UPDATE

OF

AIRBAG FATALITIES APPROXIMATION FOR PASSENGER CAR FLEET

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16. Abstract

This study estimated how much airbags reduce the fatality risk in crashes for drivers and right front seat occupants of passenger cars. Four different approaches were used to make the estimate. One compared fatality rates per registered vehicle year, another compared the fatality risks of the drivers of two colliding cars, the third compared the fatality rates of drivers and right front seat occupants of the same car, and the fourth compared the distribution of impact points on cars between airbag and nonairbag cars where the driver, or the right front seat occupant was killed.

Statistical techniques were used to control for the effects of several confounding factors. Separate estimates were made for car weight classes, and driver age classes, and attempted for some crash conditions.

Overall, airbags reduce the driver fatality risk in a crash. However, it appears to differ between vehicle classes and crash types. It may be higher than 60% in certain crash types, and there might be no overall effect for certain car classes. It is strongest in frontal impacts, and there primarily in 12 o'clock impacts. There may be no effect in other than frontal impacts.

When belts are not used, airbags appear to have no overall effect, though they have an effect in frontal impacts. When belts are used, airbags do offer additional protection, in frontal as well as in all impacts.

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airbags, aircushion restraint systems, effectiveness, passenger cars, fatality risk

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TECHNICAL SUMMARY

Estimating the effects of airbags is not a straightforward problem. No existing data base contains all the necessary information. Either data bases have to be combined, or certain critical assumptions must be made. First, these conceptual questions are discussed, then the analyses, and finally the findings are presented.

1. The conceptual approach

Airbags are designed to reduce a car occupant's fatality risk, and to reduce injury severity in frontal impacts. The purpose of this study was to estimate the reduction of the fatality risk, and how it depends on driver, vehicle, and crash conditions.

To estimate the fatality risk, one needs the numbers of drivers (and right-front-seat occupants) killed in crashes, and involved in comparable crashes. Crashes must be "comparable" with respect to various driver, vehicle, and crash factors which influence the fatality risk--some of which have more influence than airbags.

The National Accident Sampling System's (NASS) Crashworthiness Data System (CDS) includes sufficient variables on both fatal and nonfatal accidents. However, case numbers are small which results in low statistical precision for estimated fatality risks.

The largest data base for fatal accidents is the Fatal Accident Reporting System (FARS) which contains practically all fatal motor vehicle accidents in the US. However, it contains only accidents in which at least one person was killed. Therefore, one cannot directly estimate fatality risks based on FARS data alone. Additional data or assumptions are needed. In general, there is no national accident data base with sufficient variables and case numbers for a detailed examination of the influence of air bags on fatality risks.

This study used four different approaches, each relying on different assumptions, and one also using additional data. They are described for the driver. Similar analyses for the right-front-seat occupant were also attempted, but with less success, because not all cars have right-front-seat occupants, and passenger side airbags are less common than driver side airbags.

The *first approach* used driver fatality rates per registered vehicle year, comparing them between airbag and nonairbag cars in classes of similar cars. That requires car registration data, and the assumption that fatality rates differ only randomly among cars of the same class. The only factors one can control for are car class and weight.

The *second approach* studies the fatalities of the two cars involved in car-car collisions, comparing collisions between two cars with no airbags with collisions of an airbag and a nonairbag car. While one cannot estimate absolute fatality risks, one can estimate the ratio of the fatality risk in an airbag, and in a nonairbag car. Only minimal assumptions are required, one can control for the effect of various driver, vehicle, and crash factors and determine how airbag effectiveness depends on such factors. A disadvantage is that the resulting estimates of airbag effectiveness hold only for car-car collisions; they may be different in other collisions.

The *third approach* studies cars with a driver and a right-front-seat occupant, comparing cars with a driver-side-only airbag with nonairbag cars. For each impact type, one can estimate the relative fatality risks of driver and right-front-seat occupant, and comparing them between airbag and nonairbag cars gives the effect of airbags. One can control for driver factors and impact type, and estimate how airbag effectiveness depends on these factors. Only minimal assumptions are required. Disadvantages are that case numbers are small because relatively few cars have a right-front-seat occupant, and that crashes where a right-front-seat occupant is present may differ from those involving a single driver.

The *fourth approach* requires the strongest assumption, that airbags have no effect in certain crashes; we assume no effect in 9 o'clock impacts. While airbags are not designed to have an effect in such impacts, they may have some small effect in such impacts, if they deploy. This approach compares the frequency distributions of driver deaths over the impact points described by the 12 clock positions around the car (and also other impacts, such as top, bottom, and unspecified impacts in rollovers). If expressed relative to the frequency of deaths at 9 o'clock impacts, the ratio of the relative frequency of driver deaths in airbag cars to that of the relative frequency of deaths in nonairbag cars gives the effectiveness of airbags for that impact type. One can control for various driver, vehicle, and crash factors. If airbags had a small beneficial effect in 9 o'clock impacts, estimates obtained by this approach would be conservative.

It would be of interest to determine the effects of airbags separately for belted, and for unbelted occupants. This cannot be reliably done. While FARS reports restraint use by vehicle occupants, this information is considered doubtful, and nearly certainly exaggerated for uninjured occupants or those with minor injuries. Using this information could grossly distort the estimates of airbag effectiveness. Therefore, we ignored belt use information. Thus, the previous effectiveness estimates are relative to a mix of belt users and non-users as present in accident involved cars during the years the data were collected.

The *fourth approach* uses only information on killed drivers. Since reported belt use for killed drivers is probably more reliable than for other drivers, using this approach we made separate estimates of airbag effectiveness for belted and unbelted drivers, and relative to belted and to unbelted drivers.

2. The data

Accident data came from the FARS data files for the years 1990 to 1993. For car registration data needed in the first approach, we used R.L. Polk data; the National Vehicle Population Profiles for 1990 to 1993, and the New Car Registration Files for 1987 to 1993.

3. The analyses performed

The *first approach* encountered some technical difficulties; complete matching of the information from the three files was not possible. The only factor that could be included in the analysis was vehicle weight according to which cars were classified.

The *second approach* allowed some control for the ages of the two drivers, distinguishing three age groups, and for the mass ratio of the two cars, distinguishing three classes. Also, front-front, front-left, and front-other impacts could be distinguished. However, for certain combinations of factors case numbers were low, and for some no cases appeared. To deal with factor combinations with low case numbers, a pseudo-Bayesian technique was used (also in the two following approaches). For factor combinations with no cases, of course, no estimates could be made.

The *third approach* allowed control for impact types (frontal/other), crash type, car weight, and driver age, separately and to some extent for combinations of these factors.

The *fourth approach* allowed control for impact point (down to the 12 clock positions, and non-collisions), car weight, driver age, speed limit, separately and in some combinations. In addition, some analyses distinguished users and non-users of seatbelts, because only killed drivers were included and belt use information for them may be more reliable.

4. The findings

We found that airbag effects differ widely among car classes and crash types. A single, overall estimate cannot realistically reflect their effects. Therefore, we present first estimates of overall effects, then of effects in frontal impacts for which airbags are designed, and finally discuss some special aspects.

4.1 Effects in all impacts combined

For the overall effect of airbags, combining all impact directions, the four approaches give quite different estimates. *Approaches three* and *four* give similar results: an apparent increase of 10% or 40% in the fatality risk for drivers of lightweight (up to 2,450 lbs) cars, reductions of 5% or 10% for drivers of midweight (2,450 to 3,450 lbs.) cars, and reductions of 10% or 25% for drivers of heavy cars; only the latter figure of 25% is statistically significantly different from zero.
The *second approach* using only car-car collisions gives in some sense the opposite results; in high delta-v involvements (mainly light cars, but also midweight cars in collisions with heavy cars) the risk is reduced by 60%, in involvements with medium delta-v (where cars are of comparable weights) the reduction is 45%, and in involvements with low delta-v (where a heavier car collides with a lighter car) the effect is only 20%. With the exception of this last figure, the reductions are significantly greater than zero.

The *first approach* shows still another pattern: about equal reductions of 40 to 50% for light and heavy, and more for midweight cars. This approach requires the strongest assumptions, and also encountered the most serious data problems. Therefore, the estimates may be considered questionable.

These values are shown in Figure 7-1 in the body of the report. Estimates from approach one are indicated by "A," approach two by "D," approach three by "C," and approach four by "B."

4.2 Effects in frontal impacts

The more detailed analyses show that airbags have an effect only in frontal impacts for which they are designed. The frontal impacts, the findings are more consistent than for all impacts combined. They are shown in Figures 1 and 2. The *first approach* does not allow one to estimate effectiveness by impact types without further assumptions, which was therefore not done. The *third* and *fourth approach* (B and C in Figure 1), and the *second approach* applied to front-front collisions (Figure 2) give a fairly consistent picture. There is no risk reductions for drivers of light cars, a reduction around 15% to 45% for midweight cars, and a reduction of up to 55% for heavier cars--though in some crash types there appears to be no reduction.

For cars frontally impacting another car elsewhere than at the front, the effectiveness seems to be independent of car weight, and in the 55% to 75% range (Figure 2).

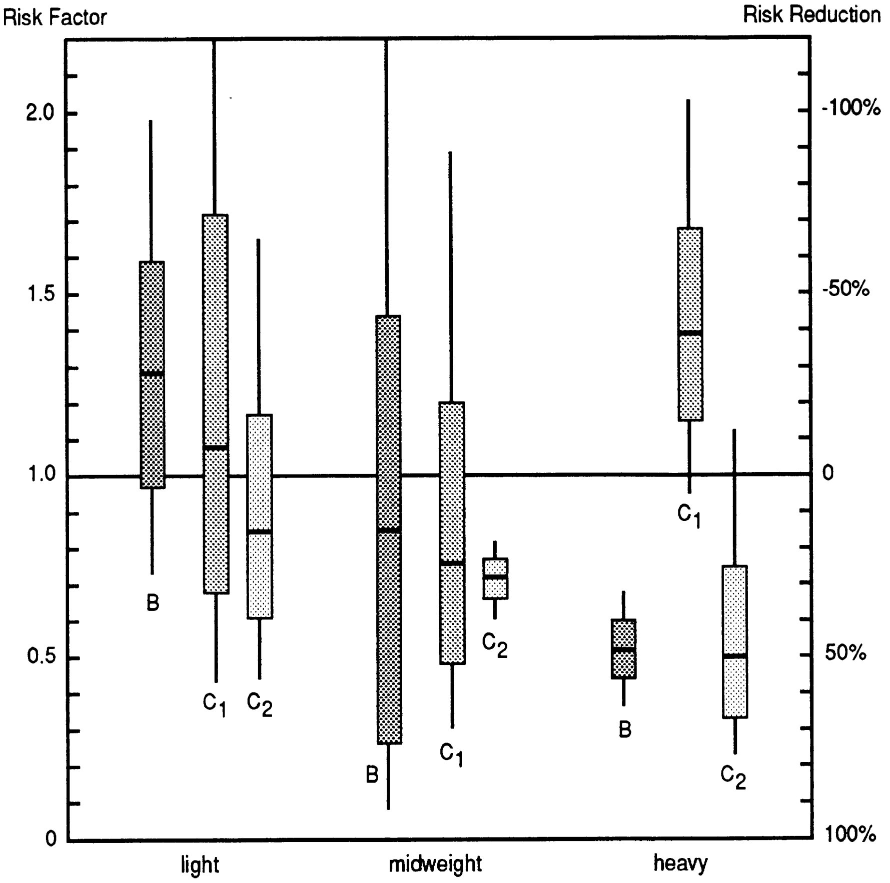

Figure 1a. Risk factors and risk reductions by driver side airbags, in frontal impacts. "C.1" and "C.2" are the estimates obtained by approach 3 for single vehicle, and for other accidents. "B" is the estimate obtained by approach 4. "Boxes" show the ± sigma range covering the true value with a probability of about 2/3. "Whiskers" show the ± 2 sigma range covering it with a probability of about 95%.

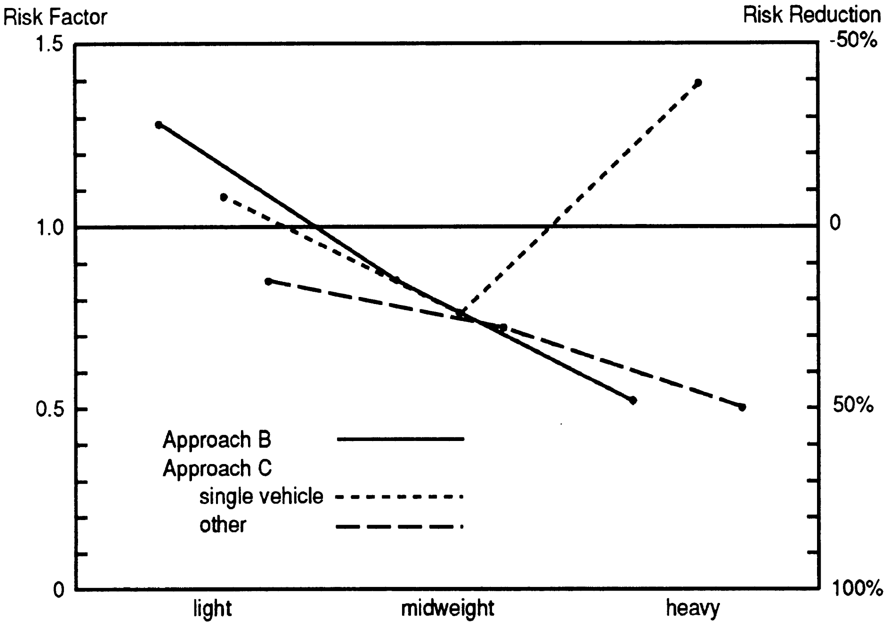

Figure 1b. Risk factors and risk reduction factors as in Figure 1a. Points are connected across car classes to show trends with car weight.

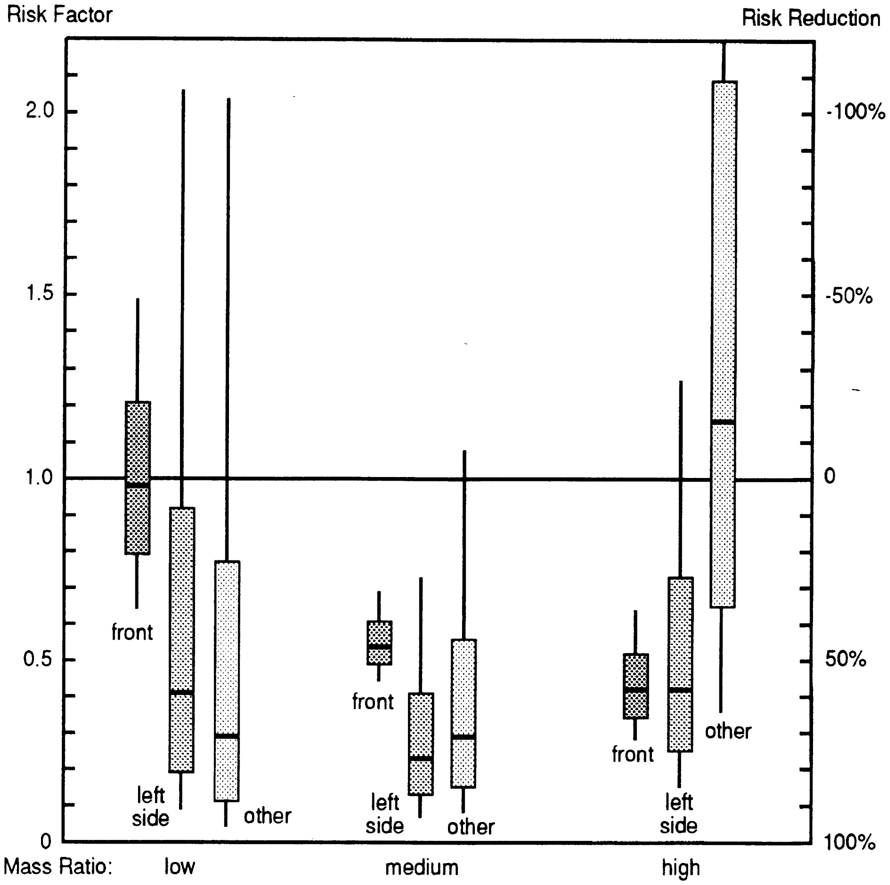

Figure 2a. Risk factors and risk reduction by driver side airbags, for frontally impacting cars, by type of impact on the other car, and mass ratio of the two cars. "Boxes" show the ± sigma range which covers the true value with a probability of about 2/3. "Whiskers" show the ± 2 sigma range which covers it with a probability of about 95%.

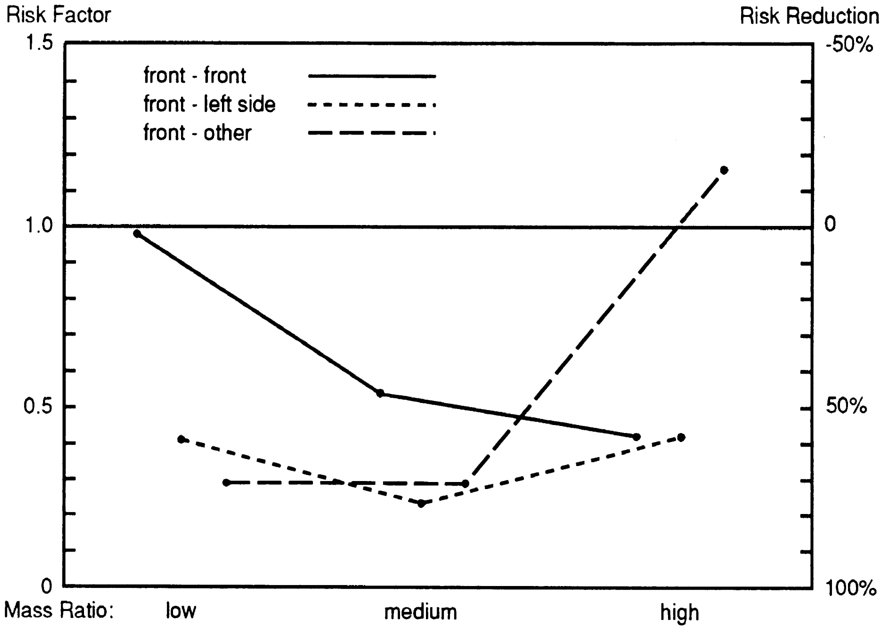

Figure 2b. Risk factors and risk reduction as in Figure 2a. Points are connected across mass ratios to show trends with mass ratio.

4.3 Special aspects

Classifying impacts more finely shows that most of the effect in frontal impact occurs in 12 o'clock impacts, and much less, if any, in 11 o'clock and 1 o'clock impacts.

Distinguishing three age groups of drivers (up to 25, over 25 to 45, and over 45 years) showed no difference in effectiveness between the groups. This, however, does not rule out potential differences for much older drivers.

Estimates for right-front-seat occupants had very low statistical precision because relatively few cars had passenger-side airbags (among them very few light cars), and relatively few cars in crashes have a right-front-seat passenger. Approach one showed no effect, there were too few cases to apply *approaches two and three*, and *approach four* showed a significant reduction of 75% for midweight cars in frontal impacts and a non-significant increase for heavy cars.

Approach four allows one to separately estimate the effects of airbags for belted and for unbelted drivers, and to compare the effects of airbags and of seatbelts--if one is willing to assume that neither airbags or belts reduce the fatality risk in 9 o'clock impacts because the fatal injury is caused by compartment intrusion.

In frontal impacts, airbags reduce the fatality risk of unbelted drivers by 11%, and that of belted drivers by 30%. When distinguishing cars by weight, an interesting pattern appears; in heavy cars, the effects for belted (40%) and for unbelted (31%) drivers do not significantly differ. For midweight cars, airbags show no effect for unbelted drivers, but still a 13% risk reduction for belted drivers. For drivers of light cars, airbags show --not significant--risk increases for belted, and for unbelted drivers.

These estimates show that airbags have a substantial effect as "supplemental restraints." To estimate their effects as "passive protection"--as which they were once advocated--the fatality risks of unbelted drivers in airbag cars were compared with those of belted drivers in nonairbag cars. The result was that in heavy cars airbags reduced the fatality risk in frontal impacts by 20% (not statistically significant), compared with seatbelts. The unbelted driver of a midweight car with an airbag faced a 40% higher risk than a belted driver of a comparable nonairbag car, and in light cars the risk was nearly 90% higher. In noncollision accidents, the risk for an unbelted driver of an airbag car was twice, four and eight times higher than that of a belted driver of a nonairbag car, for heavy, midweight, and light cars, respectively. Clearly, airbags are no substitute for seatbelts.

4.4 Brief summary

To sum up, airbag effectiveness depends on several factors. It is much greater if seatbelts are used than if they are not used. As to be expected, the effect appears mainly in frontal impacts, and primarily in 12 o'clock impacts. For light cars--except if impacting another car other than at front--airbags seem to have no effect, possibly they may even increase the fatality risk. For midweight and heavy cars, they reduce the driver fatality risk in frontal impacts by between 10% to 50%. If impacting another car elsewhere than at front, for all car weight classes airbags appear to reduce the driver fatality risk by 50% to 75%.

Estimates of effects for right-front-seat occupants are very uncertain.

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1. Introduction

To estimate how much airbags reduce car occupants' fatality and injury risks in crashes, compared with no restraint, or other restraints, one needs very specific information. One needs a data base of crash involved vehicles providing information on occupant injury severity (including uninjured occupants), a good measure of crash severity for the vehicle (e.g., delta-v), and information on other factors influencing the fatality and injury risk. Such information is currently available only from the National Accident Sampling System (NASS), but the case numbers are too small, and even in this data base information on delta-v is frequently missing. Therefore, estimates have to be based on less than ideal data bases, and are restricted to certain types of crashes, or depend critically on certain assumptions.

This study is based on the Fatal Accident Reporting System (FARS), which contains information on practically all fatal motor-vehicle accidents in the US. To be included in FARS, at least one person has to be killed in the accident. Therefore, this study is restricted to fatality risks.

Since FARS contains only a very limited and not representative selection of uninjured car occupants, fatality risk in crashes cannot be directly estimated. Additional data or assumptions are needed. We used several alternative approaches with very different assumptions.

The first approach used driver (and in a separate analysis also right front-seat occupant) fatality rates per registered vehicle for each make/series. Registration data were obtained from the R.L. Polk data files residing in NHTSA's computer. To obtain sufficient case numbers we did not go to the make/series level, but distinguished cars only by weight (six classes).

