes and BMW. 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. In 1990-93, they began to appear on typical "family" cars such as Taurus, Corsica, Accord and Camry. By the end of model year 1993, air bags were common in all market classes of cars.

A principal task in the analyses of fatality reduction for air bags is identifying groups of crashes or occupants that will be helped by air bags as well as control groups of crashes or occupants that are unlikely to be helped by air bags. One factor in the phase-in process for FMVSS 208 had an unexpected benefit that aided the analysis. The regulation exempted the right-front passenger position from automatic protection until September 1, 1993 in cars with driver air bags. Through mid-1993, over 90 percent of the crash-involved cars equipped with air bags had them only for the driver. In cars with driver-only air bags, the right-front passengers are a "control group": they are unlikely to be helped by the [driver] bags.

The ratio of driver to right-front passenger fatalities in cars with driver air bags (where both seats are occupied) is compared to the corresponding ratio in earlier cars of the same makes and models, equipped only with manual belts at both positions. The effectiveness of air bags is estimated by the difference in the ratios. The only real disadvantage of this method is that the analysis has to be limited to cars where both seats are occupied (about 1/3 of the fatality data sample).

Table 1 lists make-models that switched from manual

Table 1

Make-Models that Switched from Manual Belts to Air Bags Plus Belts: Model Years Included in the Effectiveness Analyses

Make-Model		Model Years with Manual Belts	Model Years with Air Bags
Chrysler	LeBaron	1987-89	1988-93
	New Yorker C	1989	1990-93
Dodge	Diplomat	1988	1988-89
	Omni	1989	1990
	Daytona	1985-88	1988-93
	Shadow	1987-89	1990-93
	Dynasty	1988-89	1990-93
	Spirit	1989	1990-93
Plymouth	Gran Fury	1988	1989
	Horizon	1989	1990
	Sundance	1987-89	1990-93
	Acclaim	1989	1990-91
Ford	Mustang	1988-89	1990-93
	Crown Victoria	1988-89	1990-93**
	Taurus	1988-89	1990-93**
Lincoln	Town Car*	1987-89	1990-93**
	Mark 7/Mark 8	1988-89	1990-93**
	Continental	1985-88	1989-93**
Mercury	Grand Marquis	1988-89	1990-93**
	Sable	1988-89	1990-93**
Buick	Electra*	1988	1991-93
	Riviera*	1988-89	1990-93
	Reatta	1989	1990-91
Cadillac	DeVille*/Fleetwood*	1988-89	1989-93**
	Eldorado*	1988-89	1990-93**
	Seville*	1987-89	1990-93**
Chevrolet	Caprice*	1989	1991-93
	Corvette	1987-89	1990-93
	Camaro	1988-89	1990-93**
	Spectrum, Storm	1987-89	1990-93
Oldsmobile	Toronado*	1987-89	1990-92
Pontiac	Firebird	1989	1990-93**
Audi	100*/200*	1989	1989-93
BMW	300	1988-89	1990-93
	500	1987-89	1989-93
	600	1986-87	1988-89
	700	1985-87	1987-93**
Nissan	300ZX*	1988-89	1991-93
	Pulsar*, NX*	1989	1990-93
Honda	Accord	1989	1991-93**
Acura	Legend*	1986-88	1987-93**
Jaguar	XJ-S*	1985-89	1990-93
Mazda	929	1988-89	1992-93***
Mercedes	basic sedan*	1985	1986
	190	1985	1986
Porsche	944	1986-89	1987-91***
Saab	900*	1987-89	1990-93
Toyota	Celica	1987-89	1990-93
	Supra	1989	1990-93
	MR-2*	1987-89	1991-93
Volvo	240	1989	1990-93
	740*/760*/940*/960*	1986-89	1987-93**

* Make-model equipped with Antilock Brake Systems at about the same time as air bags: excluded from the analysis of frontal vs. nonfrontal fatalities

** Some of the cars have dual air bags; these cars are excluded from the analysis of driver vs. right front passenger fatalities