Fatality rates per registered vehicle reflect more than fatality rates in crashes, because crash involvement per registered vehicle differs between car makes/series, presumably due to differences in use and users. A rigorous accounting for such influences is not possible, but we tried to at least partially do it by including factors known to be related to accident and fatality risk in the analysis.

The second approach requires the least assumptions, but the results apply only to special risk situations. It uses collisions between two cars, in which at least one driver is killed. This allows estimation of relative fatality risk. An important characteristic is that delta-v is implicitly controlled for if the mass ratio of the cars is included in the analysis. In addition, we used collision configuration and the drivers' ages, both of which have a strong influence on the fatality risks. Disadvantages of this approach are the smaller case numbers, and that the results apply only to collisions between cars.

The third approach uses cars with a driver and a right-front-seat occupant, comparing cars with a driver-side-only airbag with those without airbags. This allows comparison of the fatality risks of the driver and right front-seat occupant. Accounting for confounding factors is limited; one can control for the effect of a person's age on the fatality risk, but not for delta-v, which is unknown. Disadvantages are small case numbers, and that driving situations where at least two people are in a car may differ from those when only the driver is present.

The fourth approach is based on the strongest assumption, that airbags have no effect in certain types of crashes; specifically in 9 o'clock impacts for drivers, and 3 o'clock impacts for right front seat occupants. Even if this is not completely true, the estimates show the relative effectiveness in other impacts compared with those where one can expect the smallest, if any, effects. If one can assume that airbags do not increase the fatality risk, except in "freak" accidents, one obtains conservative estimates. However, one must consider the possibility that airbags might induce some drivers not to use belts, and thus increase the risk of ejection.

A difficult problem is to separately evaluate the effects of airbags relative to belted and unbelted drivers. In principle, this can be done with the information given in FARS. However, the information on belt use is considered questionable at best, and unreliable for surviving occupants. Thus, any analysis distinguishing belted and unbelted drivers must be considered dubious.[1] What can be done with more confidence is to estimate the effectiveness relative to the current mix of belt users and nonusers.

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[1] D. Mela has illustrated how much overreporting of belt use by uninjured occupants can distort estimates of belt effectiveness ("How accurate are seatbelt statistics?" Highway Safety Highlights, Vol. 7, #2, April 1974). The same holds for interactions of belts and airbags.

2. Data Bases

All analyses are based on data from the Fatal Accident Reporting System (FARS) for accidents during the calendar years 1990 to 1993. The first step was to select accidents that involved at least one passenger car of the model years 1987 and more recent (1989 and more recent for the analyses of passenger side air bags), the model years when airbags were available in more than negligible numbers. Depending on the analysis, further selections were made.

Selected data from the person, vehicle and accident files were merged. Also, a special file was created which kept the information on both cars and their drivers together, for collisions between two passenger cars of the selected model years.

Less than 1 percent of the passenger cars in FARS had a missing model year. The percentage of cars of 1987 and later model years increased from 30 to 47 over the calendar years 1990 to 93 (14 to 32 for cars of model year 1989 and later). Thus, at most 3% of the eligible study cars could have been lost due to a missing model year.

A computer program developed by NHTSA, AOPVIN, was used to determine airbag availability for the study cars of 1987 and later model years. This program could determine airbag availability for 97% - 98% of the entered cars.

Larger losses, however, occurred where cars were stratified by weight. Weight was missing for between 7 and 14% of the case vehicles, with an average of 10%. Further losses of cars occurred when information needed for specific analyses was missing; these losses, however, were relatively small.

It would be of great interest to compare airbag effectiveness with seatbelt effectiveness. FARS provides police-reported information on belt use by vehicle occupants. The reliability of this information, however, is generally doubted. Only in cases of severe and fatal injury is the investigating police officer likely to observe belt use. In other cases he will usually report what he or she is told by the people involved. It is well known that self-reported belt use is exaggerated, even in situations where there is no threat of a penalty for non-use, and even more so after belt-use laws went into effect. In some cases there is physical evidence for use or non-use of belts, so that an officer could infer belt use. However, considering that a fatal accident requires immediate actions to secure the victims and the scene, and investigating responsibility for the accident because of the potential for criminal charges for homicide, investigating belt use, especially by a survivor, has low priority. Therefore, belt use information cannot reliably be used without in-depth investigation of its reliability. At most belt use information for killed persons may be considered less biased.

The analysis of fatality rates used, in addition to fatality data, car registration data from the R.L. Polk data files residing on NHTSA's computer. There are two files which had to be merged for this study: the National Vehicle Population Profile (NVPP), and the

New Car Registration File. The first gives a "snapshot" of cars registered at the middle of the calendar year. For each make, series, body style, model year (and additional classifications) it gives the number of registered cars. Of the other information, we used only weight, which was used in all of our analyses. It contains no information on restraint type.

The New Car Registration File gives, for each month in a calendar year, the number of new car registrations, by make, series, body style, restraint type (and several other classifiers). It does not contain information on car weight.

These files had to be merged for two reasons: 1) to get more precise exposure information for cars of the current and subsequent model year, and 2) to combine information on weight and restraint type for the various car classes.

For older cars one can reasonably assume--if attrition is uniform over the calendar year--that the number of cars registered at mid-year represents the overall number of car years of actual registration during the year. Cars of the subsequent model year (e.g., 1993 model cars sold in the calendar year 1992) are used during part of that year, but not represented in the NVPP. The actual registration months for these vehicles had to be obtained from the New Car Registration File. Similarly, for cars of the 1993 model year sold in 1993, the number registered at mid-year does not reflect the number of actually registered car years. Again, one has to use the New Car Registration File to obtain the actual number of registered car months.

Thus, data from the NVPP for 1990 to 1993, and from the New Car Registration Files for 1987 to 1993 (1994 could not be used, because 1994 NVPP data would be needed to assign weight to the cars in the 1993 New Car Registration Files) had to be combined.

One obstacle was that the NVPP has different make codes than the New Car Registration File. Also, there is no one-to-one correspondence between these codes. The series codes are largely the same, although there are some that had no match in the other file. With careful attention to the details, between 98.2% and 99.8% of the eligible cars in the NVPP could be matched with cars in the New Car Registration File. On the other hand, many cars in the New Car Registration File could not be matched with cars in the NVPP; between 1.9% and 3.5% of the cars in the NVPP.

Somewhat disturbing is that eligibility of cars could not be very reliably determined; the number of eligible cars increased from 30% to 48% over the calendar years 1990 to 1993, but the number of cars with missing model year increased from 10% to 12% over the same time. Thus, the number of cars with missing model year is about one quarter to one third of the eligible cars. Depending on whether the missing cars are randomly distributed or whether they have certain characteristics, this could have a major impact on registration-based fatality rates.

3. Fatality Rates Per Registered Vehicle-Year

3.1 General considerations

To compare car models in terms of accident risk and crashworthiness, or to estimate the effects of safety features, occupant fatality rates per registered vehicle are sometimes used. To address our question, fatality rates for car models with, and without airbags would be compared. If airbags were randomly installed in cars (even better, if in addition their owners did not know whether an airbag was installed), a valid comparison would be simple. In reality, cars with and without airbags differ in many respects. Initially, only large, heavy, expensive cars had airbags. These cars had, even without airbags, lower occupant fatality risks than smaller and lighter cars. Therefore, a simple comparison would be grossly misleading. In addition, in many models an airbag was an option to be selected at additional cost by the buyer. It is highly likely that these owners differ in their attitudes toward risk from others.

There are many other confounding factors. Annual vehicle miles of travel--which are the simplest, though crude, measure of exposure to accidents--differ among vehicles and change with vehicle age. The type of accident vehicles are involved in also changes with vehicle age, as does the risk of serious or fatal driver injury per crash. Fatality rates per registered vehicle year have declined over the years. Even if one compares vehicles of one class, of the same age, in one calendar year, noticeable differences remain. The data published by the Highway Loss Data Institute (HLDI) on injury claims per insured vehicle year show consistent differences between two-door, four-door, and station-wagon body styles of the same car model. There is no physical reason for this; there must be subtle differences in users and uses.

In the case of the passenger airbag, another complication arises; one does not know how often a right front passenger is present. The presence of a passenger is likely to be related to car size, and to driver characteristics.

In principle, one can try to account for such confounding factors by statistical modeling. This would require stratification of accidents and registration data according to the relevant factors, to calculate fatality rates for each combination of such factors, and model these rates in relation to the factors.

In our case, this is possible only to a limited extent. While accident data can be stratified according to many factors, the registration data can be stratified only according to vehicle factors. Stratification according to driver and use factors is not possible. One can try to account for driver and use factors by the following approach. One stratifies accident and registration data according to vehicle characteristics into a large number of "cells." Then, one calculates averages of driver and use factors (e.g., driver age) for each of these cells from the accident-involved cars. If these averages vary among the cells, one can use them as independent variables in statistical models explaining the fatality rates in the cells. While this approach sometimes gives models which fit the data well, their interpretation is difficult because the approach makes several implied assumptions.

In sum, our analyses of fatality rates must be considered as speculative, and the results interpreted with great caution.

3.2 Data

From the R.L. Polk data bases, for the calendar years 1990 to 1993, registration years for passenger cars of model years 1987 through 1993 were obtained by calendar year, model year, airbag availability (separate for drivers and right front seat passengers) and car class, mini-compact under 1,950 lbs., sub-compact 1,950 to 2,449 lbs., compact 2,450 to 2,949 lbs., intermediate 2,950 to 3,449 lbs., full-size 3,450 to 3,949 lbs. and large 3,950 or more (NHTSA's classification). In order to compare airbag cars with otherwise similar cars, only combinations of calendar year, model year and car class were used for which both airbag and nonairbag cars were registered (a few cases with fewer than 1,000 registered car years were dropped; they appeared to be miscodings). The resulting files contained 131 million vehicle years of nonairbag cars, and 29 million years of driver airbag cars (the corresponding figures for passenger side airbags are 34 and 2 million).

From the FARS files, car involvements where the driver (or the right front seat occupant) was killed, were selected for the same combinations of calendar years, model years and car class. There were 13,327 drivers killed in nonairbag cars, 2,292 in airbag cars (for right front seat passengers, the numbers are 963 and 57).

3.3 Drivers

For the combinations of the four calendar years, seven model years, and four weight classes, driver fatality rates per 100,000 registered vehicles were calculated for nonairbag, and for airbag cars. Table 3.3-1 show these rates for the combinations with both airbag and nonairbag cars. Combinations without airbag cars were omitted, because their inclusion could have biased the results.

TABLE 3.3-1. Passenger Car Driver Fatality Rates Per 100,000 Registered Vehicle Year, by Calendar Year, Model Year and Car Weight. The first entry is for nonairbag, the second for airbag cars.

MODEL YEAR	CALENDAR YEAR			
	1990	1991	1992	1993
	Minicompact (<1,950 lbs.)			
1990	--	22.7, 0.0	16.5, 0.0	19.6, 0.0
	Subcompacts (1,950-2,449 lbs.)			
1989	16.3, 0.0	13.6, 0.0	12.0, 0.0	12.0, 0.0
90	18.6, 22.7	14.7, 20.8	12.5, 12.5	11.5, 7.3
91		16.9, 19.2	15.1, 12.5	13.9, 19.2
92			15.4, 7.0	9.6, 7.0
93				11.3, 0.6
	Compact (2,450-2,949 lbs.)			
1987	12.3, 17.2	10.4, 6.8	11.3, 10.5	12.7, 0.0
88	10.2, 4.2	9.2, 7.2	9.0, 4.4	10.3, 4.5
89	10.9, 10.4	10.4, 8.6	9.8, 11.4	10.4, 12.3
90	9.3, 21.8	8.1, 15.5	7.1, 13.8	7.0, 18.6
91		9.6, 13.8	7.5, 10.8	7.0, 13.0
92			18.3, 12.1	11.2, 9.8
93				8.2, 8.2
	Intermediate (2,950-3,449 lbs.)			
1987	10.4, 11.3	9.6, 2.2	10.3, 2.3	10.3, 0.0
88	11.0, 11.3	10.5, 7.8	10.2, 7.9	10.7, 4.0
89	11.2, 3.6	9.8, 2.2	8.7, 0.0	8.8, 3.0
90	12.8, 12.6	8.4, 9.4	8.5, 7.6	8.6, 6.7
91		8.5, 11.8	7.2, 9.8	6.3, 8.0
92			10.3, 6.8	9.8, 5.0
93				7.2, 5.4
	Full size (3,450-3,949 lbs.			
1987	8.1, 2.4	8.5, 16.8	7.8, 2.4	9.2, 5.0
88	7.0, 9.1	8.7, 5.5	7.6, 0.0	8.6, 1.9
89	6.0, 5.2	9.0, 4.2	7.8, 1.7	4.9, 4.4
90	8.1, 6.8	5.4, 5.5	6.5, 4.0	3.7, 5.8
91		8.8, 5.2	7.9, 4.8	4.2, 5.3
92			10.8, 7.5	12.9, 7.4
93				7.9, 3.5
	Large (≥ 3, 950 lbs.)			
1987	7.0, 0.0	6.0, 0.0	6.2, 0.0	9.4, 0.0
88	6.5, 0.0	4.7, 0.0	4.8, 0.0	5.9, 0.0
89	6.7, 0.0	7.2, 0.0	3.3, 0.0	10.3, 0.0
90	0.0, 7.8	5.4, 5.0	12.5, 1.8	7.0, 6.5
91		9.5, 7.1	13.5, 2.8	16.8, 5.8
92			8.6, 10.8	0.0, 5.6

For each of these 208 groups ("cells"), the percentages of fatalities occurring at day/night, on roads with three speed limit ranges, in single/multi-vehicle accidents, and the percentages of four driver age classes, of male/female drivers, and of drivers using and not using seatbelts were calculated. Statistical models were developed trying to "explain" the fatality rates as functions of these variables together with categorical variables for calendar year, car age, car mass and airbag availability. Also, separate models for car classes were tried.

Though some statistically "significant" models were found, they were not satisfactory, because they were very "fragile"; omitting one or a few variables could change the coefficients of others dramatically. This is not surprising because many of the variables are correlated. We only retained 24 models, for the 12 car classes combined with airbag availability, using calendar year and vehicle age as independent variables, though only a few of these were statistically "significant." The reason is that changes in fatality rates over time are well established, as is the pattern that fatality rates are high for new cars, decline until a car is a few years old, and then increase with age. Though not always showing these patterns clearly, the data were compatible with them.

The risk factors varied very widely between the cells in Table 3.3-1. Therefore, instead of averaging the factors for the cells of each car class, the rates for cars without, and separately those for cars with airbags were averaged, and the ratio of the averages calculated as an estimate of the risk factor for the car class. The errors of the factors were calculated from standard formulas; correlations between rates for airbag and for nonairbag cars were so small that their effect could be neglected. In the case of mini-compacts, the formulas would have given an error estimate of zero. To provide some indication of the magnitude of the error a speculative estimate was made. It is the error which would have resulted for a factor of 1, using the actual error for the nonairbag cars, and assuming the same error for the airbag cars, inflated according to their much lower number of registration years. This error estimate is probably an overestimate.

Averaging the rates for combinations of model years and calendar years had the effect providing some degree of "standardization" (see Appendix A-2).

Figure 3.3-1 shows the resulting risk factors. Estimates are shown by bold horizontal lines, the ± 1 sigma range is indicated by "boxes," and the ± 2 sigma range by "whisker" extending from the boxes. Factors with errors are shown for the fine, and for the coarse classification; for the overall average no error is shown.

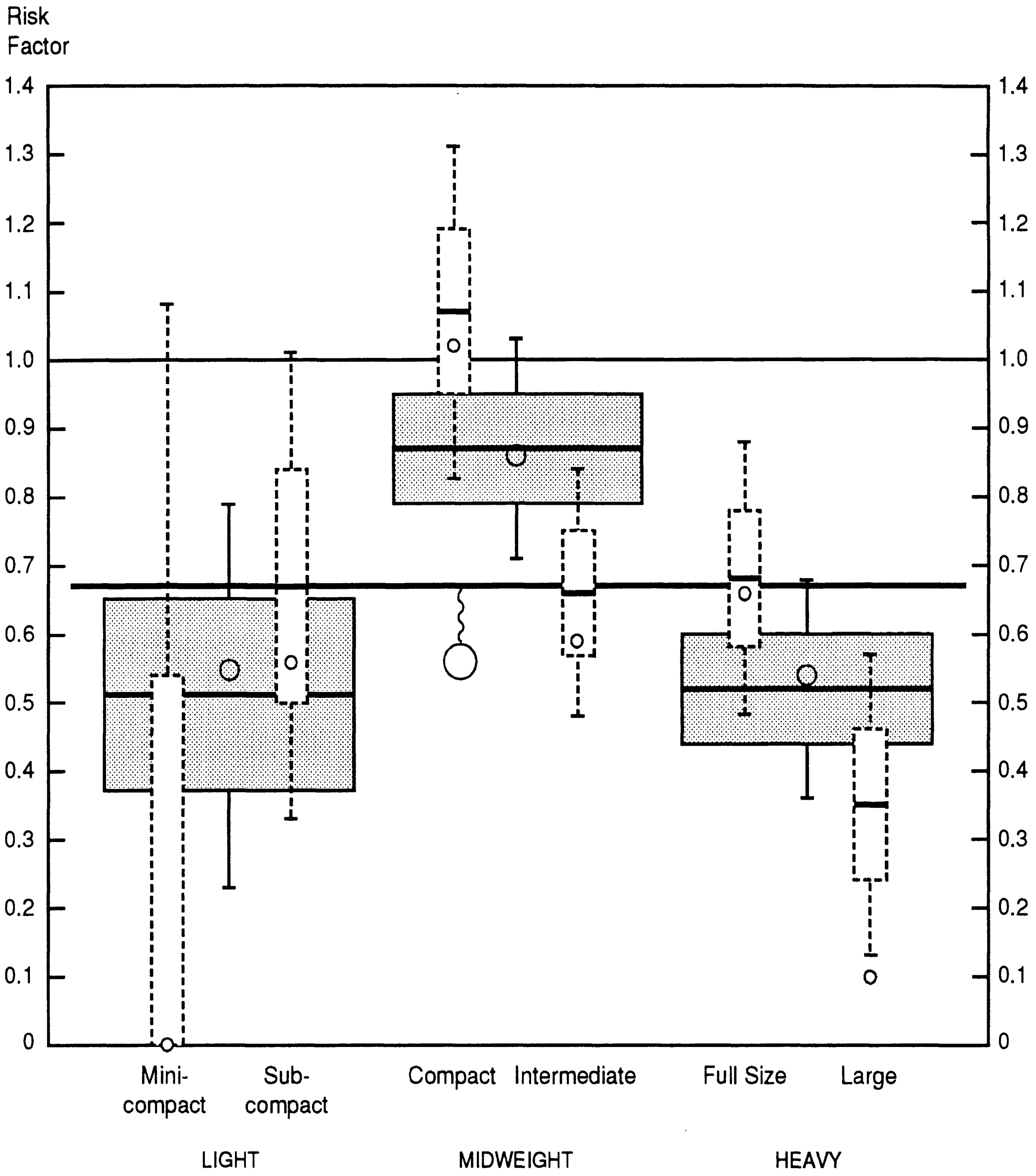

Figure 3.3-1. Risk factors for drivers based on fatality rates per registered vehicle year, by car class, fine and coarse classification. "Boxes" show the ± 1 sigma range, "whiskers" extend to the ± 2 sigma range. Factors are calculated from unweighted means of rates for combinations of calendar years and model years. Circles show standardized factors. The error estimate for minicompacts (*) is speculative (see text).

The circles show values that are standardized in a different way. For each calendar-year/model-year cell, the number of deaths that would have occurred in the nonairbag cars if they had had airbags was calculated using the airbag car rate. These estimates were added within each car class. Divided by the actual counts, they gave risk factors standardized to the distribution of registered cars over calendar and model years among the nonairbag cars. With two exceptions, the circles are close to the corresponding bold lines.

The pattern appearing in Figure 3.3-1 is surprising; the risk factors in light and heavy cars are about equal, corresponding to a risk reduction of nearly 50%, but the reduction for midweight cars is much smaller, only about 15%. This is mainly due to the lack of any reduction for compact cars; for intermediates the risk factor is close to those for light and heavy cars.

While it is conceivable that some cars are so crashworthy, and that their drivers use belts more than drivers of other cars, so that airbags would offer only little additional protection, it appears unlikely that this holds for an entire class of cars. Rather, one should suspect the effect of confounding factors. For instance, it appears likely that drivers with high annual mileage prefer cars of a certain class, and that because of their high exposure they are the first to select cars with airbags. In such a situation, the higher accident rates due to high exposure could compensate the effect of the airbags. While this is a speculative hypothesis, the implausible pattern should at least warn against relying on fatality rates based on registered vehicle year when studying crashworthiness and related safety measures.

Figure 3.3-2 shows a similar analysis, however weighting each fatality rate with the number of registered vehicle years, when averaging. This is equivalent to dividing the total deaths for one vehicle class by the total registration years; this procedure, however, would not allow calculation of errors for the risk factors. One effect is that fatality rates for airbag cars are largely based on more recent calendar and model years, while those for nonairbag cars are largely based on earlier calendar and model years. That can lead to biases.

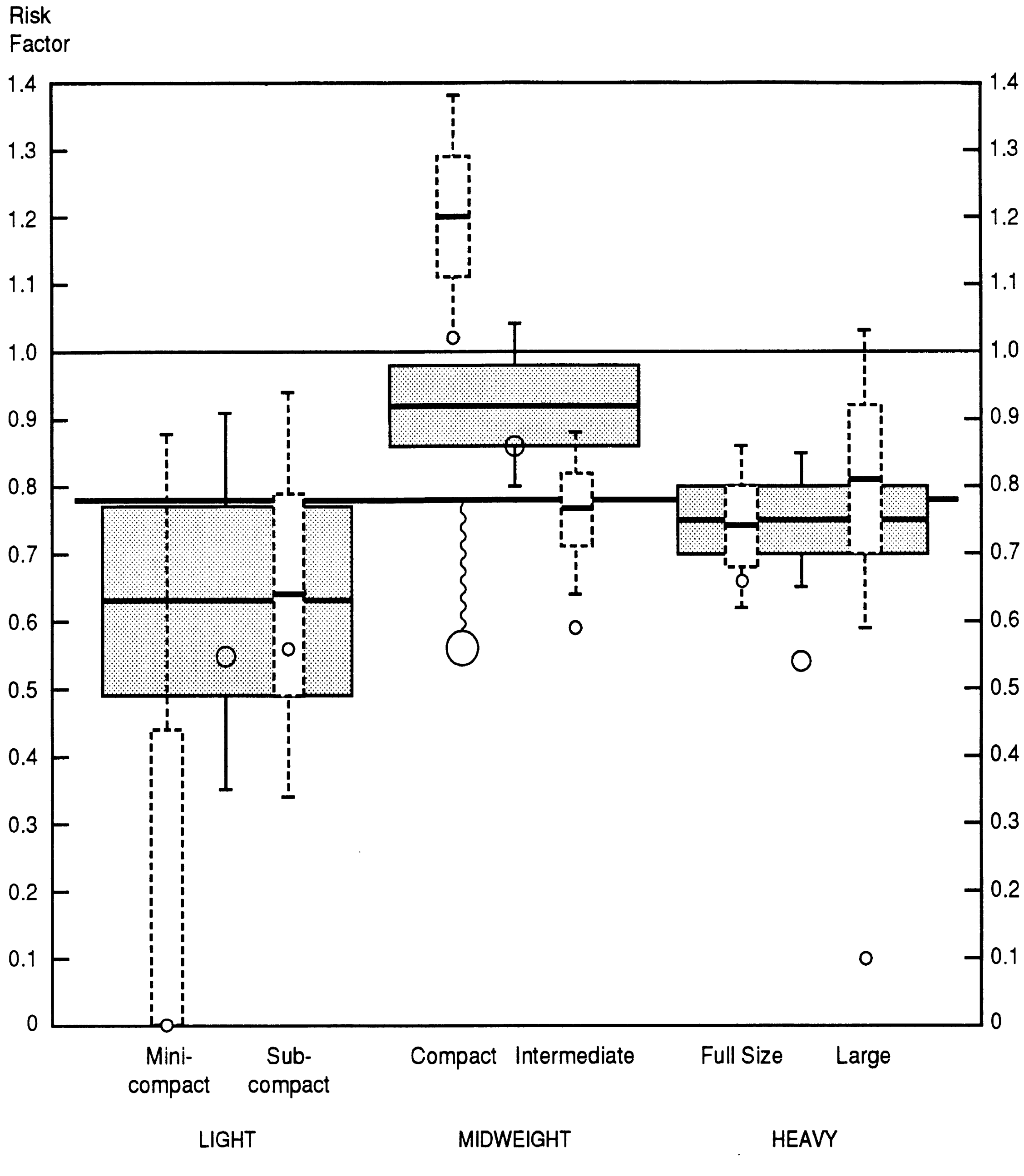

Figure 3.3-2. Risk factors for drivers based on fatality rates per registered vehicle year, by car class, fine and coarse classification. "Boxes" show the ± 1 sigma range, "whiskers" extend to the ± 2 sigma range. Factors are calculated from means of rates for combinations of calendar year, and model year, weighted by registered vehicle years. Circles--the same as in Figure 3.3-1--show standardized factors. The error estimate for minicompacts (*) is speculative (see text).

The overall pattern is similar to that of Figure 3.3-1; however, the risk reductions are smaller. For compacts, the factor is significantly larger than 1. This should even more caution against relying on an analysis of registration based fatality rates.

As already mentioned, among the regression models fitted some used, within each coarse car class, rates per model year and calendar year combination as dependent variables, and categorical variables for calendar year and model year as independent variables; they were so structured that the intercept represented the fitted values for 1992 cars in 1993 accidents. From these rates, risk factors were calculated. Table 3.3-2 show them, weighting all data points equally, and weighting them proportional to the registered vehicle years on which they are based.

TABLE 3.3-2. Risk Factors for Drivers by Car Class, Based on Regression Models Which Implicitly Standardize to 1992 Model Cars in Accidents in 1993. Standard errors are in parenthesis. In the "unweighted" row, rates for all model-year/calendar-year combinations are weighted equally, in the "weighted" row, they are weighted according to registered vehicle years.

		CAR CLASS	
MODEL	**LIGHT**	**MIDWEIGHT**	**HEAVY**
Unweighted	0.64(.29)	1.06(.26)	0.52(.17)
Weighted	0.60(.24)	0.91(.13)	0.96(.22)

Very grossly, the patterns in Table 3.3-2 are similar to those in Figures 3.3-1 and 3.3-2. However, there are some differences. In the unweighted model, the factor for mid-size cars is larger than in the weighted model, and in the weighted model there is practically no reduction for heavy cars.

Considering our doubts about the practical relevance of fatality rates per registered vehicle year, these extensive analyses may not appear justified. However, we think that they were worthwhile because they demonstrate how much differing numerical results can be obtained using different techniques none of which appear more appropriate than the others.

3.4 Right front seat occupants

Airbags for right-front-seat occupants became available with the 1989 model year. In 1989 only full size and large cars had them, in 1990 also intermediate cars offered them. Compacts with passenger airbag became available with the 1990 model year. No subcompacts and minicompacts had them.

Table 3.4-1 shows the right front seat occupant fatality rates per 100,000 registered vehicle years, by calendar year, model year and car class, for cars without and with airbags. Not shown are the figures for compacts--only 1993 models in 1993 accidents--

3.3 for the nonairbag, 0.0 for the airbag cars. However, they are included in calculations for "all" cars.

TABLE 3.4-1. Right Front Seat Passenger Car Occupant Fatality Rates Per 100,000 Registered Vehicle Years, by Calendar Year, Model Year and Car Weight. The first entry is for cars without, the second for cars with passenger airbag.

MODEL YEAR	CALENDAR YEAR			
	1990	**1991**	**1992**	**1993**
	Intermediate (2,950-3,449 lbs)			
1990	4.4, 0.0	3.0, 15.2	3.3, 0.0	3.3, 0.0
91		3.8, 0.0	3.3, 29.3	2.9, 0.0
92			3.3, 3.8	2, 4, 1.0
93				2.8, 2.1
	Full size (3,450-3,949 lbs.)			
1989	1.9, 0.0	1.9, 1.8	1.9, 1.9	2.1, 0.0
90	2.4, 2.9	1.8, 8.6	0.9, 4.5	1.7, 6.7
91		2.2, 0.0	2.6, 7.3	2.1, 7.2
92			3.0, 0.0	3.6, 1.5
93				1.3, 1.1
	Large (≥ 3,950 lbs.)			
1989	1.5, 0.0	3.5, 0.0	1.6, 0.0	6.3, 0.0
90	5.5, 4.5	3.1, 3.2	0.7, 1.1	2.0, 4.5
91		4.0, 0.0	1.1, 7.9	2.7, 0.0
92			1.6, 7.4	3.3, 1.6
93				3.6, 19.6

Table 3.4-2 shows the average risk factors by car class, calculated as for drivers in section 3.3. Surprisingly, the data show no reductions of the fatality rate. This does not necessarily mean that airbags have no effect on the right-front-seat occupant fatality risk. One confounding factor which cannot be accounted for with the available data is the presence or absence of a right-front-seat occupant; without a right-front-seat occupant, no right front seat occupant fatality can occur. If owners of cars who frequently travel with a right front seat occupant should buy passenger side airbags because of this, while owners of cars who rarely travel with a right front seat occupant do not, the result would be a higher right front seat occupant fatality rate for cars with a passenger airbag than for those without it. Therefore, no conclusion on the effects of passenger side airbags should be drawn from these data.

TABLE 3.4-2. Risk Factors for Right Front Seat Passengers Based on Fatality Rates Per Registered Vehicle Year, by Car Class. Standard errors are in parentheses. In the "unweighted" row, rates for all model-year/calendar-year combinations are weighted equally, in the "weighted" row, they are weighted according to registered vehicle years.

	CAR CLASS			
MODEL	**INTERMEDIATE**	**FULL SIZE**	**LARGE**	**ALL**
Unweighted	1.58(.95)	1.47(.42)	1.24(.53)	1.36(.37)
Weighted	0.76(.33)	1.06(.32)	1.70(.56)	1.02(.22)

4. Car-Car Collisions

4.1 Approach

Collisions between cars allow one to compare occupant fatality risks without requiring an exposure measure. While this is an advantage, disadvantages are that they cover only part of the collisions where an airbag can have an effect, and that the effect in car-car collisions may differ from that in collisions with other types of vehicles, collisions with fixed objects, or overturns.

A collision between two cars appears in FARS only if at least one of their occupants is killed. This occurrence depends on the probability of an occupant being killed, which often differs between the two cars, on the occupant's seating position, the occupant's age (and possibly sex), and vehicle characteristics and crash conditions. To simplify the analysis, only drivers were considered; the number of cars with passenger side airbag was too small to allow a meaningful analysis, especially since often no right-front-seat occupant is present. Cases where no driver was killed (which appear in FARS if another occupant is killed) were excluded. Even if the data are restricted to cases where at least one driver is killed, the analysis requires some care. Appendix A-1 discusses the details.

Empirically, delta-v is the best single predictor of occupant fatality risk. It must be controlled for when estimating the effects of airbags, especially because cars initially equipped with airbags were heavier, and therefore experienced lower delta-v values. Delta-v can be computed from the masses of the two cars, which is available in FARS, and the closing speed which is not available. The speed limit at the accident site may be considered as a proxy (in NASS data, it is correlated with delta-v). However, under certain conditions the ratio of two risks may depend only on the ratio of the two delta-v, and therefore not on the velocities (Appendix A-3).

Another important factor is driver age. Older drivers suffer more severe injuries and are more likely to die than younger drivers in comparable crashes. If airbag cars were initially more likely to be used by older drivers, this could confound, at least partially, an effect of an airbag. Also, driver age and crash configuration are correlated. Thus, the ages of both drivers have to be taken into account.

Attempts to model the effects of vehicle mass, speed limit, and driver age are discussed in Appendix A-3. While analytical models could be developed for crashes involving two cars with no airbags, no meaningful models could be developed for crashes involving one airbag car, because case numbers were too small.

As an alternative, we tried case matching; finding for each airbag case one or several nonairbag cases which are similar in the factors included in the analysis, and also for each nonairbag case a similar airbag case. This proved to be not practicable. While for "average" cases many matches could be easily found, there were many cases for which no, or no acceptable match could be found (e.g., for a case where one driver was 86 years old, the other 89). Therefore, this approach was not further pursued.

A simpler categorical approach was used; cases were categorized by the mass ratio of the two vehicles, and the ages of the drivers. The categories for the mass ratio were: 1.25 or higher, 0.80 to less than 1.25, under 0.80. Those for driver age were: up to 25, 26 to 45, over 45. The breakpoints were somewhat arbitrarily chosen: round numbers, so that very roughly one third of the cases fell into each of the three categories. While this did succeed for age, it did not work so well for mass ratio; the upper and lower groups contain each only 27% of the total involvements.

While the initial aim was to make effectiveness estimates for each combination of factors, e.g., middle age drivers in a high mass ratio (their car at least 25% heavier than the other) involvement, these estimates turned out to be fairly uncertain. Therefore, aggregate estimates were also made, e.g., for all middle mass ratio involvement. Then, questions of confounding and standardization arise. They are discussed in Appendix A-2.

Finally, since belt use information in FARS, especially for uninjured occupants, is considered unreliable, it was ignored. Therefore, all effectiveness estimates give the effectiveness of airbags above that achieved by the average nationwide usage of safety belts at the time the accidents occurred.

4.2 Front-to-front (11, 12, 1) collisions

From the two-car collisions where at least one driver was killed, cases where both initial impacts were 11, 12, or 1 o'clock and where the vehicle masses and the drivers' ages were known, were selected. Initial impacts were used because they should trigger the airbag, not any subsequent (possibly more severe) impact.

Table 4.2-1 shows the distribution of restraint systems[2] among the cars in front-to-front collisions. In 3,602 collisions, both cars are equipped with safety belts (no distinction is made between types of belts). These collisions allow one to establish a baseline with which to compare the experience of the 382 airbag cars colliding with belt-equipped cars, and to control for mass ratio and driver ages. The six cases where two airbag cars collided are too few to allow any kind of analysis.

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[2] Cars with driver-side only, and dual airbags were combined.

TABLE 4.2-1. Restraint System Availability in Front-Front Collisions. Number of cases.

		CAR 2	
CAR 1	**BELT**	**AIRBAG**	**UNKNOWN**
Belt	3602	382	5
Airbag		6	1
Unknown			0

Table 4.2-2 shows the data classified by restraint system, mass ratio, and driver ages. Cell entries are the number of crashes where only the driver of car 1 (characterized by the row) was killed, the number of crashes where both drivers were killed, and the number of crashes when only driver 2 (characterized by the column) was killed. Fractions appear in the upper part of the table because symmetric cells represent the same crashes (a high mass ratio for one car is a low one for the other, a medium age driver for car 1, and a young one in car 2 represent the same situation as a young one in car 1 and a middle aged one in car 2, etc.) and crashes were distributed evenly over symmetric situations.

TABLE 4.2-2. Distribution of Cases in Front-to-Front Collisions by Restraint System, Driver Age, and Car Mass Ratio. The first cell entry gives cases where only the driver in the car characterized at the left was killed, the second where both were killed, and the third where only the driver characterized at the top of the table was killed.

FRONT IMPACT		FRONT IMPACT, NO AIRBAG		
		YOUNG	MEDIUM	OLD
NO AIRBAG				
Young	High	14, 8.5, 60.5	16, 11, 86.5	5.5, 5.5, 56
	Med.	59.5, 35, 59.5	61, 31, 82.5	28.5, 14.5, 125.5
	Low	60.5, 8.5, 14	83, 20.5, 22	33.5, 18.5, 37
Med.	High	22, 20.5, 83	19, 19.5, 103	13.5, 8, 87.5
	Med.	82.5, 31, 61	99.5, 44, 99.5	44, 32.5, 136
	Low	86.5, 11, 16	103, 19.5, 19	46.5, 23, 46.5
Old	High	37, 18.5, 33.5	46.5, 23, 46.5	16, 9.5, 58.5
	Med.	125.5, 14.5, 28.5	136, 32.5, 44	99, 47, 99
	Low	56, 5.5, 5.5	87.5, 8, 13.5	58.5, 9.5, 16
AIRBAG				
Young	High	0, 1, 2	0, 0, 1	0, 0, 1
	Med.	5, 2, 3	2, 2, 15	1, 1, 19
	Low	1, 0, 1	3, 4, 0	1, 1, 1
Med.	High	0, 2, 15	0, 0, 15	0, 0, 20
	Med.	8, 6, 10	4, 5, 19	2, 0, 15
	Low	2, 0, 0	2, 2, 0	2, 2, 0
Old	High	9, 1, 14	6, 5, 10	1, 4, 25
	Med.	7, 4, 3	16, 7, 11	7, 4, 18
	Low	1, 2, 0	3, 1, 0	7, 1, 0

From these data, relative risks were calculated, using the case numbers in the AIRBAG cells, e.g.,

0, 1, 2

and those in the corresponding cells for cars without airbags, in this example

14, 8.5, 60.5

From this, a risk factor of ((0 + 1)/(1 + 2))/((14 + 8.5)/(8.5 + 60.5)) = 1.02 would be obtained (see Appendix A-1). Combining all cells we obtain the overall array

90, 57, 208
1540, 530, 1540

from which a risk factor of 0.56 with an error range 0.52-0.62 can be calculated.

Since risk factors for the individual cells are often based on very few airbag cases, and in some cases would require division by zero, instead of the actual counts pseudo-Bayesian estimates (see Appendix A-2) were used, using aggregates over all cells with the same mass ratio as prior distribution. This prior was selected because the aggregates had sufficient numbers of cases, but still separated the data by the strongest factor influencing risk, mass ratio. In our case, the pseudo-Bayesian estimate gives

0.26 1.01 3.28

14.27 8.81 58.35

From this, one calculates a risk factor ((0.26 + 1.01)/(1.01 + 3.28))/((14.27 + 8.81)/(8.81 + 58.35)) = 0.86. These factors and their error ranges are shown in Table 4.2-3. Since the age of the other driver should not affect the effect of an airbag in the case vehicle, the risk factors in each row should be the same. In only one row are they relatively close; in the others they vary widely. However, in all cases the error ranges overlap. To obtain better values, we average the three values in a row.

TABLE 4.2-3. Front-to-Front Collisions. Risk Factors by Ages of the Drivers and the Mass Ratio. For explanation of the error range in parentheses see the text. The true value will be in the range with a probability of about 2/3.

FRONT IMPACT		**FRONT IMPACT, NO AIRBAG**		
		YOUNG	**MEDIUM**	**OLD**
AIRBAG				
Young	High	0.86(0.37-1.99)	0.45(0.06-3.45)	0.40(0.02-9.16)
	Med.	0.93(0.59-1.47)	0.69(0.43-1.10)	0.34(0.17-0.68)
	Low	0.60(0.22-1.64)	0.86(0.53-1.41)	1.08(0.52-2.21)
Med.	High	0.50(0.30-0.85)	0.21(0.08-0.55)	0.11(0.03-0.44)
	Med.	0.69(0.50-0.96)	0.54(0.39-0.75)	0.32(0.16-0.66)
	Low	2.32(0.41-13.0)	0.71(0.41-1.22)	1.94(1.15-3.28)
Old	High	0.64(0.42-0.98)	0.74(0.52-1.04)	0.47(0.29-0.76)
	Med.	0.49(0.33-0.72)	0.59(0.44-0.78)	0.57(0.41-0.80)
	Low	0.31(0.18-0.53)	0.91(0.39-2.14)	1.68(0.74-3.82)

As explained in Appendix A-2 we do not average the values, but convert to logarithms, average them, and revert back to a risk factor. We also calculate an error range based on the variance of the logarithms of the risk factor. These error ranges should be more realistic than those of the cell entries which are based on linear approximations and the assumption of Poisson variability of accident counts.

These averages, by driver age and mass ratio, are shown in Table 4.2-4. The margins contain average values which are calculated from the nine cell factors represented in each row and column, and in the lower right corner from the 27 cells of Table 4.2-3. This latter value of 0.61 is larger than the 0.56 obtained by the simple estimate, suggesting that confounding factors, such as heavier cars being equipped with airbags exaggerate the effect. The error range of this estimate is also wider (0.15) than that of the simple estimate (0.10). This wider range must be considered more realistic.

TABLE 4.2-4. Front-to-Front Collisions. Risk Factors by Age of Driver With Airbags and Mass Ratio of the Cars. Values are averages of data in Table 4.2.-3. See text for details of averaging and explanation of the error range shown in parentheses. The true value will be in this range with a probability of about 2/3.

DRIVER AGE	MASS RATIO HIGH	MEDIUM	LOW	AVERAGE
Young	0.54(0.42-0.68)	0.60(0.44-0.81)	0.82(0.61-1.10)	0.63(0.55-0.72)
Medium	0.22(0.14-0.35)	0.49(0.39-0.62)	1.47(1.02-2.13)	0.55(0.39-0.76)
Old	0.60(0.53-0.69)	0.55(0.51-0.58)	0.78(0.48-1.27)	0.64(0.54-0.74)
Average	0.42(0.34-0.52)	0.54(0.49-0.61)	0.98(0.79-1.21)	0.61(0.54-0.69)

Within the table there is a consistent pattern that the factor for low mass ratios is always much larger than for the other columns. In the "average" row, this pattern becomes clearer; the risk factor increases with decreasing mass ratio over the entire range, but the difference between the first two values is still within the error range.

There are two potential explanations for this pattern. One is that the effect of the airbag decreases with increasing delta-v, the other that the airbag has less effect in lighter cars, which amount for most cases with low mass ratio, because of compartment intrusion. Detailed information on vehicle damage would be needed to determine which effect applies.

The right column shows no difference in the risk factors by driver age; all these values are well within each other's error ranges.

Finally, we take a look at the three cells in Table 4.2-2 where the mass ratio is medium, and the driver ages fall into the same category. This matches airbag and nonairbag cases as closely as possible within the used categorization. Using the aggregate of the three cells as prior, we obtain risk factors of 0.72, 0.50, and 0.53 with a logarithmic average of 0.57 and an error range of 0.47-0.70. This value is practically no different from the previous estimates.

4.3 Front (11,12,1) -to-left (8,9,10) collision

Front-to-left side collisions are more likely to occur at intersections than front-to-front collisions. If cars approach each other from opposite directions in a front-front collision, with speeds v_1 and v_2, Delta-v is proportional to $v_1 + v_2$. If cars approach each other at right angles, as in an intersection, Delta-v is proportional to $\sqrt{v_1^2 + v_2^2}$. If one of the two speeds is much higher than the other, Delta-v is about the same in both situations. If, however, both speeds are the same, then Delta-v is proportional to 2v if the vehicles approach from opposite directions, proportional to $v\sqrt{2}$ when they approach each other at a right angle. Thus, in the latter case Delta-v is about 30% lower than in the former. Thus, one can expect, under comparable circumstances, lower Delta-v in angle collisions than in frontal collisions, and possibly different effects of airbags for the frontally impacting car.

For the impacted car, the situation is more complicated. When compartment intrusion occurs near the driver, an airbag is unlikely to have an effect, even if it deploys. However, an impact at 8 o'clock or 10 o'clock may not result in compromising the driver's space, and a deploying airbag may prevent contact with a forward object when the car decelerates. Thus, the airbag might possibly also have an effect for the driver of the impacted car. Appendix A-4 discusses reported airbag deployment.

Tables 4.3-1, 4.3-2, and 4.3-3 present information corresponding to 4.2.-1, 4.2.-2, and 4.2.-3. Differences are that because of the asymmetric situation Table 4.3-2 also shows a field for nonairbag cars frontally impacting airbag cars on the left.

TABLE 4.3-1. Restraint System Availability in Front-to-Left Collisions.
Number of cases.

FRONT IMPACT	LEFT SIDE IMPACT		
	BELT	AIRBAG	UNKNOWN
Belt	2255	106	1
Airbag	154	9	1
Unknown	2	0	0

TABLE 4.3-2. Distribution of Cases in Front-to-Left Collisions by Restraint System, Driver Age, and Car Mass Ratio. The first cell entry gives cases where only the driver in the frontally impacting car was killed, the second where both drivers were killed, and the third where only the driver of the side-impacted car was killed.