*** All of the cars have dual air bags; make-model is excluded from the analysis of driver vs. right front passenger fatalities belts only to air bags plus belts at some time during 1986-93, showing the ranges of model years used in the analysis. These ranges are chosen to assure that each make-model has an accident sample of manual-belt cars as close as possible to **double** its air-bag equipped sample: a uniform ratio of manual-belt to air-bag cars, by make-model, assures that the manual-belt and air-bag samples have a similar make-model mix. In this particular data set, a ratio of **two** manual-belt cars to one air-bag equipped car minimizes sampling error. Cars with dual air bags or automatic belts are not included in this analysis.

Table 2

Effectiveness of Driver Air Bags Based on Reduction of Driver Fatalities Relative to Right Front Passenger Fatalities

(both seats occupied; make-models that switched from manual belts to driver air bags)

	Driver Fatalities	Right Front Fatalities	Risk Ratio	Percent Reduction
IN PURELY FRONTAL CRASHES (12:00 principal impact; most harmful event is not a rollover)				
Cars w. manual belts only	327	356	.919	
Cars w. driver air bags	105	177	.593	35
(statistically significant difference: chi-square = 9.14)				
IN ALL FRONTAL OR PARTIALLY FRONTAL CRASHES (10:00-2:00 principal and/or initial impact)				
Cars w. manual belts only	668	728	.918	
Cars w. driver air bags	263	337	.780	15
(not a statistically significant difference: chi-square = 2.72)				
IN ALL CRASHES				
Cars w. manual belts only	1081	1205	.897	
Cars w. driver air bags	503	609	.826	8
(not a statistically significant difference: chi-square = 1.27)				

Fatality reduction for air bag cars at current belt use rates relative to manual-belt cars at 1983 use rates: 21 percent

Table 2 computes the effectiveness of cars with driver air bags, relative to cars with manual belts only at current use rates, for three groups of crashes. The first section of Table 2 addresses "purely frontal" crashes, where air bags are expected to be most effective: the principal impact location, as defined in FARS, is 12:00, and the most harmful event is a collision with a vehicle or object (i.e., not a rollover). There were 327 driver fatalities and 356 right-front passenger fatalities in the manual-belt cars, a risk ratio of .919. But in the air-bag cars, there were only 105 driver fatalities (with air bags) as opposed to 177 right-front passenger fatalities (without air bags), a risk ratio of .593. That is a 35 percent fatality reduction for driver air bags relative to manual belts at current use rates in "purely frontal" crashes and it is statistically significant at the .01 level: Chi-square (χ^2) for the 2 x 2 table is 9.14.[15]

In the middle section of Table 2, the accident sample is extended to include all frontal or partially frontal crashes, where either the principal or the initial impact, as defined in FARS, is between 10:00 and 2:00. These included most of the crashes in which air bags are likely to have some effect.[16] The risk ratio in the manual-belt cars is .918, almost the same as before, but the risk ratio in the air-bag cars is up to .780. Effectiveness drops off substantially from the preceding case: the fatality reduction for driver air bags relative to manual belts at current use rates is 15 percent and it is not statistically significant ($\chi^2 = 2.72$).[15]

The lower section of Table 2 extends the analysis to all crashes, including both frontals and nonfrontals. In the cars with driver air bags, there are 503 driver and 609 right-front passenger fatalities. The driver-to-right-front risk ratio is .897 in the manual-belt cars and .826 in the air-bag cars. Thus, the fatality reduction for driver air bags relative to manual belts at current use rates is 8 percent and it is not statistically significant ($\chi^2 = 1.27$).[15] However, the ultimate goal of the analysis is to compare air-bag equipped cars at current belt use rates to manual-belt cars at baseline, 1983 use rates. It was shown above that the fatality reduction for manual belts as currently used relative to manual belts at 1983 baseline use is 14.3 percent. As a result, the **fatality reduction for driver air bags relative to the baseline of manual belts at 1983 use rates** is