FRONT	LEFT SIDE IMPACT					
	NO AIRBAG			AIRBAG		
IMPACT	YOUNG	MEDIUM	OLD	YOUNG	MEDIUM	OLD
NO AIRBAG						
Young High	1, 1, 59	1, 0, 77	0, 0, 100	0, 0, 1	0, 0, 1	--
Med.	10, 4, 84	2, 1, 115	7, 0, 230	0, 0, 3	0, 0, 5	0, 0, 16
Low	8, 2, 20	5, 1, 20	3, 3, 74	--	0, 0, 1	1, 0, 6
Med. High	2, 0, 72	4, 2, 74	0, 0, 147	0, 0, 1	0, 0, 1	0, 0, 5
Med	8, 8, 74	7, 6, 87	4, 1, 53	0, 1, 4	1, 0, 4	0, 0, 18
Low	5, 0, 15	13, 3, 33	7, 2, 251	1, 0, 0	0, 0, 1	0, 1, 5
Old High	2, 2, 43	8, 2, 49	3, 0, 99	--	0, 0, 1	1, 0, 5
Med.	16, 4, 34	15, 2, 41	9, 8, 123	1, 0, 0	1, 0, 1	2, 0, 8
Low	14, 1, 4	13, 0, 5	14, 1, 22	--	0, 1, 0	4, 0, 3
AIRBAG						
Young High	1, 0, 6	0, 0, 5	0, 0, 3			
Med.	0, 0, 2	0, 0, 5	0, 0, 13			
Low	--	--	0, 0, 2			
Med. High	0, 0, 11	1, 0, 6	0, 0, 13			
Med	1, 0, 6	1, 0, 6	0, 0, 18			
Low	0, 0, 1	0, 0, 1	0, 0, 3			
Old High	0, 0, 5	0, 0, 7	1, 0, 10			
Med.	0, 0, 5	1, 0, 2	1, 1, 14			
Low	--	1, 0, 0	1, 0, 1			

TABLE 4.3-3. Front-to-Left Collisions Where the Impacted Car has no Airbag. Risk Factors by Ages of the Driver and the Mass Ratio. For explanation of the error range in parentheses see section 4.2. The true value will be in the error range with a probability of about 2/3.

FRONT IMPACT AIRBAG		**LEFT SIDE IMPACT, NO AIRBAG**		
		YOUNG	**MEDIUM**	**OLD**
Young	High	2.06(0.53-8.07)	0.35(0-49.7)	1.44(0-48000)
	Med.	0.38(0.04-3.57)	0.23(0-42.1)	0.14(0-7.33)
	Low	--	--	0.36(0.01-11.8)
Med.	High	0.22(0.01-4.95)	0.89(0.20-3.99)	0.51(0-56.8)
	Med	0.81(0.24-2.70)	0.84(0.22-3.16)	0.02(0-5.00)
	Low	0.10(0-42.0)	0.05(0-26.9)	0.17(0-199)
Old	High	0.25(0.01-6.09)	0.01(0-4.39)	1.73(0.51-5.84)
	Med.	0.01(0-9.51)	1.16(0.32-4.16)	0.94(0.40-2.22)
	Low	--	10.6(0.06-1936)	1.42(0.34-5.97)

TABLE 4.3-4. Risk Factor for the Driver of the Frontally Impacting Car in Front-to-Left Collisions. For explanation of estimates, see text.

	MASS RATIO			
TYPE OF ESTIMATE	**HIGH**	**MEDIUM**	**LOW**	**ALL**
Pseudo-Bayesian	0.42 (0.25-0.73)	0.23 (0.13-0.41)	0.41 (0.19-0.92)	0.33 (0.24-0.47)
Based on Aggregate Counts	.92 (.50-1.71)	0.54 (0.34-0.87)	1.60 (0.72-3.56)	.64 (0.46-0.90)
Based on Average of Cell Proportions	0.68	0.43	1.47	0.57

There are three cells, all for low mass ratios, with nonairbag cars impacting others. Therefore, no risk factors could be calculated, and the averages for young, and for old drivers, for low mass ratio, and the overall average do not balance the other factors. How serious that is cannot be assessed.

The risk factors in Table 4.3-3 show so large standard errors that one cannot hope to recognize any pattern. Table 4.3-4 shows averages by mass ratio, and the overall average. The pseudo-Bayesian estimates show surprisingly low values. Therefore, also direct estimates based on aggregate counts by mass ratio were made. These numbers are substantially higher. A closer look at the cell entries in Table 4.3-2 explains this. The cell for old drivers with high mass ratios colliding with middle age drivers has these entries

0	0	7
15	2	41

This indicates a very high reduction of the risk. If there were no effect, one would expect

1	0	6
15	2	41

Similarly, the cell for old drivers with median mass ratios colliding with young drivers and entries

0	0	5
16	4	34

indicates a very high reduction of the risk. Without an effect, one would expect

2	0	3
16	4	34

If risk factors are averaged, such cells have a relatively large effect, while when simply aggregating the cell counts these cells are overwhelmed by cells with higher case numbers. Since the purpose of the straight averaging of cell factors was to control to some degree for unequal cell frequencies and correlations between airbags and cell characteristics, the pseudo-Bayesian estimates should be considered as better estimates than those based on simple aggregates.

To check this matter further, an additional heuristic approach was used. For each of the cells, the proportions of the six entries were calculated, and these proportions averaged over cells. Though not statistically "clean," this reduces the effect of uneven cell frequencies. Table 4.3-4 shows also these estimates. These are all lower than those obtained from aggregate counts; the difference reflects the effects of uneven cell frequencies. They are higher than those resulting from the pseudo-Bayesian approach, because the effect discussed above still holds; high effects in certain cells are not retained, but are lost in the aggregation.

While the pseudo-Bayesian estimates and those based on cell proportions agree within or near the error limits for high and medium mass ratios, there is still a large discrepancy for low mass ratios, and for the overall average.

Table 4.3-5 (arranged similar to 4.3-4) shows risk factors by driver age. Again, the pseudo-Bayesian estimates are much lower than those obtained when simply aggregating the counts within each driver age class. There is no indication that the factors differ among the age classes; they are all well within their error ranges.

TABLE 4.3-5. Risk Factor for the Driver of the Frontally Impacting Car in Front-to-Left Collisions. For explanation of estimates, see text.

TYPE OF ESTIMATE	DRIVER AGE YOUNG	 MEDIUM	 OLD
Pseudo-Bayesian	0.40 (0.27-0.58)	0.22 (0.14-0.34)	0.36 (0.15-0.85)
Based on Aggregate Counts	0.63 (0.23-1.76)	0.53 (0.29-0.97)	0.53 (0.34-0.82)

Table 4.3-6 shows estimates of the risk factor for the driver of the impacted car. No clear pattern is apparent. However, the pseudo-Bayesian estimates tend to be higher than those based on aggregate counts, contrary to the situation for the driver of the impacting car. Only the single estimate for low mass ratios is so low that it would be statistically significant. However, the corresponding pseudo-Bayesian estimate is close to one. Thus, a conservative interpretation of the data would find no effect of the airbag in the car impacted on the left side.

TABLE 4.3-6. Risk Factor for the Driver of the Car Impacted on the Left Side in Front-to-Left Collisions. For explanation of estimates, see text.

TYPE OF ESTIMATE	MASS RATIO HIGH	 MEDIUM	 LOW	ALL
Pseudo-Bayesian	0.76 (0.60-0.97)	1,03 (0.59-1.80)	0.90 (0.48-1.70)	0.92 (0.69-1.22)
Based on Aggregate Counts	0.62 (0.22-1.77)	1.28 (0.83-1.97)	0.24 (0.16-0.37)	0.68 (0.51-0.90)

4.4 Front-right (2,3,4) and front-rear (5,6,7) collisions

Tables 4.4-1 and 4.4-2 show the counts of driver fatalities in front-right (2,3,4 o'clock) and front-rear (5,6,7 o'clock) impacts. Since the numbers of airbag cases were even smaller than in the front-left impacts, no analyses for the driver in the impacting car were performed. Rather, data for all front-to-other side impacts were aggregated and analyzed. This is described in section 4.5.

TABLE 4.4-1. Distribution of Cases in Front-to-Right Collisions by Restraint System, Driver Age, and Car Mass Ratio. The first cell entry gives cases where only the driver in the frontally impacting car was killed, the second where both drivers were killed, and the third where only the driver of the side-impacted car was killed.

FRONTAL IMPACT			NO AIRBAG	RIGHT IMPACT		AIRBAG	
		YOUNG	MEDIUM	OLD	YOUNG	MEDIUM	OLD
NO AIRBAG							
Young	High	2, 1, 43	1, 1, 46	0, 0, 56	0, 0, 2	0, 0, 2	--
	Med.	11, 3, 50	6, 3, 42	4, 3, 86	--	--	0, 0, 6
	Low	9, 0, 4	3, 2, 11	4, 2, 27	0, 1, 0	1, 1, 1	1, 0, 3
Med.	High	5, 1, 65	5, 2, 50	1, 0, 57	0, 0, 3	0, 0, 1	0, 1, 3
	Med.	18, 6, 50	11, 7, 62	5, 4, 90	1, 0, 1	2, 0, 2	0, 0, 4
	Low	5, 1, 9	8, 4, 14	5, 1, 17	1, 0, 0	1, 0, 0	0, 0, 1
Old	High	3, 4, 27	4, 5, 34	2, 1, 49	0, 0, 1	0, 0, 4	0, 0, 1
	Med.	19, 6, 21	14, 3, 24	4, 2, 59	1, 0, 0	0, 1, 0	2, 0, 4
	Low	8, 1, 1	14, 3, 4	11, 2, 3	1, 0, 0	--	1, 0, 4
AIRBAG							
Young	High	0, 0, 1	0, 0, 5	0, 1, 4			
	Med.	1, 0, 4	1, 0, 3	0, 0, 4			
	Low	--	--	0, 0, 1			
Med.	High	0, 0, 9	1, 0, 11	0, 0, 12			
	Med.	1, 0, 7	0, 0, 7	0, 0, 15			
	Low	--	--	0, 0, 3			
Old	High	0, 0, 3	0, 0, 5	0, 1, 2			
	Med.	0, 0, 2	1, 0, 1	2, 0, 9			
	Low	--	--	--			

TABLE 4.4-2. Distribution of Cases in Front-to-Rear Collisions by Restraint System, Driver Age, and Car Mass Ratio. The first cell entry gives cases where only the driver in the frontally impacting car was killed, the second where both drivers were killed, and the third where only the driver of the rear-impacted car was killed.

FRONTAL IMPACT		REAR IMPACT					
		NO AIRBAG			AIRBAG		
		YOUNG	MEDIUM	OLD	YOUNG	MEDIUM	OLD
NO AIRBAG							
Young	High	0, 0, 16	2, 0, 17	1, 0, 19	--	--	--
	Med.	8, 0, 23	8, 1, 13	4, 0, 14	0, 0, 1	--	0, 0, 1
	Low	4, 0, 3	3, 0, 5	2, 0, 4	--	--	--
Med.	High	5, 0, 5	6, 0, 8	1, 0, 12	--	--	--
	Med.	8, 0, 20	6, 1, 20	5, 0, 9	2, 0, 1	--	--
	Low	10, 0, 2	9, 1, 3	6, 0, 4	--	--	2, 0, 0
Old	High	2, 0, 2	6, 0, 8	2, 0, 7	--	--	--
	Med.	9, 0, 3	14, 0, 8	10, 0, 9	2, 0, 0	1, 0, 0	--
	Low	6, 0, 0	15, 1, 0	13, 0, 0	--	1, 0, 0	2, 0, 0
AIRBAG							
Young	High	1, 0, 1	1, 0, 0	--			
	Med.	--	--	0, 0, 1			
	Low	--	--	--			
Med.	High	1, 0, 2	0, 0, 1	1, 0, 0			
	Med.	--	0, 0, 1	0, 0, 4			
	Low	--	0, 0, 1	0, 0, 1			
Old	High	0, 0, 3	0, 0, 2	--			
	Med.	0, 0, 1	0, 0, 1				
	Low	--	1, 0, 0	--			

However, since right impacts pose a very different situation for the driver than left impacts, we performed a simple analysis for the driver of the impacted car, if it had an airbag Only matching cells from Table 4.4-1 were used. The results are shown in Table 4.4-3. The estimates show no consistent pattern, with the exception of an increased risk for the drivers of the heavier cars in the collision.

TABLE 4.4-3. Risk Factor for the Driver of the Car With Right-Side Impact in Front-to-Right Collisions. For explanation of estimates, see text.

TYPE OF ESTIMATE	MASS RATIO HIGH	 MEDIUM	 LOW	ALL
Pseudo-Bayesian	2.20 (1.14-4.22)	0.79 (0.48-1.30)	0.76 (0.40-1.42)	1.20 (0.76-1.88)
Based on Aggregate Counts	2.89 (1.08-7.71)	0.64 (0.42-1.00)	0.92 (0.60-1.44)	0.77 (0.58-1.02)

4.5 Front-other (2-10) collisions

Because the analysis of front-to-left side collisions gave only fairly uncertain results, and front-to-right side and front-to-rear collisions were even less numerous, all front-to-"other" collisions ("other" meaning not a frontal impact) were combined and analyzed. Tables 4.5-1, and 4.5-2 show the data; they correspond to Tables 4.2.-1, and 4.2-2. Risk factors for the combinations of driver age and mass ratio are not shown because they are highly uncertain. Only estimates by mass ratio, and by driver age are shown in Tables 4.5-3, and 4.5-4.

TABLE 4.5-1. Distribution of Front-Other Collisions by Restraint Type.

FRONT IMPACT	OTHER IMPACT BELT	 AIRBAG	 UNKNOWN
Belt	3989	180	2
Airbag	284	16	2
Unknown	2	0	0

TABLE 4.5-2. Distribution of Cases in Front-to-Other Collisions by Restraint System, Driver Age, and Car Mass Ratio. The first number gives cases where only the driver in the frontally impacting car was killed, the second where both drivers were killed, and the third where only the driver of the car with non-frontal impact was killed.

		OTHER IMPACT					
FRONTAL		NO AIRBAG			AIRBAG		
IMPACT		YOUNG	MEDIUM	OLD	YOUNG	MEDIUM	OLD
NO AIRBAG							
Young	High	4, 2, 120	5, 1, 140	1, 0, 173	0, 0, 3	0, 0, 3	--
	Med.	30, 7, 162	18, 1, 171	15, 3, 331	0, 0, 4	0, 0, 6	0, 0, 23
	Low	21, 2, 27	11, 3, 37	9, 6, 105	0, 1, 0	1, 1, 2	2, 0, 9
Med.	High	13, 1, 149	15, 4, 136	2, 0, 216	0, 0, 4	0, 0, 2	0, 1, 8
	Med.	35, 14, 145	28, 16, 171	17, 6, 353	3, 1, 6	3, 0, 6	0, 0, 22
	Low	21, 2, 27	30, 8, 50	16, 2, 75	2, 0, 0	1, 0, 1	2, 1, 6
Old	High	9, 7, 73	20, 7, 92	7, 1, 155	0, 0, 1	0, 0, 5	1, 0, 6
	Med.	46, 10, 61	44, 6, 74	23, 10, 191	4, 0, 0	2, 1, 1	5, 0, 12
	Low	29, 2, 0	43, 4, 9	39, 3, 25	1, 0, 0	1, 1, 0	7, 0, 8
AIRBAG							
Young	High	2, 0, 7	1, 0, 10	0, 1, 7			
	Med.	1, 0, 6	1, 0, 8	0, 0, 8			
	Low	--	--	0, 0, 3			
Med.	High	1, 0, 22	3, 0, 18	1, 0, 26			
	Med.	2, 0, 13	1, 0, 14	0, 0, 37			
	Low	0, 0, 1	0, 0, 2	0, 0, 7			
Old	High	0, 0, 12	0, 0, 14	1, 1, 12			
	Med.	0, 0, 8	4, 0, 4	6, 1, 23			
	Low	--	2, 00	1, 0, 1			

TABLE 4.5-3. Risk Factor for the Driver of the Frontally Impacting Car in Front-to-Other Collisions by Car Mass Ratio. For explanation of estimates, see text.

	MASS RATIO			
TYPE OF ESTIMATE	HIGH	MEDIUM	LOW	ALL
Pseudo-Bayesian	1.16 (0.65-2.09)	0.29 (0.15-0.56)	0.29 (0.11-0.77)	0.49 (0.32-0.74)
Based on Aggregate Counts	1.18 (0.80-1.62)	0.75 (0.57-0.97)	0.46 (0.24-0.88)	0.65 (0.54-0.80)

TABLE 4.5-4. Risk Factor for the Driver of the Frontally Impacting Car in Front-to-Other Collisions by Driver Age. For explanation of estimates, see text.

TYPE OF ESTIMATE	DRIVER AGE YOUNG	MEDIUM	OLD
Pseudo-Bayesian	1.16 (0.60-2.24)	0.26 (0.15-0.45)	0.47 (0.19-1.15)
Based on Aggregate Counts	1.44 (0.93-2.22)	0.39 (0.27-0.57)	0.58 (0.44-0.75)

The overall pseudo-Bayesian estimate in Table 4.5-3 for front-other collisions (0.49), and Table 4.3-4 for front-to-left collisions (0.32), differ by about one standard error; those based on simple aggregates of counts are practically identical (0.65 and 0.64). The latter are also very similar to the presumably more realistic pseudo-Bayesian estimate for front-front collisions, 0.61.

The patterns by mass ratio in Tables 4.5-3 and 4.3-4, however, show no similarity. With regard to driver age, the patterns in Tables 4.5-4, 4.3-5, and 4.2.-4 also show no similarity.

A closer look at the data explains the great uncertainty of the estimates for front-to-other collisions. In front-to-front collisions, there were 3602 cases where both cars had belts only, and 382 where one car had belts, and the other airbags. Of front-to-other collisions, 3989 had belts in both cars, in 284 the frontally impacting car had an airbag, the impacted car a belt. Overall, these numbers appear similar, however, in front-to-front impacts, 147 drivers with airbags were killed, in front-to-other cars only 30 drivers with airbags. Therefore, estimates of airbag effectiveness in front-to-other cases should have at least twice as large standard errors as those for front-to-front crashes. If, in addition, delta-v differed between the crash configurations aggregated in “other” impacts, the error would be even greater.

4.6 All car-car collisions combined

Airbag effectiveness showed different patterns in different impact types. Therefore, to obtain an estimate of overall effectiveness in car-car collisions, all impact types were combined for an additional analysis. To make the results compatible with those obtained by the other approaches, mass was treated differently; collisions were not stratified by mass ratio, but by the weights of both cars. While this gives results that can be compared with those of the other approaches, they cannot be strictly compared with those of the preceding sections. However, heavier cars will, on the average have the higher mass ratios, whereas lighter cars will have the lower mass ratios. Thus, trends of effectiveness relative to mass ratio will at least qualitatively be comparable with trends relative to mass.

Table 4.6-1 shows the data in a format similar to that of the tables in the preceding sections. For each combination of car weights and driver ages, entries are blocks of six numbers. The first row shows fatalities in collisions between airbag cars (characteristics shown at left) and nonairbag car (characteristics shown at the top); the first number being collisions where only the driver of the airbag car was killed, the second collision where both drivers were killed, and the third collision where only the driver of the nonairbag car was killed. The lower row gives corresponding figures for collisions between two nonairbag cars. Because a collision between nonairbag cars can arbitrarily be placed into a cell, or the cell symmetric to the main diagonal of the table, one half collision was placed into each of these cells, resulting sometimes in fractional counts.

For each of the 74 cells of the table without missing data, the fatality risk factor was calculated as in the preceding sections. Because there were many cells with zero or small counts of some airbag fatalities, the pseudo-Bayesian approach was used, using the aggregate of the data for each combination of car weights as prior. These aggregates were closest to the original data, but had enough cases to calculate a meaningful prior. Only for collisions between light airbag and heavy nonairbag cars were no cases in enough cells so that no risk factors could be calculated.

TABLE 4.6-1. Total Fatalities in Car-Car Collisions by Weight of the Car and Ages of the Driver. The treatment group contains half of the cases in collisions between cars without airbags, and the airbag car in collisions with no airbag cars, the "comparison" group the other cars. The first figure is the number of drivers killed in the "treatment" car, the second the number killed in both cars, the third the number killed in the "comparison" car. The first row contains the figures for the airbag-nonairbag collisions, the second those for collisions between nonairbag cars.

					COMPARISON GROUPS				
TREATMENT		**HEAVY**			**MIDWEIGHT**			**LIGHT**	
GROUP	**YOUNG**	**MEDIUM**	**OLD**	**YOUNG**	**MEDIUM**	**OLD**	**YOUNG**	**MEDIUM**	**OLD**
Heavy									
Young	--	--	0,0,4	1,0,2	1,0,5	0,0,4	1,0,1	0,0,6	0,1,1
	2.5,3,2.5	6,1,6.5	2.5,1.5,12	8,5.5,25	2.5,6,47	2.5,1,59	2.5,1,32	2.5,2.5,43.5	1.5,1,35.5
Medium	0,0,2	1,0,2	0,0,6	1,0,8	0,0,4	1,1,27	1,0,10	3,0,9	1,0,8
	6.5,1,6	13.5,9,13.5	9.5,4.5,26	18,13,51	24.5,14.5,59	6,6,99.5	5,3,54.5	4.5,3.5,61	2,0.5,54
Old	4,0,1	4,4,2	2,1,6	12,1,11	13,3,7	10,4,22	2,0,11	2,2,12	1,1,20
	12,1.5,2.5	26,4.5,9.5	18,12,18	36,14.5,22.5	44,9.5,48	21.5,9.5,70.5	14.5,4,31.5	14.5,7,34.5	5,2,48
Midweight									
Young	2,0,2	4,3,0	2,0,3	7,1,7	7,2,17	3,2,27	1,2,8	2,1,18	0,0,17
	25,5.5,8	51,13,18	22.5,14.5,36	87.5,22,87.5	74.5,20,111.5	38,15.5,153	33,8.5,104	26,5,8,114	6.5,3.5,111
Medium	5,0,2	4,3,5	6,2,12	11,6,17	7,4,21	3,0,29	3,2,26	2,0,18	1,1,24
	47,6,2.5	59,14.5,24.5	48,9.5,44	111.5,20,74.5	107,24,107	43,17.5,199	39.5,15.5,96	29,16.5,115	10,7.5,118
Old	4,1,0	16,3,1	17,1,5	19,1,9	27.3,12	14,3,28	8,3,7	3,3,8	1,1,2
	59,1,2.5	99.5,6,6	70.5,9.5,21.5	153,15.5,38	199,17.5,43	107,27,107	73,14.5,34	55,19.5,56	21.5,6,67.5
Light									
Young	--	--	--	2,1,0	5,1,1	0,0,5	2,0,0	1,0,2	0,0,1
	32,1,2.5	54.5,3,5	31.5,4,14.5	104,8.5,33	96,15.5,39.5	34,14.5,73	36.5,8,36.5	38,6.5,46	11,2.5,53
Medium	2,0,0	1,0,0	0,0,1	0,1,0	1,0,2	0,0,2	2,0,0	1,0,1	0,0,1
	43.5,2.5,2.5	61,3.5,4.5	34.5,7,14.5	114,8,26.5	115,16.5,29	56,19.5,55	46,6.5,38	35.5,9,35.5	11.5,4,41
Old	--	--	1,0,0	0,1,0	1,0,0	1,0,0	0,0,1	1,0,0	0,0,1
	35.5,1,1.5	54,0.5,2	48,2,5	111,3.5,6.5	118,7.5,10	67.5,6,21.5	53,2.5,11	41,4,11.5	18.5,6,18.5

Table 4.6-2 shows the fatality risk factors calculated from the pseudo-Bayesian estimates. As in the previous sections; logarithmic means were calculated to obtain "standardized" risk factors for the three car-weight classes, and the three driver-age classes. Tables 4.6-3 and 4 show these values, together with the ± sigma (in the logarithms) range.

TABLE 4.6-2. Risk Factors, Calculated From the Data in Table 4.7-1 Using a Pseudo-Bayesian Approach.

TREATMENT GROUP	COMPARISON GROUPS								
	HEAVY			MIDWEIGHT			LIGHT		
	YOUNG	MEDIUM	OLD	YOUNG	MEDIUM	OLD	YOUNG	MEDIUM	OLD
Heavy									
Young	--	--	.16	1.12	1.31	0.31	5.00	0.55	5.56
Medium	0.40	0.55	0.15	0.82	0.57	0.66	0.94	1.64	2.00
Old	1.12	0.65	0.51	0.82	1.68	1.29	0.40	0.59	0.71
Midweight									
Young	0.70	0.87	0.95	0.74	0.66	0.55	0.71	0.56	0.07
Medium	0.44	0.59	0.54	0.55	0.60	0.38	0.41	0.43	0.56
Old	0.31	0.57	0.96	0.64	0.56	0.59	0.61	0.55	1.10
Light									
Young	--	--	--	0.66	0.97	0.01	1.30	0.77	0.08
Medium	2.83	1.72	0.07	0.30	0.24	0.04	2.14	1.00	0.10
Old	--	--	1.41	0.09	3.78	0.60	0.005	10.42	0.54

TABLE 4.6-3. Average Risk Factor by Car Weight. For explanation of the error range in parentheses, see text. The true value will be in this range with a probability of about 2/3.

CAR WEIGHT			
HEAVY	MIDWEIGHT	LIGHT	ALL
0.80 (0.68-0.95)	0.55 (0.50-0.60)	0.42 (0.25-0.58)	0.56 (0.48-0.65)

TABLE 4.6-4. Average Risk Factor by Driver Age. For explanation of the error range in parentheses, see text. The true value will be in this range with a probability of about 2/3.

	DRIVER AGE		
YOUNG	MEDIUM	OLD	ALL
0.55 (0.41-0.74)	0.50 (0.42-0.62)	0.63 (0.49-0.82)	0.56 (0.48-0.65)

4.7 Summary for car-car collisions

The preceding sections present risk factors for a number of different impact modes. To allow easier recognition of common trends, Tables 4.7-1 and 4.7-2 present the estimates we considered most reliable, those based on the pseudo-Bayesian approach, in a summary manner. To make overall patterns cleaner, figures are shown only to one digit, and the estimate combined with a ± 1 sigma range (sometimes asymmetric due to the logarithmic averaging used).

TABLE 4.7-1. Summary of Risk Factors by Mass Ratio or Car Weight. Factors are for the occupant of the vehicle with the first listed impact. Values in the second part of the table are not quantitatively comparable with those in the first, but they should allow qualitative comparisons of the direction of any trend. The middle entry is the pseudo-Bayesian estimate, the left and right indicate a ± 1 sigma range.

IMPACT TYPE		MASS RATIO		
	HIGH	MEDIUM	LOW	ALL
Front-front	.3/.4/.5	.5/.5/.6	.8/1.0/1.2	.5/.6/.7
Front-left	.2/.4/.7	.1/.2/.4	.2/.4/.9	.2/.3/.5
Front-other	.6/1.1/2.1	.2/.3/.6	.1/.3/.8	.3/.5/.7
Left-front	.6/.8/1.0	.6/1.0/1.8	.5/.9/1.7	.7/.9/1.2
Right-front	1.1/2.9/7.7	.4/.6/1.0	.6/.9/1.4	.6/.8/1.0
		CAR WEIGHT		
	HEAVY	MIDWEIGHT	LIGHT	ALL
All	.7/.8/1.0	.5/.5/.6	.2/.4/.6	.5/.6/.7

TABLE 4.7-2. Summary of Risk Factor by Driver Age. The middle entry is the best estimate, the left and right entries indicate a ± 1 sigma range.

IMPACT TYPE	DRIVER AGE YOUNG	 MIDDLE	 OLD
Front-front	.6/.6/.7	.4/.6/.8	.5/.6/.7
Front-left	.3/.4/.6	.1/.2/.3	.2/.4/.9
Front-other	.6/1.2/2.2	.2/.3/.4	.2/.5/1.2
All	.4/.6/.7	.4/.5/.6	.5/.6/.8

The overall picture is clear: there is an overall risk reduction by 40%, the same as in front-to-front collisions that are most frequent in fatal accidents. The effect is even greater: a 70% reduction, for drivers striking another car on the left, and possibly also, (but only by 50%), for drivers striking a car elsewhere. For drivers whose car was struck on the left or on the right, small, but not significant risk reductions appear. That is not surprising because airbags have at best a secondary effect in those impacts.

How airbag effectiveness varies with the mass ratio of the two cars, which strongly influences the delta-v values that the cars experience, is much less clear. There are two clear, but opposite trends in Table 4.7-1. In frontal impacts, the effect of airbags is largest (60%), for the high mass involvements, where the driver experiences the lowest delta-v, and lowest (none), for drivers who experience the highest delta-v in low mass ratio involvements. For "all" impacts, the trend is opposite, though not quite as pronounced as for front-front impacts. The two trends are not quantitatively comparable, because for one involvements are classified by mass ratio, and for the other by car weight. However, heavy cars are, on the average, involved in high mass ratio collisions, light cars in low mass ratio collisions. Thus, the trends should be qualitatively comparable.

The opposite direction of the two trends requires that there are collision types where drivers of heavy cars benefit little, if at all. There are indeed two such modes: frontally striking another car neither at the front nor left side, and being struck by another car on the right side. In the first case, the airbag appears to have no effect, in the second it appears to increase the risk dramatically, but the increase would not be considered significant. In the other collision modes, no trends with mass ratio are apparent.

With regard to driver age, the data in Table 4.7-2 show no strong trends. In front-left, and front-other collisions the middle-age group appears to benefit most, but the differences are not significant.

5. Comparing Drivers and Right Front Seat Occupants

5.1 Approach

Accidents where a driver and a right front seat occupant are present, but only the driver has an airbag, offer an opportunity to study airbag effectiveness. However, because of the different risks they face in different impacts, and because even in symmetric crashes the steering assembly may result in a different risk for the driver, careful controls are needed.

Passenger cars where both the driver, and a right front seat occupant 16 years of age or older were present, with a driver side only airbag were selected. As control, cars with safety belts only, and the same driver and occupant characteristics were selected. To have only comparable cars, only model years from 1987 on were used. Initially, it was attempted to control for the effects of person age by cross-classifying according to the ages of the driver and of the passenger. However, there were no cases where an old driver was with a young passenger, and where a young driver was with an old passenger. This would have made a simple control for age effects impossible. Therefore, a different approach was used. To control for age effects, only cases where the age of driver and passenger differed by less than 10 years were selected. The average of both ages was used to classify age. For an average age of 25 or less, occupants were classified as "young," 26 to 45 as "medium," and over 45 as "old." Vehicle weight was classified as "light" (up to 2,450 lbs.), "medium" (over 2,450 to 3,450 lbs.), and "heavy" (above 3,450 lbs.). This corresponds to the gross vehicle classification used by NHTSA (an apparent difference is due to NHTSA's rounding of the weight to the nearest 100 lbs. before classifying). Of the initial impact point, the clock positions 1 to 12 were retained, all others combined into an "other" category. Crashes were categorized into single vehicle crashes, collisions with another car, and collisions with other motor vehicles.

The final file contained 7,877 cases, 1,207 of which were cars with airbags.

5.2 Overall effects and coarse impact classification

The analyses use the approaches outlined in Appendices A-1 and A-2. The basic data for each accident class are summarized in a 2 x 3 table

$$\begin{array}{ccc} x_1 & x_2 & x_3 \\ y_1 & y_2 & y_3 \end{array}$$

where x_i apply to the airbag cars, y_i to the control cars with belts only; x_1 and y_1 are the numbers of cases in which only the driver is killed, x_2, y_2 those in which both driver and passenger are killed, and x_3, y_3 those in which only the passenger is killed. As shown in the Appendices,

$$f = \frac{x_1 + x_2}{x_2 + x_3} / \frac{y_1 + y_2}{y_2 + y_3}$$

is an estimate of the factor by which the airbag reduces a driver's fatality risk. If accidents were classified by several factors, some of the x_i become very small, and consequently the f very large or very small. Then, the x_i and y_i were replaced by a pseudo-Bayesian estimate (Appendix A-2), using the distribution of the x_i and y_i for the most similar aggregate of accident classes as prior distribution.

Standard errors were estimated by the common linearization approach; thus, they are only approximations. Again, where case numbers were small, the pseudo-Bayesian estimates were used for calculating the standard errors. This also avoided the problem of calculating standard errors when certain counts are zero.

Since f must be positive but has no upper bound, it has an asymmetric distribution. This asymmetry is especially pronounced if some of the $x_i + x_j$ or $y_i + y_j$ are small. Then, a standard error can give a misleading idea of the potential range within which the "true" value of r may be. The logarithm of f has a more symmetric distribution, which removes this problem. Therefore, to present a more realistic picture of the errors, we calculated the ± 1 sigma range for the logarithm of f, and then the corresponding values of f. Whenever the asymmetry of the distribution of f is noticeable, we present this range instead of the standard error. To the extent the normal approximation is valid, the "true" value will be in this range with a probability of 2/3. However, one must not attempt to double this range to obtain a ± 2 sigma range; this requires more complex calculations.

Table 5.2-1 shows first an overall estimate of the airbag effect. The risk factor is 0.92, with a standard error of 0.04. This would be considered a significant effect. However, because the error estimate is an approximation, one should be cautious.

TABLE 5.2-1. Case Numbers and Risk Factors for Drivers, and Right Front Seat Occupants as Controls. The first row of case numbers applies to cars with driver side airbags, the second to cars with belts only. The first number refers to cases in which only the driver is killed, the second to cases where both occupants are killed, and the third to those where only the passenger is killed. Fatality risk for the driver in passenger-and-occupant-airbag-cars is lower by the risk factor compared with drivers in belt only cars.

ACCIDENT TYPE	CASE NUMBERS	RISK FACTOR	STANDARD ERROR
All impacts	434, 212, 561 2529, 1244, 2897	0.92	.04
(11,12,1) impacts	184, 95, 255 1271, 672, 1381	0.84	.06
Other impacts	250, 117, 306 1258, 572, 1516	0.99	.07
Single vehicle crash	238, 86, 241 1197, 422, 1268	1.03	.07
Two-car collision	77, 32, 150 530, 260, 750	0.77	.09
Other accidents	121, 93, 170 802, 562, 956	0.91	.07

Distinguishing frontal, left side, right side, rear, and other impacts showed great differences. However, only the differences between frontal impacts (11, 12, 1 clock positions) and all others were clear; differences among the other impact types were inconsistent and uncertain. It is not surprising that there is no apparent risk reduction in "other" impacts (0.99 with a standard error of 0.07), whereas the reduction in frontal impacts, 0.84 with a standard error of 0.06 is obvious.

Distinguishing accident types shows an unexpected picture. In single vehicle crashes, airbags seem to have no effect, (the risk factor 1.03 differs from 1 by less than the standard error of 0.07). The risk reduction in two-car collisions is large, by a factor 0.77 ± 0.09, whereas in "other" accidents it is marginal (0.91 ± 0.07). The difference between the risk factors for two-car collisions, and "other" accidents is 1.2 times its standard error, suggestive of a real difference, but not conclusive.

Since no effect was apparent in other than frontal impacts, frontal impacts were also disaggregated by accident type. Table 5.2-2 shows the data. Again, there is no apparent effect in single vehicle crashes (the risk factor suggests an even larger increase than before). The effects in two-car collisions, and in other accidents are larger than in all impacts combined. The risk reductions are 36% and 26%, respectively; the difference between these values, however, is well within one standard error.

TABLE 5.2-2. Case Numbers and Risk Factors for Frontal Impacts. Definitions are the same as in Table 5.2-1.

ACCIDENT TYPE	CASE NUMBERS	RISK FACTOR	STANDARD ERROR
Single vehicle crashes	107, 40, 104 575, 229, 673	1.14	.12
Two-car collisions	32, 13, 77 271, 154, 392	0.64	.11
Other accidents	45, 42, 74 425, 289, 416	0.74	.09

Based on these findings, we performed more detailed analyses only for frontal impacts. Also, we combined two-car collisions and "other" accidents in one category "other"; otherwise cell frequencies would have become even lower. Though we had not found an effect for single vehicle accidents, we studied them, to determine whether the lack of effect might be due to unfavorable combinations of vehicle weight and occupant ages.

Table 5.2-3 shows the data on which the detailed analyses are based. In many cases, cell frequencies for airbag cases were extremely low, in one cell there was even no airbag car. Because of this, not the actual cell frequencies, but the pseudo-Bayesian estimates were used, using the combined counts for single vehicle crashes, and those for other crashes or priors, respectively. The margins of Table 5.2-4 show averages calculated by using the logarithms of the cell values and error ranges derived from the standard deviations of the logarithms of the cell values. Using logarithms reduces biases resulting from the very asymmetric distributions of the risk factors, and averaging the risk factors rather than using the aggregates of cases by rows or columns is a simple way to standardize the averages. This reduces the effect of correlations between car weight and occupant age.

TABLE 5.2-3. Case Numbers for Frontal Crashes, by Accident Type, Average Occupant Age, and Car Weight. Definitions are the same as in Table 5.2-2.

ACCIDENT TYPE	CAR WEIGHT			
OCCUPANT	**LIGHT**	**MEDIUM**	**HEAVY**	**UNKNOWN**
Single Vehicle				
Young	5, 2, 11 125, 38, 121	41, 18, 31 186, 68, 190	3, 0, 1 4, 4, 5	8, 4, 9 39, 11, 32
Medium	3, 0, 2 32, 15, 55	20, 5, 17 80, 29, 101	2, 0, 2 4, 1, 4	5, 3, 4 15, 4, 17
Old	-- 19, 11, 24	5, 4, 18 104, 38, 54	15, 3, 7 11, 6, 14	0, 1, 2 6, 4, 3
Other				
Young	1, 0, 4 102, 59, 121	13, 13, 20 119, 63, 95	1, 0, 1 5, 4, 2	2, 2, 5 18, 15, 21
Medium	1, 0, 1 75, 36, 72	10, 10, 21 107, 41, 100	1, 1, 4 15, 2, 5	3, 3, 5 18, 5, 20
Old	2, 1, 0 42, 42, 79	27, 19, 49 157, 149, 238	12, 3, 26 31, 42, 79	4, 2, 12 7, 3, 22

TABLE 5.2-4. Risk Factors in Frontal Impacts, by Accident Type, Occupant Age, and Vehicle Weight, Based on Data in Table 4.2-3. Estimates are pseudo-Bayesian, using frequencies for all single vehicles, and for all other accidents, respectively, as prior. In parentheses are the ranges corresponding to log(f) ± 1 sigma ranges. The true value of the risk factors should be in this range with a probability of about 2/3.

ACCIDENT TYPE	CAR WEIGHT				
OCCUPANT	LIGHT	MEDIUM	HEAVY	UNKNOWN	AVERAGE
Single Vehicle					
Young	.68 (.47-.98)	1.20 (1.00-1.44)	1.21 (.39-3.75)	0.92 (.62-1.37)	.98 (.85-1.12)
Medium	1.72 (.87-3.40)	1.20 (.90-1.59)	1.10 (.33-3.71)	1.20 (.68-2.12)	1.28 (1.16-1.42)
Old	--	.30 (.21-.43)	2.03 (1.29-3.19)	.42 (.16-1.08)	.63 (.35-1.14)
AVERAGE	**1.08** **(.68-1.72)**	**.76** **(.48-1.20)**	**1.39** **(1.15-1.68)**	**.77** **(.56-1.06)**	**.96** **(.81-1.14)**
Other					
Young	.54 (.31-.93)	.69 (.55-.86)	.68 (.17-2.68)	.68 (.39-1.20)	.64 (.60-.68)
Medium	.71 (.36-1.39)	.64 (.50-.82)	.22 (.10-.50)	.78 (.46-1.32)	.53 (.39-.71)
Old	1.58 (.87-2.88)	.83 (.70-.98)	.83 (.60-1.14)	.92 (.53-1.59)	1.00 (.86-1.17)
AVERAGE	**.85** **(.61-1.17)**	**.72** **(.66-.77)**	**.50** **(.33-.75)**	**.79** **(.72-.86)**	**.70** **(.61-.80)**

5.3 Fine impact classifications

For the "other" accidents, all but one of the cells have risk factors of less than 1. This is strong evidence for a pervasive effect, even though for half of the cells 1 is within the indicated error range. There is no apparent pattern among the cells. For single vehicle crashes, only 4 of the 11 cells have risk factors less than 1, only one has an error range definitely below 1, another just below 1. It may be noteworthy that old occupants have the two lowest risk factors, but they also have the highest risk factor. Overall there is no pattern that suggests an effect of the airbag for certain age groups or car weights in single-car crashes.

In other than single car crashes, there is an indication of a driver age effect; older drivers don't seem to benefit from the airbag, whereas for middle-age drivers the reduction is as large as 47% (-18/+14). There is a weaker suggestion of a car weight effect; occupants of heavy cars benefit most, those of light cars least; however, all error ranges overlap.

While it was necessary for the detailed analyses to aggregate impact points into the four broad categories "front," "left," "right," and "others" in order to maintain adequate cell frequencies, this aggregation may hide potentially important patterns (e.g., effect in left front impacts, clock directions 10 or 11). Therefore, risk factors were also calculated for each of the 12 clock positions, stratified only as single vehicle crash, or other accident. Since the actual factors sometimes fluctuated widely because of very low cell frequencies, again pseudo-Bayesian estimates were used, with the aggregate cell frequencies for single vehicle crashes, and other accidents, respectively as priors.

Figure 5.3-1 shows the pattern of risk factors for single vehicle crashes. In addition to the value of the factor, an error range is indicated. It is derived from an error range for the logarithm of r, ±1.28*sigma, which means that if the normal approximation holds, the true value could be with 10% probability below, with 10% probability above these limits. Figure 5.3-1 clearly shows the expected pattern; the risk is lower for the impact points 11, 12, and 1. There is no suggestion that the effect extends to the 10 and 2 impact points. There is no suggestion of a reduction for the left side impacts (8, 9, 10); the apparent increase at 8 o'clock is highly uncertain. This is not surprising because in these impacts passenger compartment intrusion is the obvious mechanism for injury. On the other hand, right side (2, 3, 4) impacts together appear to have slightly lower risks. Again, this is not surprising since a right side intrusion will only in rare cases affect the driver directly, and he will benefit in cases when the airbag deployed. However, because of the low cell frequencies, only the estimates for frontal impacts can be taken seriously. The pattern of the factors for 11, 12, and 1 suggests an effect increasing from 11 to 1. This is plausible, because an 11 o'clock impact is more likely to cause a passenger compartment intrusion and cause injury to the driver not preventable by the airbag than an impact at 1 o'clock. However, such a conclusion is speculative because the differences between the risk factors are too small to be significant.

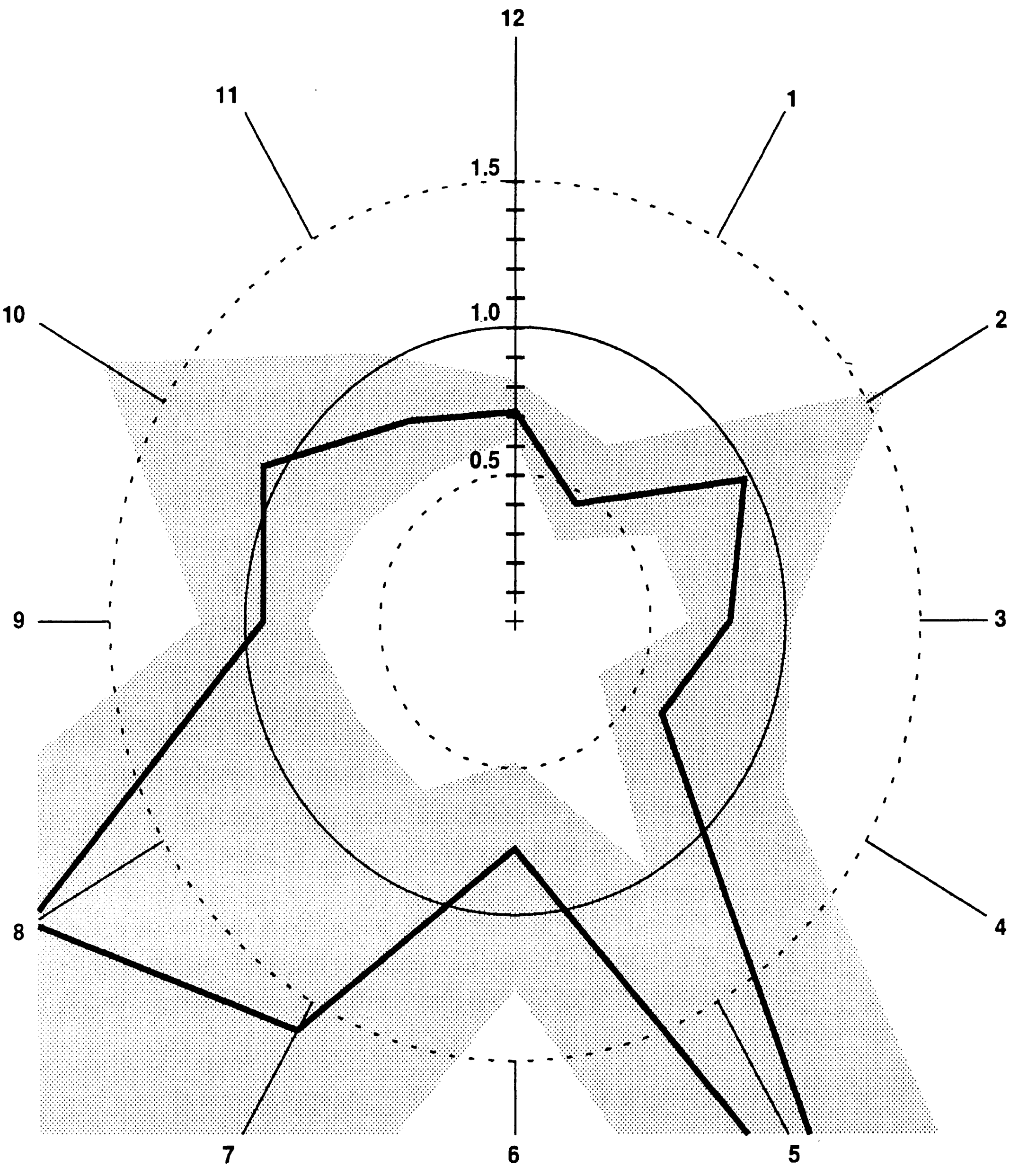

Figure 5.3-1. Risk factor in other than single vehicle crashes by clock position of first impact. The true value can be expected to be outside the shaded range, on each side, in 10% of the cases.