$$1 - [(1 - .143)(1 - .08)] = \mathbf{21\ percent}$$

Another distinctive characteristic of air bags, which leads to a second method for estimating effectiveness, is that they are primarily designed for action in frontal crashes. With an inclusive definition of "frontal and partially frontal" crashes (initial or principal impact location between 10:00 and 2:00 on FARS), it can be assumed that air bags have little effect, relative to manual-belt cars at current use rates, in the remaining "nonfrontal" crashes. These nonfrontal fatalities are a control group. The ratio of frontal to nonfrontal driver fatalities in cars with driver air bags is compared to the corresponding ratio in earlier cars of the same makes and models, equipped only with manual belts.[16] The effectiveness of air bags in frontal crashes is estimated by the difference in the ratios. This analysis has the disadvantage of relying on the unproven assumption of zero effectiveness in nonfrontal crashes, but allows a larger sample size than the preceding method (since it is not limited to cases where the right-front seat was occupied).

Table 1 lists make-models that switched from manual belts only to air bags plus belts at some time during 1986-93. However, not all of them are appropriate for the current analysis. Make-models that received Antilock Brake Systems (ABS) on all or most of the cars, simultaneous with or close to the switch to air bags must be excluded. That is because ABS, which improves a driver's control during braking and can reduce stopping distances in certain situations, may also be causing a shift from frontal to nonfrontal impacts. Drivers of cars with ABS may be able to avoid frontally striking other vehicles; a higher proportion of their crash involvements would be as the "struck" vehicle in the collision (nonfrontal damage). The effect of ABS (reduced involvements in frontal relative to nonfrontal crashes) would be mistakenly attributed to air bags (reduced fatality risk in frontal relative to nonfrontal crashes). The analysis has to be limited to make-models that received ABS well before (e.g, Chevrolet Corvette) or well after air bags (e.g., Chevrolet Camaro). Table 1 shows which make-models are excluded and what ranges of model years for the other models are used in the analysis.

Table 3

Effectiveness of Driver Air Bags Based on Reduction of Frontal Fatalities Relative to Nonfrontal Fatalities

(make-models that switched from manual belts to air bags; make-models that got ABS with air bags are excluded)

	Cars with Manual Belts	Cars with Driver Air Bags	Frontal Fat. Red. for Air Bags (%)
PURELY FRONTAL CRASHES (12:00 principal impact; most harmful event is not a rollover)			
Nonfrontal fatalities	911	498	
Purely frontal fatalities	924	362	28
(statistically significant difference: chi-square = 16.02)			
OTHER FRONTAL OR PARTIALLY FRONTAL CRASHES (10:00-2:00 principal and/or initial impact, excluding purely frontal crashes)			
Nonfrontal fatalities	911	498	
Other frontal fatalities	802	411	6
(not a statistically significant difference: chi-square = 0.61)			
ALL FRONTAL OR PARTIALLY FRONTAL CRASHES (10:00-2:00 principal and/or initial impact)			
Nonfrontal fatalities	911	498	
Frontal fatalities	1726	773	18
(statistically significant difference: chi-square = 7.99)			

Overall fatality reduction for air bag cars at current belt use rates relative to manual-belt cars at current use rates: 12 percent

Overall fatality reduction for air bag cars at current belt use rates relative to manual-belt cars at 1983 use rates: 24 percent