Figure 5.3-2 shows the risk factors for single vehicle crashes. No indication of a reduction appears. To the contrary, there is an increase of the risk for 2 o'clock impacts which is better than 10% significant (one-sided). However, with 12 impact points and a 10% significance level one can expect one point to appear significantly higher due to chance.

Figure 5.3-3 shows the risk factors for all accidents combined. There is still an indication of a risk reduction for frontal impacts, but only for 12 o'clock does it reach significance at the 10% (one-sided) level. However, the apparent increase of risk at 2 o'clock observed in single vehicle crashes remains, and has the same level of significance. A closer look explains this: even in "other" crashes (Figure 5.3-1) the risk reduction at 2 o'clock is less than for the other nearby clock positions.

In sum, the detailed graphs show an effect of airbags only for frontal impacts in other than single vehicle crashes. There is a weak suggestion that the risk reduction is lowest in 11 o'clock impacts, higher for 12 o'clock impacts, and highest for 1 o'clock impacts. There is also a stronger suggestion that drivers of airbag cars have a higher risk than drivers of nonairbag cars in single vehicle crashes with 2 o'clock impacts.

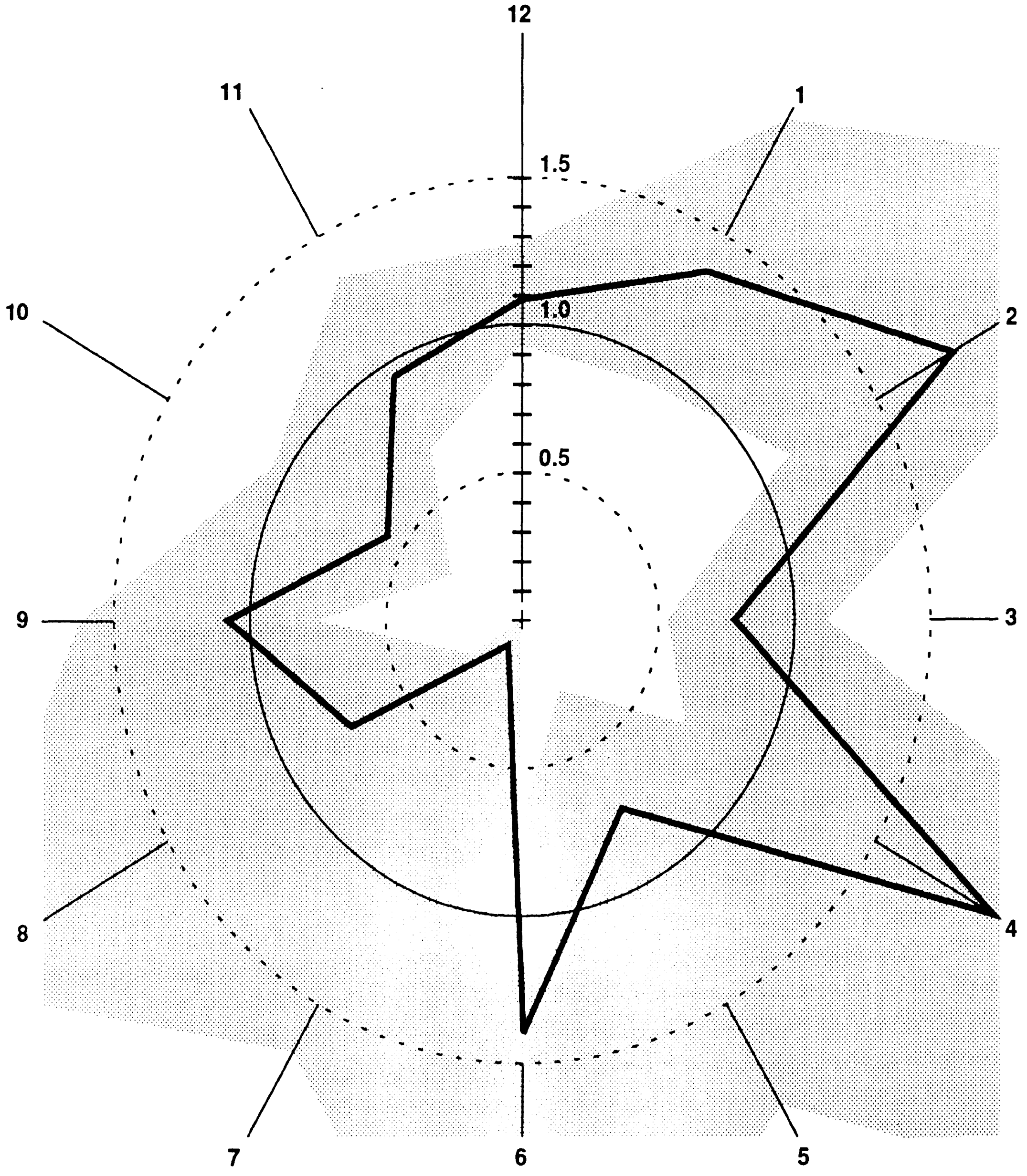

Figure 5.3-2. Risk factor in single vehicle crashes. The true value can be expected to be outside the shaded range, on each side, in 10% of the cases.

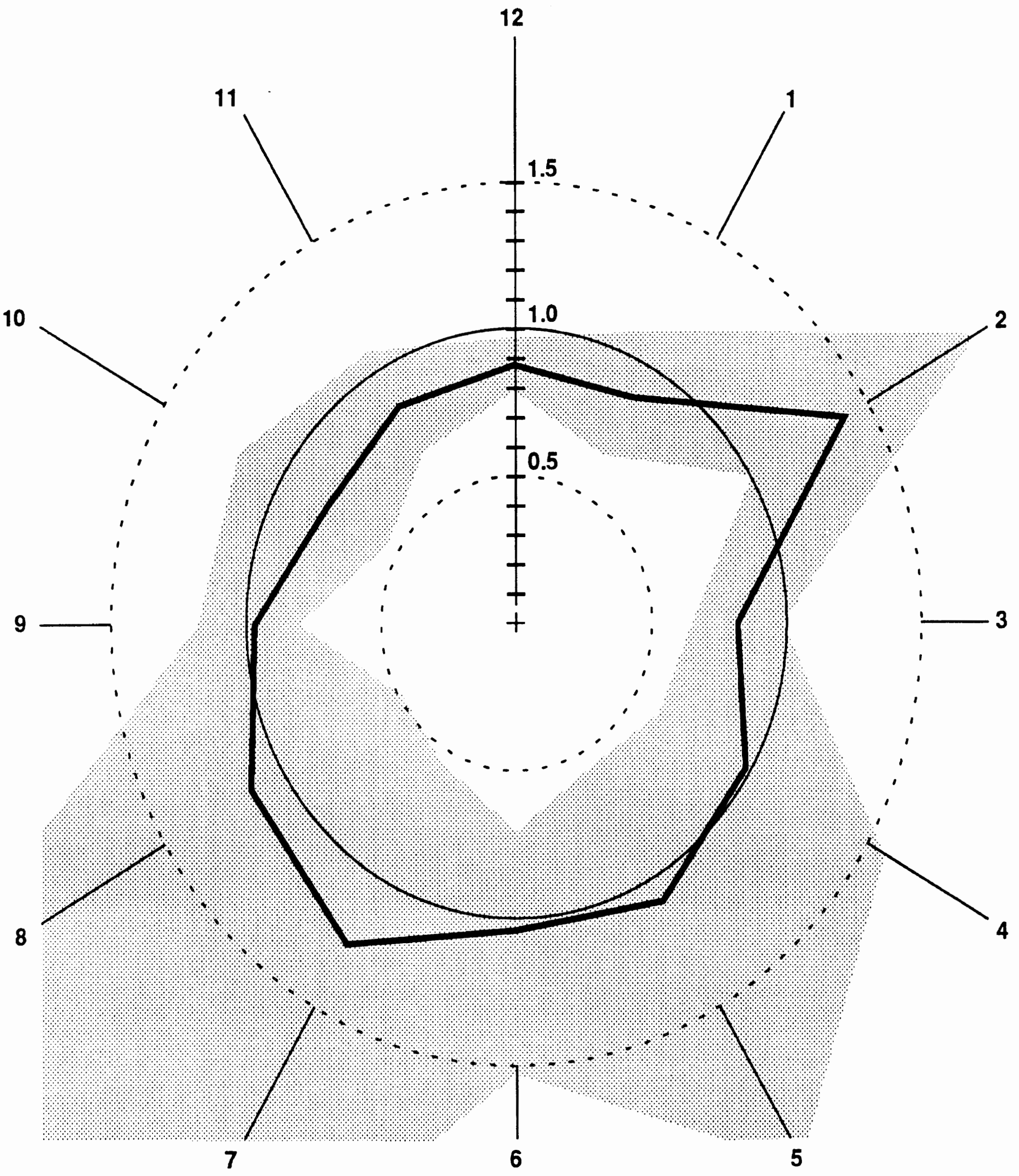

Figure 5.3-3. Risk factor in all crashes. The true value can be expected to be outside the shaded range, on each side, in 10% of the cases.

5.4 Summary for occupant comparisons

For accidents where at least the driver and right-front-seat passenger are in the car, we found an overall fatality risk reduction of 8%(±4) for the driver in cars with driver side airbags. There was no reduction in other than frontal impacts, the reduction was 16%(±6) in frontal impacts. In frontal impacts, there was a reduction of 30%(-10/+9) for other than single vehicle accidents; a simple standardization for driver age and vehicle weight did not change this value. There was no reduction in single vehicle accidents.

Beyond these fairly firm overall conclusions, the data allow only some speculations. One is that the effect is limited to 11, 12, and 1 o'clock impact points in other than single vehicle crashes; it does not extend to 10, nor to 2 o'clock. The data are compatible with the hypothesis that the risk reduction is least for 11 o'clock, greatest for 1 o'clock impacts.

There is a fairly strong indication that older drivers don't benefit from the airbag, whereas middle age drivers benefit most.

The data are compatible with the hypothesis that drivers of heavier cars benefit most, those of light cars least from the airbag; however, they do not support any conclusions to that effect.

A curious point is the apparent increase in the risk for drivers of airbag cars in single vehicle crashes with 2 o'clock impacts. While this may well be due to chance, it may merit further attention.

It must be emphasized that no control for crash severity in terms of delta-v was possible. Therefore, differences between single vehicle and other crashes may well be due to differences in crash severity. Also, apparent effects of driver age (or lack of effects) may be due to confounding by crash severity.

6. Distributions of fatalities over impact points

6.1 Approach

One expects airbags to have the largest effect on driver fatality risk in frontal impacts, less in other impact areas, and least, if any, in impacts at the driver's door (9 o'clock). For right-front-seat occupants one expects this for impacts at the right front door (3 o'clock). If one is willing to assume no airbag effect in these impacts, one can compare the distributions of deaths by impact point, relative to 9 o'clock (or 3 o'clock) between airbag and nonairbag cars, and estimate the effect of airbags on the fatality risk. An additional assumption is that airbag cars have the same accident pattern as nonairbag cars (e.g., intersection and section accidents, etc). If x_i is the number of deaths in airbag cars for impact point I, and y_i that for nonairbag cars, then

$$f_i = \frac{x_i}{x_9} / \frac{y_i}{y_9}$$

is the factor by which airbags reduce the fatality risk in impacts at clock position i.

If the x_i and y_i are independently distributed Poisson-variables, the standard error of f_i is approximately

$$\text{stderr}(f_i) = f_i\sqrt{1/x_i + 1/y_i + 1/x_9 + 1/y_9}$$

For small x_i and y_i, the approximation is not very good. Also, the assumption that the x_i and y_i are Poisson-variables is probably not quite realistic. However, this formula is commonly used. Under statistical aspects, the choice of 9 o'clock impacts as "base" is favorable because the number of deaths in such impacts is large, second only to 12 o'clock impacts.

In addition to the fatality risk for specific impact points, one can also estimate the overall reduction of the fatality risk due to airbags. If x_o and y_o are the drivers killed in other than 9 o'clock impacts, one would expect $x_9(y_o/y_9)$ drivers of airbag cars to be killed if airbags had no effect. With airbags x_o are killed, and the ratio

$$f_a = \frac{x_9 + x_0}{x_9 + x_9(y_0 / y_9)}$$

is the factor by which airbags reduce all deaths in airbag cars. Again, under the assumption that x_9, x_9, y_o, and y_9 are independent Poisson-distributed variables, the standard error of f_a can be approximated by

$$\text{stderr} = f_a\sqrt{1/x_9 - 1/(x_0 + x_9) + 1/y_9 - 1/(y_0 + y_9)}$$

These analyses can also be performed with subsets of the data, disaggregated (e.g., by driver characteristics, vehicle characteristics, and environmental characteristics). For example, angle collisions and therefore 9 o'clock impacts tend to be more frequent for older drivers, frontal collisions for younger drivers. Disaggregating by driver age and other factors reduces such confounding effects.

With this approach, one can also try to account for the effect of seatbelts with some degree of credibility. While belt use information for noninjured, and probably also for not severely injured occupants is highly suspect and nearly certainly exaggerated, it is more likely to be correct for killed occupants, many of which the reporting police officer can directly observe at the accident scene. Since this analysis relies only on killed occupants, the information on seatbelt use is likely to be more reliable. The reported belt use was the same for killed drivers in airbag and in nonairbag cars, 33%.

6.2 Data

Selected were crash involvements of passenger cars where the driver was killed. All airbag cars were used, but for nonairbag cars only those of the same model year as airbag cars (1987 and later) to avoid comparing cars that might differ too much in other characteristics. Information from occupant, vehicle, and accident files was merged.

A total of 21,466 fatal involvements was selected. The actual number used depended on the variables included in the analysis. Car weight for instance, was not available for 2,137 involvements.

There were 4,352 cars where the right front seat occupant was killed in cars of model year 1989 or later, when passenger-side airbags became available. However, for 634 cars the weight was unknown, and 1,038 cases were lightweight cars, none of which had a passenger-side airbag. Therefore, lightweight cars had to be excluded from this analysis.

6.3 Drivers

All comparisons were based on the assumption that airbags have no effect on the driver fatality risk in 9 o'clock impacts. Risk factors for specific impact points, and overall risk factors were calculated as discussed in section 6.1.

Table 6.3-1a shows the risk factors for airbags for all drivers, belted drivers, and unbelted drivers for frontal (11 o'clock - 1 o'clock) impacts, and the overall risk factor. Table 6.3-1b shows a finer breakdown for forward impact points, and for non-collision (rollovers). Figures 6.3-1a-c- show the same information in greater detail for all frontal impact positions 11 o'clock - 2 o'clock.

TABLE 6.3-1a. Driver Fatality Risk Factors For Airbags and Seatbelts, by Type of Impact, and Overall Risk Factor.
n_1 and n_2 are the numbers of nonairbag, and of airbag cars, or of unbelted and of belted drivers. Standard errors of the factors are in parentheses.

	AIRBAG FACTOR			BELT FACTOR	
IMPACT	ALL DRIVERS	BELTED DRIVERS	UNBELTED DRIVERS	AIRBAG CARS	NO BAG CARS
Frontal (11 - 1)	0.81(.05)	0.70(.06)	0.89(.07)	0.65(.03)	0.52(.06)
Overall	0.90(.04)	0.83(.05)	0.96(.06)	0.68(.02)	0.59(.05)
Case Numbers					
n_1	18,644	6,272	12,372	12,372	1,887
n_2	2,822	935	1,887	6,272	935

TABLE 6.3-1b. Driver Fatality Risk Factors For Airbags and Seatbelts, by Impact Point. Standard errors of the factors are in parentheses.

	AIRBAG FACTOR			BELT FACTOR	
IMPACT	ALL DRIVERS	BELTED DRIVERS	UNBELTED DRIVERS	AIRBAG CARS	NO BAG CARS
Non-collision	1.10(.10)	0.86(.17)	1.21(.13)	0.26(0.5)	.36(.03)
10	1.02(.11)	1.29(.21)	0.85(.13)	1.16(.23)	.76(.06)
11	0.92(.07)	0.76(.10)	1.03(.10)	0.50(.08)	.68(.42)
12	0.75(.04)	0.66(.06)	0.80(.06)	0.54(.06)	.66(.03)
1	1.07(.10)	0.93(.17)	1.15(.14)	0.41(.08)	.51(.04)
2	1.07(.14)	0.93(.22)	1.17(.19)	0.52(.14)	.65(.07)

There is a clear effect of airbags: a 10% overall reduction in the fatality risk. However, it is due mainly to reducing the risk in frontal (11 - 1) impacts, where it is 19%, and even more specifically in 12 o'clock impacts where it is 25%.

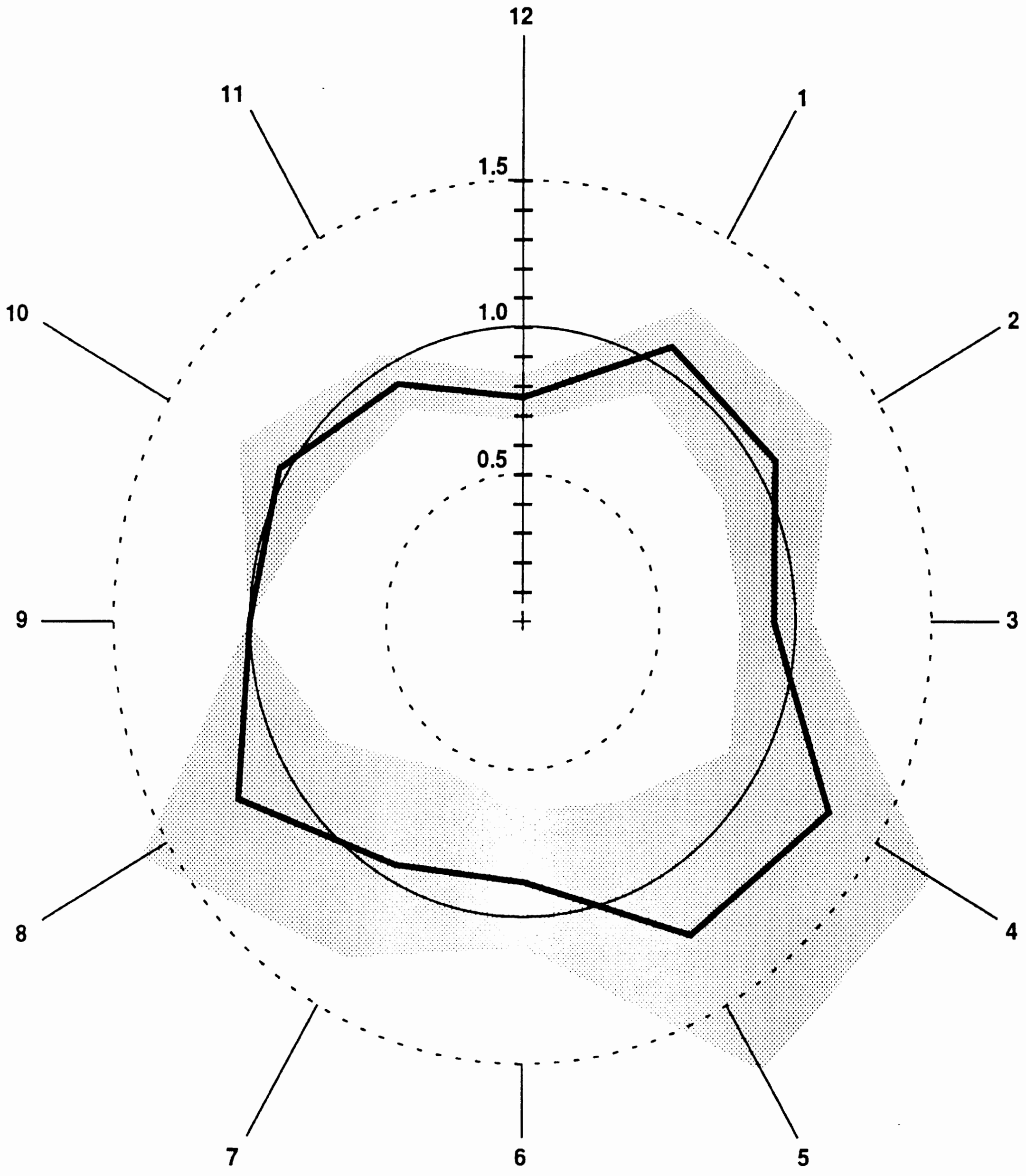

Figure 6.3-1a. Risk factor by impact point, based on the assumption of no airbag effect in 9 o'clock impacts. The true value will be outside the shaded area on each side with a probability of 5%.

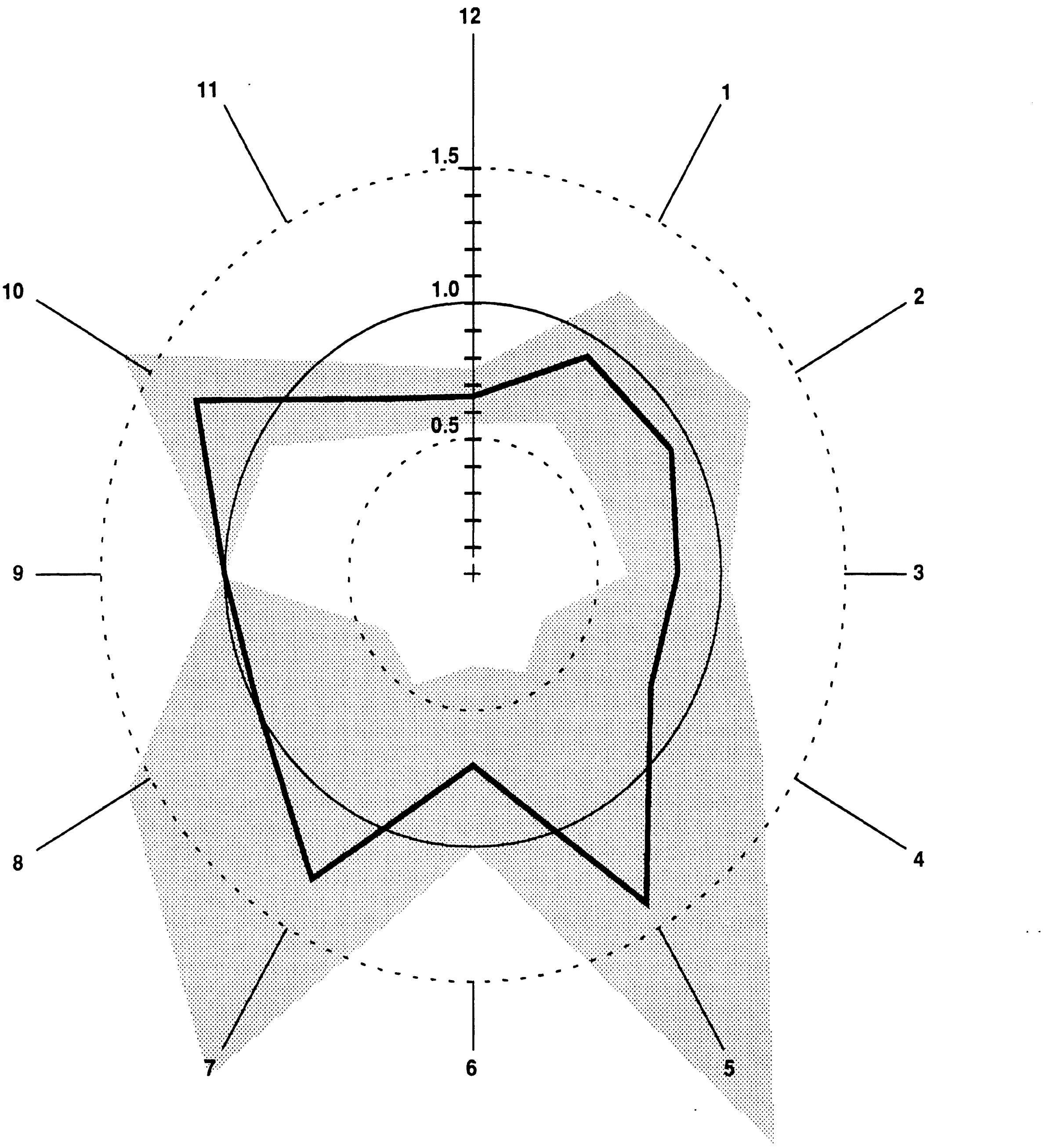

Figure 6.3-1b. Risk factor by impact point, for belted drivers, based on the assumption of no airbag effect in 9 o'clock impacts. The true value will be outside the shaded area on each side with a probability of 5%.

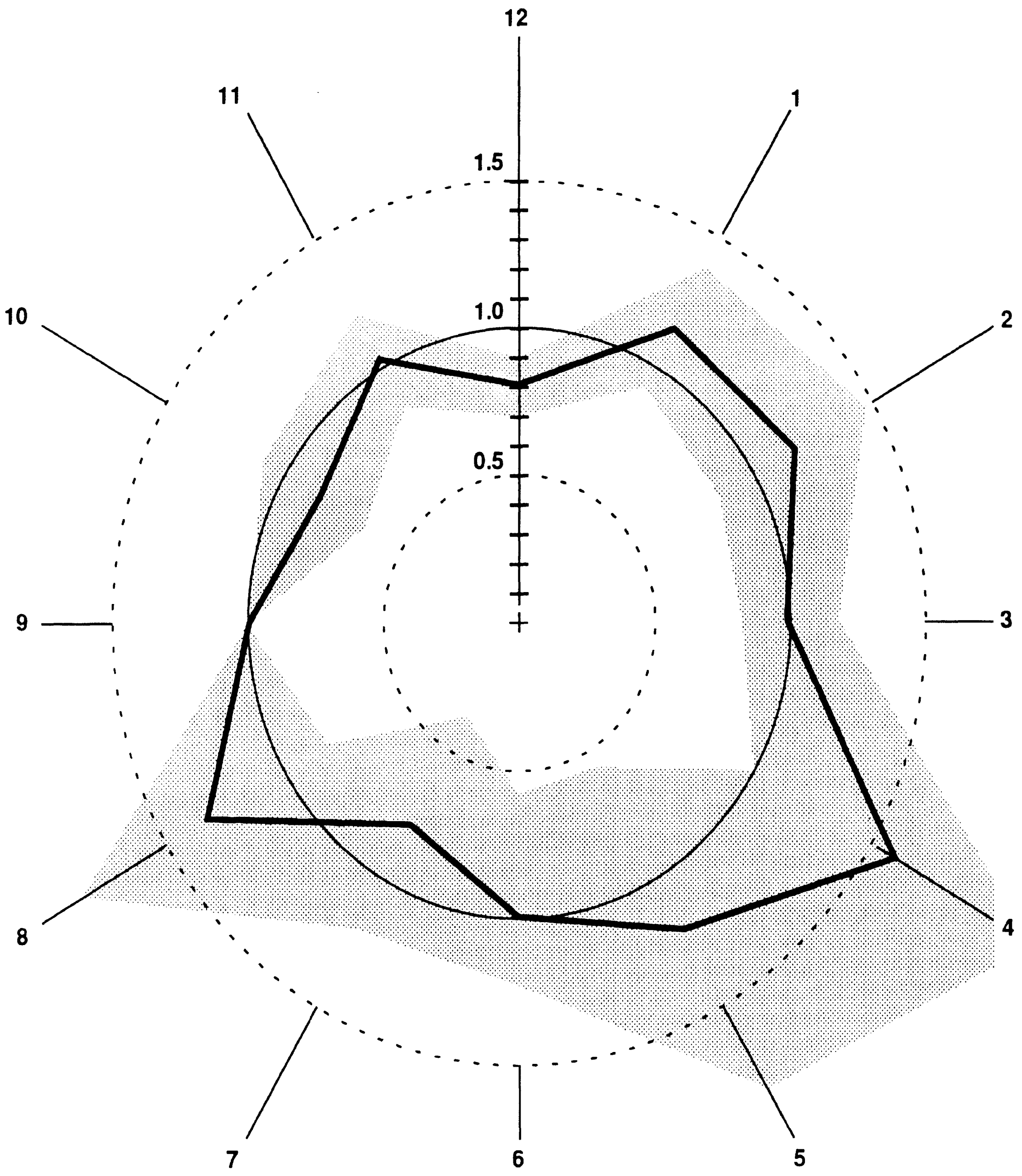

Figure 6.3-1c. Risk factor by impact point, for unbelted drivers, based on the assumption of no airbag effect in 9 o'clock impacts. The true value will be outside the shaded area on each side with a probability of 5%.

If one distinguishes belted and unbelted drivers, belted drivers benefit more from airbags than unbelted drivers in addition to the risk reducing benefits of belts. There is also a slight indication (significant only for 11 o'clock) that belted drivers benefit from the airbag in all frontal impacts.

Tables 6.3-1a and b, and Figures 6.3-2a and b also show the risk reduction due to belts, for drivers of airbag cars and of other cars. In nonairbag cars, belts provide a large risk reduction in all impact directions and also in rollovers. In airbag cars, they also provide a risk reduction in nearly all impacts and in rollovers. It is noteworthy that their effects are largest in 1 o'clock impacts, where airbags tend to have less of an effect.

Tables 6.3-2a and b, and Figure 6.3-3 show similar information, disaggregated by car weight. The striking feature is that there is no apparent effect for lightweight cars. For midweight cars, only belted drivers show a significant overall effect, together with a clear effect in frontal impacts. Unbelted drivers show an effect only for 12 o'clock impacts. Heavy cars show a large reduction of 31% for unbelted, and 40% for belted drivers; they also show large reductions in all frontal impacts.

Figure 6.3-4 shows this information for all drivers, regardless to belt use, for all impact points. There are slight numerical differences, because this Figure is calibrated on the assumption of no airbag effect in all 2 o'clock - 10 o'clock impacts.

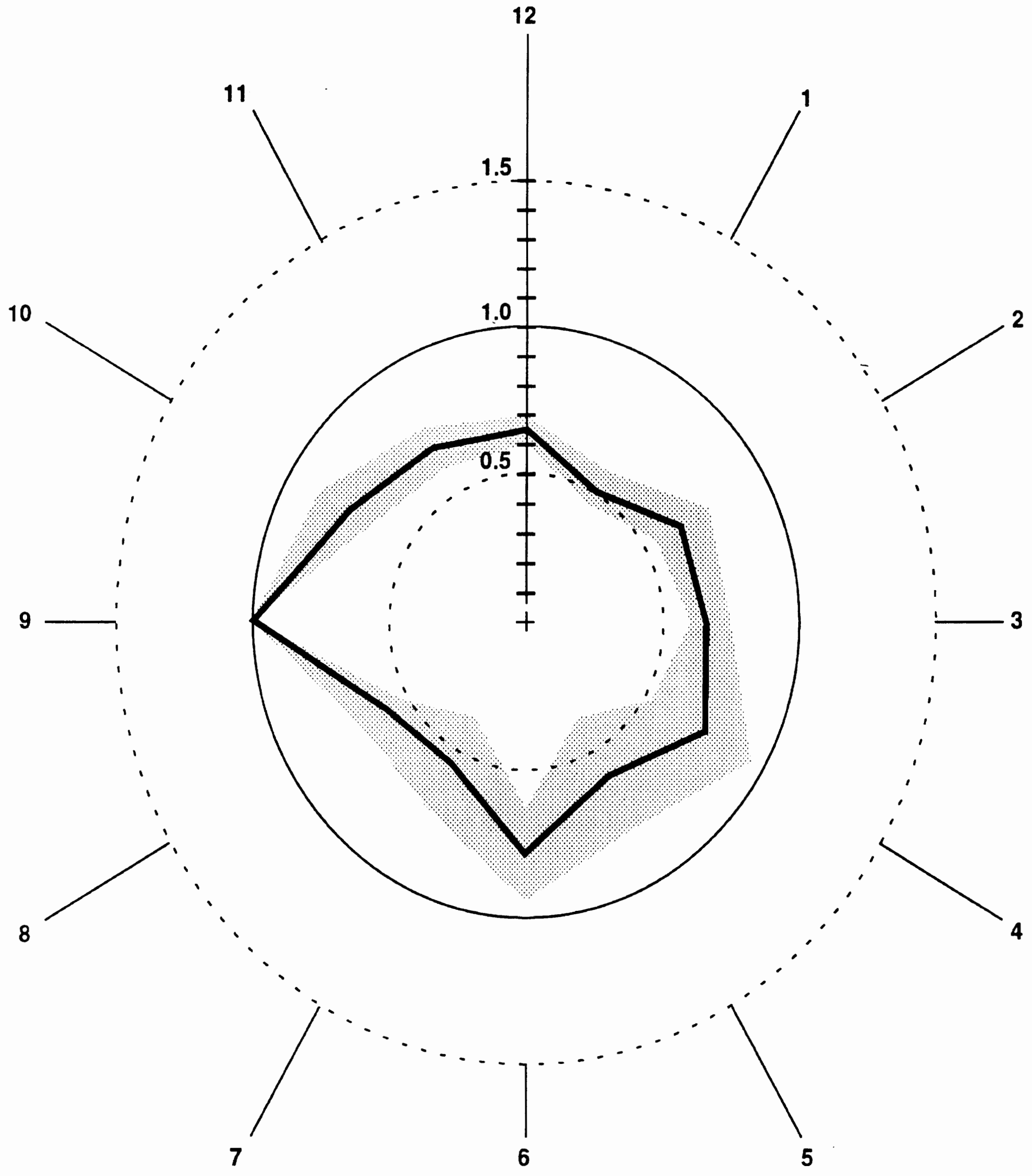

Figure 6.3-2a. Risk factor for seatbelts in no-airbag cars, by impact point: based on the assumption of no airbag effect in 9 o'clock impacts. The true value will be outside the shaded area on each side with a probability of 5%.

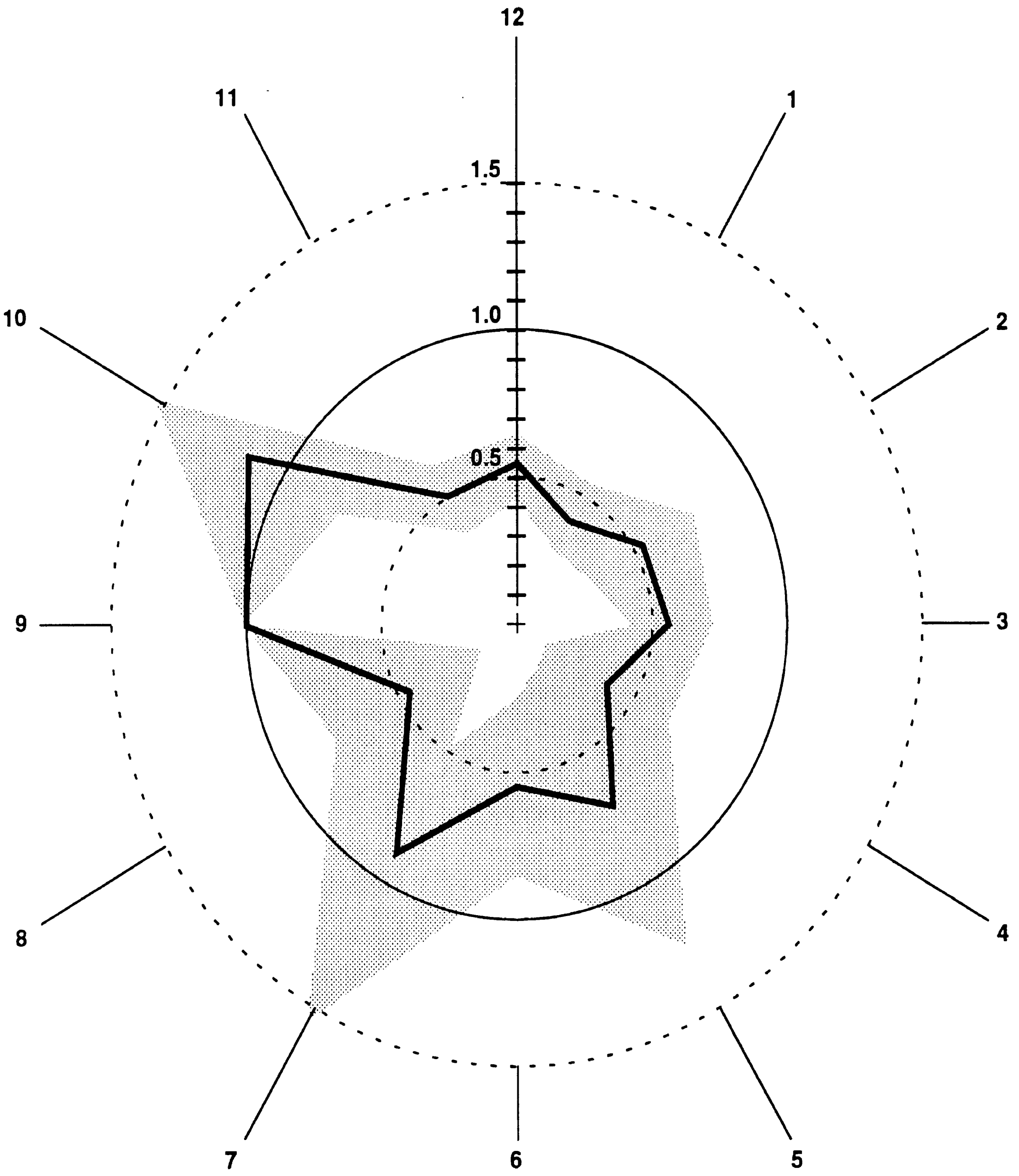

Figure 6.3-2b. Risk factor for seatbelts in airbag cars, by impact point: based on the assumption of no airbag effect in 9 o'clock impacts. The true value will be outside the shaded area on each side with a probability of 5%.

TABLE 6.3-2a. Driver Fatality Risk Factors by Car Weight, Belt Use and Impact Type, and Overall Risk Factors. n_1 and n_2 are the numbers of nonairbag, and of airbag cars. Standard errors of the factors are in parentheses.

IMPACT	ALL DRIVERS	BELTED	UNBELTED
	Heavy		
Frontal (11 - 1)	0.52(.08)	0.44(.11)	.58(.12)
Overall	0.64(.08)	0.60(.11)	.69(.12)
Case Numbers			
n_1	938	318	620
n_2	499	181	318
	Midweight		
Frontal (11 - 1)	0.85(.06)	0.73(.09)	0.91(.09)
Overall	0.96(.06)	0.87(.07)	1.02(.08)
Case Numbers			
n_1	9,641	3,238	6,403
n_2	1,661	518	1,143
	Light		
Frontal (11 -1)	1.28(.31)	1.40(.59)	1.19(.35)
Overall	1.36(.29)	1.53(.55)	1.25(.32)
Case Numbers			
n_1	6,383	2,040	4,343
n_2	207	59	148

TABLE 6.3-2b. Driver Fatality Risk Factors by Car Weight, Belt Use and Impact Point. Standard errors of the factors are in parentheses.

IMPACT	ALL DRIVERS	BELTED	UNBELTED
	Heavy		
Non collision	.98(.26)	1.30(.64)	.93(.31)
10	.80(.25)	.98(.44)	.63(.28)
11	.55(.16)	.44(.17)	.71(.20)
12	.48(.08)	.42(.11)	.54(.11)
1	.71(.20)	.66(.30)	.80(.27)
2	.69(.23)	.57(.22)	.79(.35)
	Midweight		
Non-collision	1.20(.14)	.74(.21)	1.35(.19)
10	1.29(.16)	1.38(.28)	.96(.18)
11	1.01(.11)	.94(.16)	1.06(.14)
12	0.78(.06)	.70(.09)	.83(.08)
1	1.06(.14)	.56(.17)	1.29(.20)
2	1.23(.22)	.80(.28)	1.44(.29)
	Light		
Non-collision	2.64(.81)	3.36(2.15)	2.30(.81)
10	1.43(.58)	1.25(1.02)	1.42(.67)
11	1.41(.44)	0.77(0.54)	1.55(.56)
12	1.17(.29)	1.55(0.67)	.99(.30)
1	1.95(.67)	1.34(0.67)	1.94(.76)
2	.84(.52)	2.40(1.96)	.35(.36)

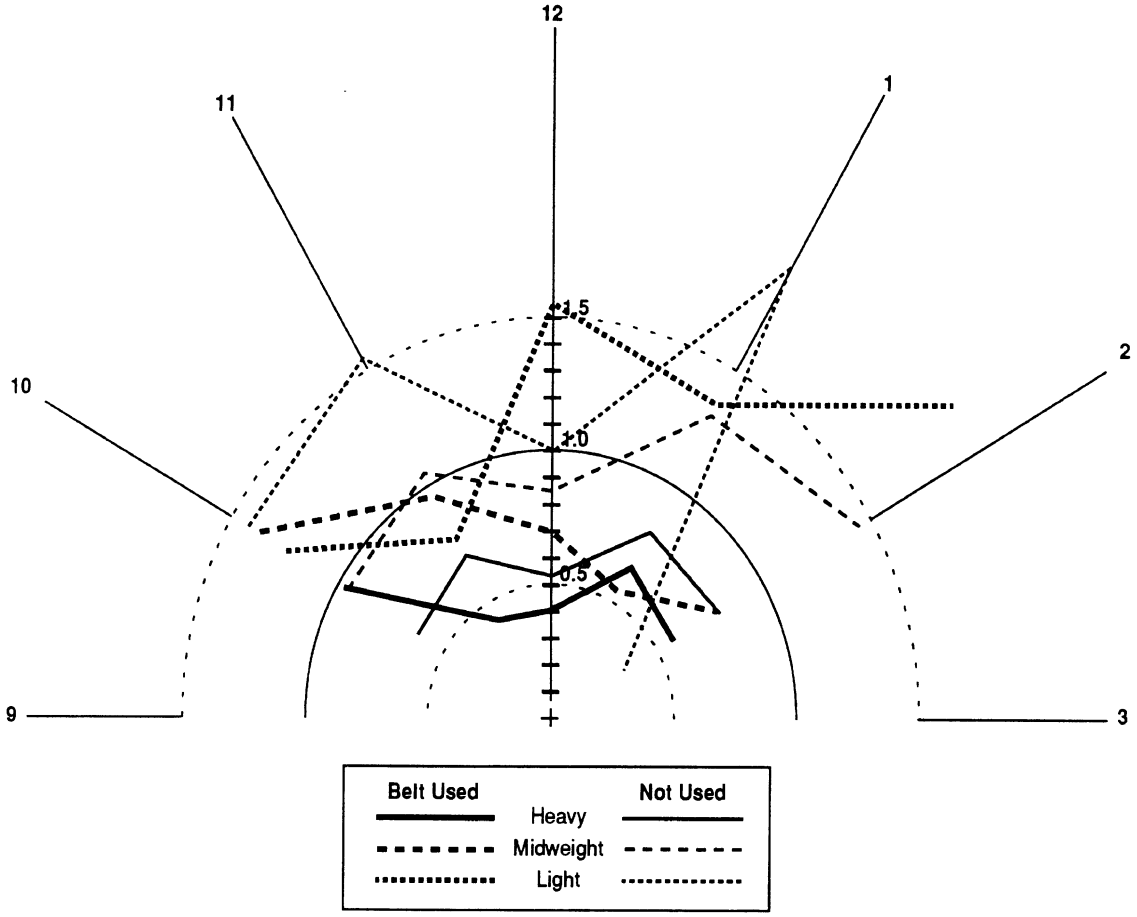

Figure 6.3-3. Risk factor for airbags, by belt use and car weight. Only the forward impact points are shown. All estimates are based on the assumption that airbags have no effect in 9 o'clock impacts.