The lower section of Table 3 presents the data needed to calculate the effectiveness of air bags in frontal crashes, and overall. There were 1726 frontal driver fatalities and 911 nonfrontal driver fatalities in the manual-belt cars. But in cars with air bags, there were only 773 frontal driver fatalities as opposed to 498 nonfrontal driver fatalities. The reduction of <u>frontal</u> fatalities for air bags, relative to manual-belt cars at current use rates, is

$$1 - [(773/498) / (1726/911)] = \mathbf{18\ percent}$$

and it is statistically significant ($\chi^2 = 7.99$).[15] The <u>overall</u> fatality reduction for air bags, relative to manual-belt cars at <u>current</u> use rates, is

$$\{1 - [(773/498) / (1726/911)]\} [1726 / (1726+911)]$$

$$= \mathbf{11.8\ percent}$$

Thus, **the fatality reduction for driver air bags relative to the baseline of manual belts at 1983 use rates** is

$$1 - [(1 - .143)(1 - .118)] = \mathbf{24.4\ percent}$$

The two upper sections of Table 3 compute the fatality reduction for air bags, relative to manual-belt cars at current use rates, for two mutually exclusive subgroups of frontal crashes. The top section compares fatalities in "purely frontal" crashes (principal impact 12:00 and most harmful event a collision) to fatalities in purely nonfrontal crashes. The reduction for air bags is

$$1 - [(362/498) / (924/911)] = \mathbf{28\ percent}$$

and it is statistically significant ($\chi^2 = 16.02$).[15] The middle section of Table 3 considers all other types of frontal and partially frontal crashes: where the principal impact is angle-frontal (10, 11, 1 or 2:00 - i.e., 15 to 75 degrees away from straight-ahead), or where a frontal impact is merely the initial crash event and it is followed by a more severe, nonfrontal event, such as a side impact, rollover or fire. In these partially frontal crashes, where the principal forces are not straight-ahead, the fatality reduction for air bags is only 6 percent, and it is not statistically significant ($\chi^2 = 0.61$).[15]

In summary, two rather different methods for computing the actual fatality reduction for driver air bags (relative to the baseline of manual-belt cars at 1983 use rates), yielded quite similar results: 21 and 24.4 percent. In both analyses, the reduction of "purely frontal" fatalities was statistically significant at the .01 level, and in the second analysis, the reduction of all frontal or partially frontal fatalities was also significant at the .01 level, relative to manual-belt cars at current use rates.

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

Each method is based on front-seat occupant fatality rates per million vehicle exposure years, derived from FARS and R. L. Polk data. These reductions are added to the benefits of 1983-93 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. Fatality and exposure data are available for model years 1985-90, by calendar year, for the period extending from January 1986 to June 1993. The goal is to average the three estimates, each of which may have its own sampling errors and biases, to obtain a single "best" estimate for each type of automatic protection.

In the first method, five actual front-outboard occupant fatality rates per million vehicle exposure years are computed, using data for all model year 1985-90 cars: the rate for cars with manual belts and the rates for the four types of automatic belts. Right-front passenger as well as driver fatalities are included in the rates, since automatic belts are installed at both positions. 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 an aggregate, log-linear regression model, calibrated from data on 1985-89 manual-belt cars. The model predicts front-seat fatalities per million years as a function of a car's mass, market class (2 door vs. 4 door; luxury, sporty or neither), vehicle 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]

Table 4

Actual vs. Expected* Fatality Rates for Automatic Belts

(cars of model years 1985-90 on the road during 1/86-6/93)

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	43497	261.71	166.20	166.21	-	14
Motorized 2 point without disconnect	2469	16.54	149.30	156.19	4	18
Motorized 2 point with disconnect	1232	8.49	145.15	145.80	none	15
Nonmotorized 3 point	3666	24.55	149.31	153.53	2	17
Nonmotorized 2 point	752	4.10	183.64	181.53	- 1	13

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

Table 4 shows that cars with manual belts, at current use rates, had actual and expected front seat fatality rates of 166 per million car years. Cars with motorized 2 point belts (without disconnect) had a lower actual fatality rate of 149.30. 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 156.19. Thus, the actual fatality rate is

$$1 - (149.30/156.19) = 4 \text{ percent}$$

lower than would be expected for comparable manual belt cars at current use rates. The actual fatality rate is

$$1 - \{[1 - .143][1 - (149.30/156.19)]\} = \mathbf{18\ percent}$$

lower than would be expected for comparable manual-belt cars at 1983 use rates. Motorized 2 point belts (with disconnect) have a fatality rate 15 percent lower than the expected baseline rate. Nonmotorized 3 point belts have 17 percent lower than baseline fatalities; nonmotorized 2 point systems, 13 percent lower.

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 FMVSS 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.[18]

Table 5 shows that the group of make-models which switched from manual to motorized 2 point belts (without disconnect) had a fatality rate of 179.79 with the manual belts and 153.18 with the automatic belts. That is a 15 percent reduction for motorized 2 point belts (without disconnect) relative to manual-belt cars at current use rates, corresponding to a **27 percent fatality reduction relative to manual-belt cars at 1983 use rates.** The other three automatic belt systems had effectiveness estimates ranging from 10 to 22 percent.

Table 5

Actual Fatality Rates for Groups of Make-Models that Switched from Manual to Automatic Belts in 1987-90

(cars of model years 1985-90 on the road during 1/86-6/93)

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	3427	19.06	179.79		
	auto	2381	15.54	153.18	15	27
Motorized 2 point with disconnect	manual	1349	8.37	161.12		
	auto	674	4.61	146.30	9	22
Nonmotorized 3 point	manual	3980	26.96	147.60		
	auto	2834	18.48	153.35	- 4	11
Nonmotorized 2 point	manual	1885	10.71	176.04		
	auto	651	3.53	184.29	- 5	10

Table 6

Actual vs. Expected Fatality Rates for Groups of Make-Models that Switched from Manual to Automatic belts in 1987-90

(cars of model years 1985-90 on the road during 1/86-6/93)

Make-models Switching from Manual to	Belt Type	Fatality Rates At Current Use: Actual	Expected	Fatality Reduction (%): Actual Rel. to Expected	Relative to 1983 Baseline
Motorized 2 point without disconnect	manual	179.79	183.93		
	auto	153.18	160.77	3	16
Motorized 2 point with disconnect	manual	161.12	175.73		
	auto	146.30	146.38	- 9	7
Nonmotorized 3 point	manual	147.60	150.56		
	auto	153.35	155.26	- 1	14
Nonmotorized 2 point	manual	176.04	183.14		
	auto	184.29	182.36	- 5	10

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 6 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 (without disconnect) had an actual fatality rate of 179.79 with the manual belts and 153.18 with the automatic belts. But the expected fatality rate also decreased, from 183.93 to 160.77, since the mix of cars with automatic belts included a larger proportion of the make-models with historically low fatality rates. The reduction in the actual relative to the expected is

$$1 - [(153.18/179.79) / (160.77/183.93)] = 3 \text{ percent}$$

which corresponds to a **16 percent fatality reduction relative to manual-belt cars at 1983 use rates**. By this method, the fatality reductions for the other three types of automatic belts range from 7 to 14 percent, relative to manual-belt cars at 1983 use rates.

In summary, three rather interrelated estimates of fatality reduction are computed for each type of automatic belt. The three estimates for motorized 2 point belts (without disconnect), 16, 18 and 27 percent are evidence that this type of automatic belt is saving many lives, relative to the baseline of manual-belt cars at 1983 use rates. The nine estimates for the other three types of automatic belts are all positive, and eight of them are 10 percent or more.

"BEST" ESTIMATES OF EFFECTIVENESS

The individual estimates of actual fatality reduction (Tables 2 and 3 for air bags, Tables 4-6 for automatic belts) are averaged[19] to derive current "best" estimates, with approximate confidence bounds[20], for five types of automatic occupant protection, relative to cars with manual belts at 1983 use rates. The results are shown in Table 7. For example, the two estimates of fatality reduction for driver air bags (21 and 24.4 percent) average out to 23 percent.

Also, the overall effectiveness of the occupant protection program for model year 1993 cars is estimated by taking a weighted average of the five individual estimates, based on the distribution of FARS of model year 1993 cars through June 1993 (which was 59 percent air bags, 13 percent motorized 2 point belts without disconnect, 4 percent motorized 2 point belts with disconnect, 19 percent nonmotorized 3 point belts and 5 percent nonmotorized 2 point belts). The weighted average represents the difference between the actual fatality rate in model year 1993 cars, at 1993 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 7

Best Estimates of Fatality Reduction (%)
Relative to Manual Belts at 1983 Use Rates

Cars Equipped with	Best Estimate	Approx. Confidence Bounds Lower	Upper
Manual belts only (at 1993 use rates)	14	-	-
Driver air bags with manual 3 point belts	23	16	30
Motorized 2 point belts (without disconnect)	19	13	25
Motorized 2 point belts (with disconnect)	13	5	21
Nonmotorized 3 point belts (with disconnect)	14	9	19
Nonmotorized 2 point belts	11	1	21
MY 1993 WEIGHTED AVERAGE	20	15	25

It is clear that the occupant protection program - the automatic protection requirement of FMVSS 208, in combination with a nationwide effort to increase belt use - has reduced fatality risk. The average fatality reduction for model year 1993 cars at 1993 belt use rates is 20 percent relative to the baseline of manual-belt cars at 1983 use rates, with confidence bounds of 15 to 25 percent. Furthermore, the average fatality reduction has improved since 1991, when it was 16 percent.[21] A market shift from automatic belts to cars with air bags and manual belts, and increased use of these belts, are contributing to the improvement.

Each of the five individual types of automatic protection has a positive and statistically significant "best estimate" of fatality 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. Air bags and motorized 2 point belts (without disconnect) have the highest "best estimates," but 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. Continued increases in the use of 3-point belts supplied with air bags, as well as other manual or automatic belt systems would boost "actual" effectiveness. As the market share for air bags increases toward 100 percent, the weighted average will rise and approach the estimate for air bags.

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14) Assuming 80 percent belt use in the cars with automatic belts, as reported in *Evaluation of the Effectiveness of Occupant Protection, Federal Motor Vehicle Safety Standard 208, Interim Report*, op. cit., p. 37, footnote 6.
15) χ^2 has to be at least 3.84 for statistical significance at the .05 level and at least 6.64 for statistical significance at the .01 level.
16) The procedures of using the initial as well as the principal impact to define "frontal" crashes, and of limiting the manual-belt comparison cars to the same make-models as the air bag cars emulate Zador, op. cit.
17) The regression model is the same as the one described in *Evaluation of the Effectiveness of Occupant Protection, Federal Motor Vehicle Safety Standard 208, Interim Report*, op. cit., pp. 39-41, except for the following modifications: the data are extended from June 1991 to June 1993, the exposure data have been modified to show scrappage of older vehicles, and the "percent male $\leq$ 30 drivers" variable is based on all the drivers in FARS, not just the fatalities, and has 5

rather than 4 class intervals.

18) The groups of make-models switching from manual to the various types of automatic belts during 1987-90 are listed in Ibid., p. 41.

19) Each average effectiveness estimate is a harmonic average (see Ibid., pp. 41-42). The two air bag effectiveness measurements (Tables 2 and 3) are given equal weight. The automatic belt results in Table 6 are given twice the weight of those in Tables 4 and 5, because they are considered least prone to bias.

20) The confidence bounds are only approximate rather than rigorous and are intentionally wide to allow for biases as well as sampling error (see Ibid., p. 42). They are derived as follows: the analyses for air bags are based on 1271 actual fatalities (in Table 3), but given that air bags reduce fatalities by 23 percent, the "expected" number of fatalities is 1651; the standard deviation of a Poisson variate with mean 1651 is 41 and ± three standard deviations are close to 7 percent of the mean. The actual fatalities for the four types of automatic belts are 2469, 1232, 3666 and 752, respectively, as shown in Table 4. The confidence bounds for the weighted average are obtained by treating it as a weighted sum of five normal, independent variates (i.e., the estimates for the five individual types of automatic protection).

21) Ibid., p. 35.