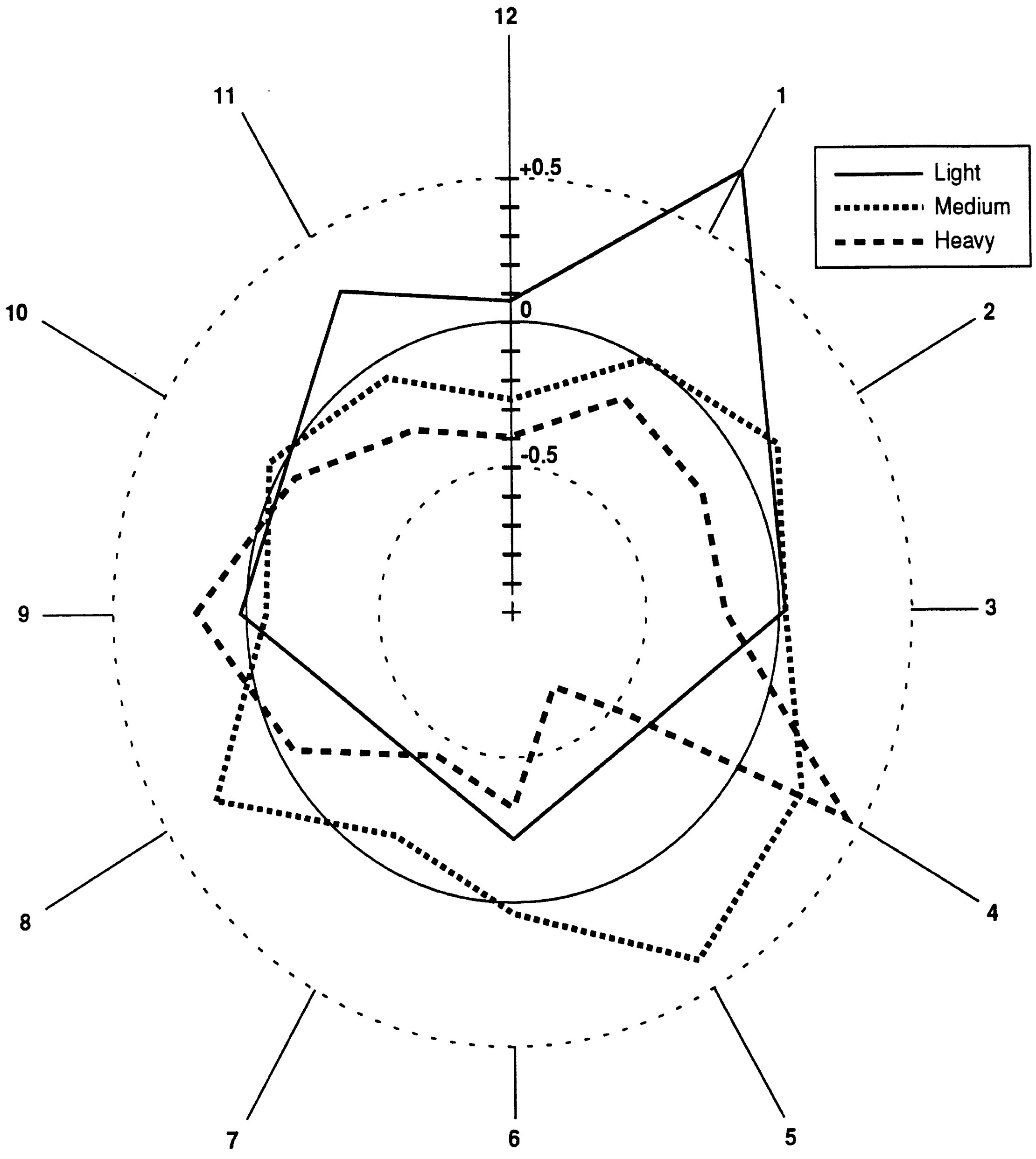

Figure 6.3-4. Risk factor by impact point and car weight. Estimates are based on the assumption of no airbag effect in 2 o'clock - 10 o'clock impacts.

Some time ago, airbags were advocated as "passive protection." Now they are called "supplementary restraint systems." Table 6.3-3 sheds some light on this distinction. It compares unbelted drivers in airbag cars with belted drivers in nonairbag cars; the risk factor shows how much an airbag alone reduces the fatality risk relative to belts alone. The results are striking. The risk in non-collisions is dramatically increased (though not statistically significant for heavy cars), presumably because the airbag does not prevent ejection. Even in frontal impacts, a risk reduction appears only in heavy cars, and it is not significant. It is obvious that airbags do not offer "passive protection" as an alternative to belts, but must be considered "supplementary restraint systems" with beneficial effects as shown in Tables 6.3-1 and 6.3-2.

TABLE 6.3-3. Risk Factor for Drivers in Airbag Cars Not Using Seatbelts Compared With Drivers in Nonairbag Cars Using Seatbelts. Based on the assumption that neither airbags nor seatbelts have an effect in 9 o'clock impacts.

IMPACT	HEAVY	MIDWEIGHT	LIGHTWEIGHT
Non collision	2.36(1.04)	3.64(.59)	8.39(3.14)
Frontal (11 - 1)	0.80(.18)	1.41(.14)	1.86(.55)
Overall effect	0.92(.17)	1.49(.12)	1.91(.50)

Table 6.3-4 shows risk factors by driver age. Differences between the three younger age groups are relatively small and rarely exceed one standard error. For the oldest age group, however, the factors are larger and do not significantly differ from 1. It appears as if the airbag has no effect for drivers over 65. Figure 6.3-5 shows corresponding data in greater detail, but aggregating the two oldest groups. Again, the calibration is based on all 2 o'clock - 10 o'clock impacts.

TABLE 6.3-4. Risk Factor by Driver Age. Based on the assumption that airbags have no effect in 9 o'clock impacts.

IMPACT	UP TO 25	26 - 45	46 - 65	OVER 65
Non-collision	1.10(.18)	1.12(.17)	1.30(.28)	1.20(.35)
Frontal (11 - 1)	0.82(.10)	0.79(.08)	0.71(.08)	0.96(.11)
Overall effect	0.97(.10)	0.89(.08)	0.81(.08)	0.99(.08)
Case Numbers				
n_1	5,589	6,225	3,324	3,501
n_2	747	937	551	585

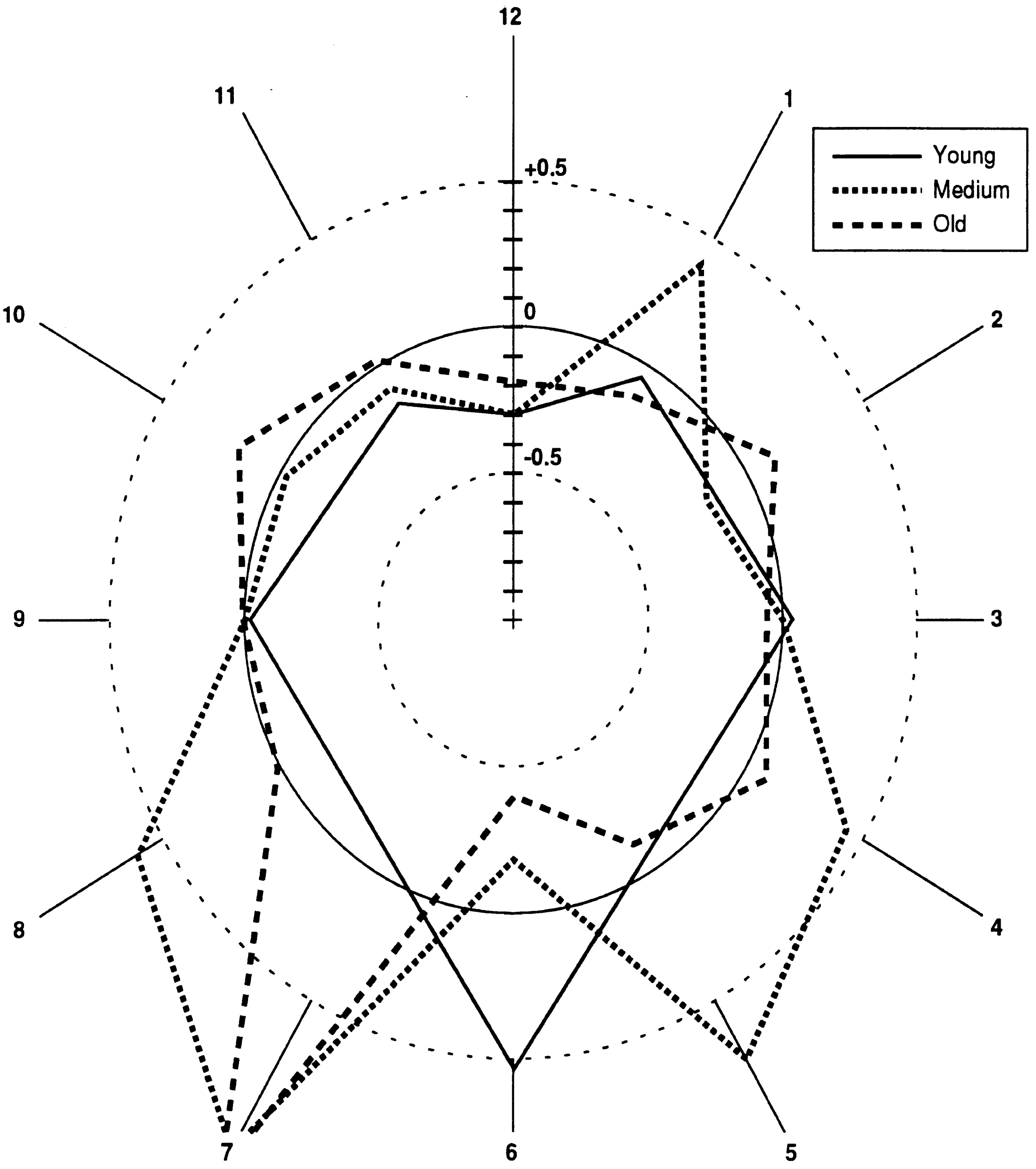

Figure 6.3-5. Risk factor by impact point and driver age. Estimates are based on the assumption of no airbag effect in 2 o'clock - 10 o'clock impacts.

Table 6.3-5 shows the risk factor by speed limit, which may be a gross indication of travel speed. Differences between the speed limits are well within the error limits. However, the more detailed data shown in Figure 6.3-6 (again using a slightly different calibration, assuming no airbag effect for 2 o'clock - 10 o'clock impact) suggest a somewhat lower effect for the lower speed range, and no difference between the two higher speed ranges.

TABLE 6.3-5. Risk Factor by Speed Limit. Based on the assumption of no airbag effect in 9 o'clock impacts.

	SPEED LIMIT		
IMPACT	**UP TO 35**	**40 - 50**	**55 AND OVER**
Non-collision	1.64(.43)	1.30(.30)	1.05(.12)
Frontal (11 - 1)	0.86(.10)	0.85(.09)	0.78(.06)
Overall effect	0.92(.08)	0.96(.08)	0.88(.06)
Case numbers			
n_1	3,293	4,570	10,435
n_2	542	701	1,530

Table 6.3-6. shows risk factors by single and multivehicle accidents, and Figure 6.3-7 show corresponding data in greater detail. There appears to be no difference in effectiveness. This contrasts with the findings of section 5.2.

TABLE 6.3-6. Risk Factor by Single/Multivehicle Accident. Based on the assumption of no airbag effect in 9 o'clock impacts.

IMPACT	**SINGLE VEHICLE**	**MULTI-VEHICLE**
Non-collision	.80(.09)	2.25(1.50)
Frontal (11 - 1)	.72(.07)	0.76(.06)
Overall effect	.80(.07)	0.86(.05)
Case numbers		
n_1	7,943	10,701
n_2	1,453	1,047

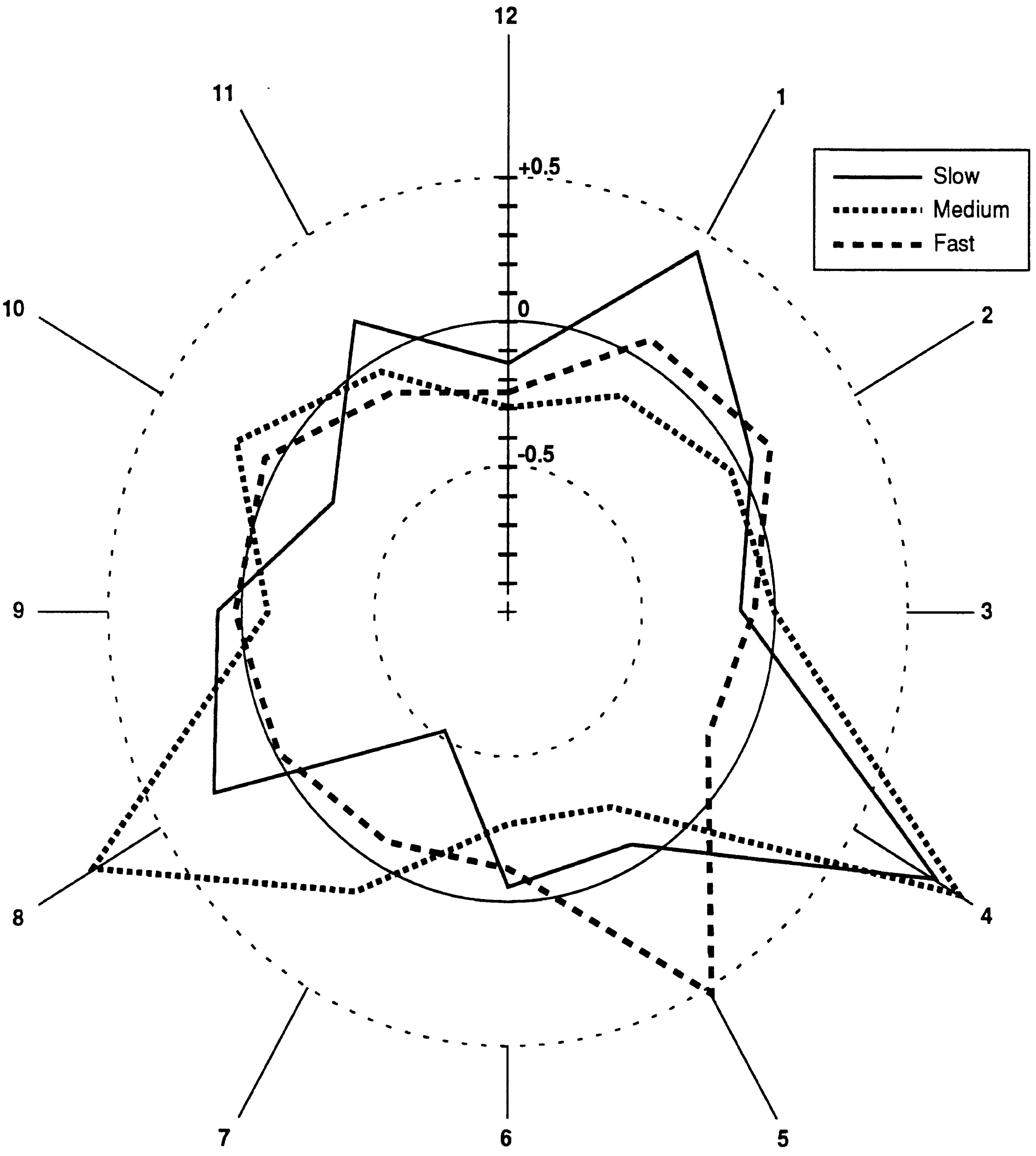

Figure 6.3-6. Risk factor by impact point and speed limit. Estimates are based on the assumption of no airbag effect in 2 o'clock - 10 o'clock impacts.

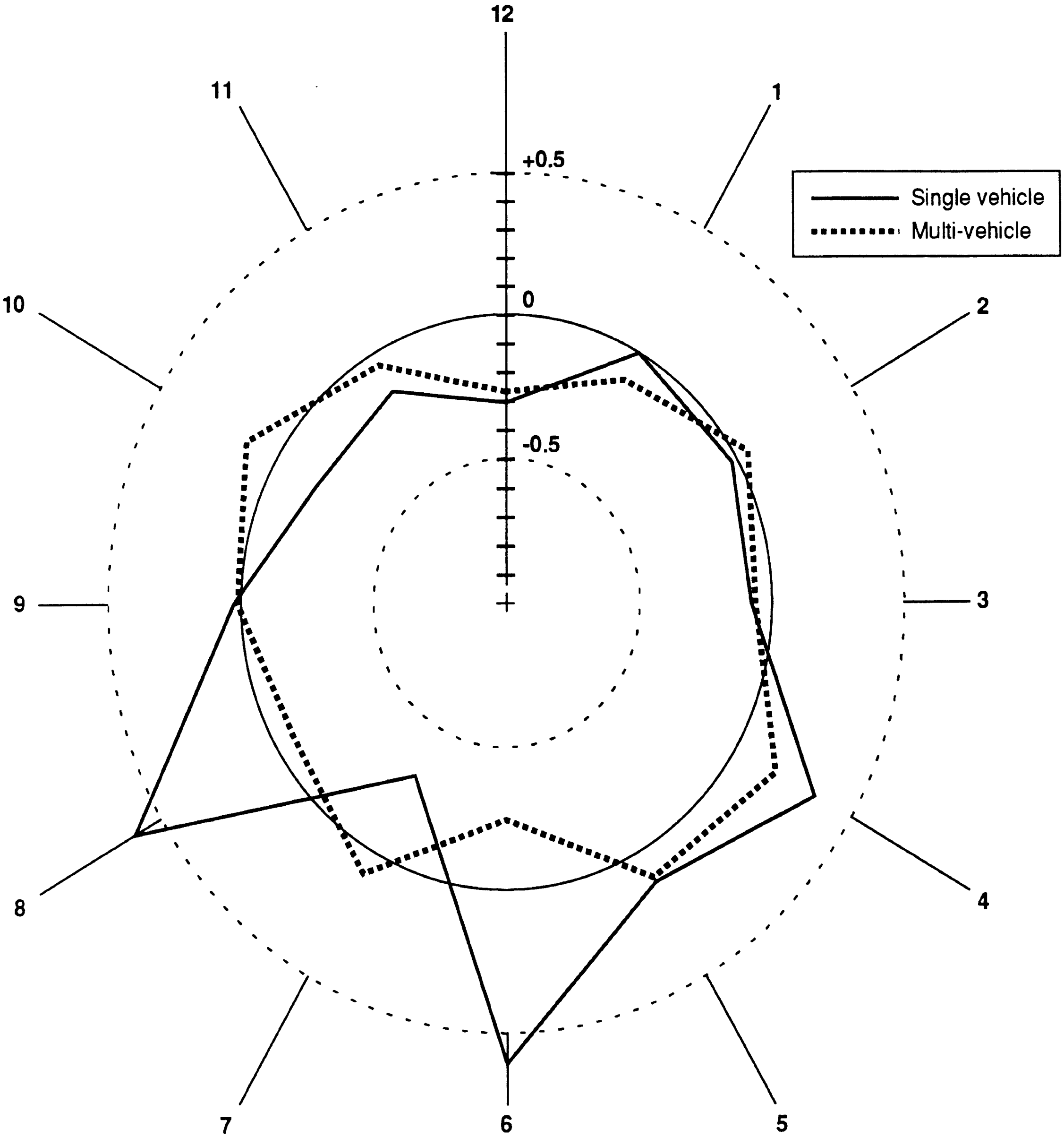

Figure 6.3-7. Risk factor by speed limit and single/multivehicle accident. Estimates are based on the assumption of no airbag effect in 2 o'clock - 10 o'clock impacts.

6.4 Passengers

Corresponding to the assumption that airbags do not reduce the fatality risk for drivers in 9 o'clock impacts, we assumed that passenger side airbags have no effect for right-front-seat passengers in 3 o'clock impacts.

Since the number of cases was very small, only a few simple comparisons could be made. Lightweight cars had to be excluded, because none had airbags; including these in the analysis would have resulted in an exaggerated estimate for airbag effectiveness. Therefore, separate estimates were made only for midweight and heavy cars. The total number of airbag cars was only 58; meaningful estimates could be made only for frontal impacts, 11 o'clock to 1 o'clock, but not for a finer impact classification. Table 6.4-1 shows the data and the resulting risk factors. There is no indication of an effect for heavy cars, but very large reductions for midweight cars, which would be extremely significant if one felt that a test would be appropriate.

TABLE 6.4-1. Case Numbers and Risk Factor for Right-Front-Seat Passengers. The numbers in the "no airbag" and "airbag" columns are actual case counts, the "factor" shows how much the airbag reduces the fatality risk for the frontal impacts 11 o'clock - 1 o'clock. The "overall" factor combines this with the assumption of no effect for 3 o'clock impacts.

	HEAVY				MIDWEIGHT			
IMPACT	NO AIRBAG	AIRBAG	FACTOR	STANDARD ERROR	NO AIRBAG	AIRBAG	FACTOR	STANDARD ERROR
3	61	8			497	8		
11 - 1	137	23	1.28	(.38)	1,205	5	0.25	(.15)
Total	294	43			2,328	15		
Overall factor			1.12	(.56)			0.40	(.08)

To some extent, this surprising finding might be due to differences in the age distributions of passengers. In heavy cars, 73% in the nonairbag, and 56% in the airbag cars are over 65, in midsize cars the corresponding figures are 32% and 27%. Since we found (section 6.3) no effect for this age group, a smaller effect and no recognizable effect for heavier cars is not surprising.

We might also note that in section 3.4 we found indications of a risk reduction for passengers only in midsize, but not in large cars (24% from the weighted estimates, though none in the unweighted estimates).

7. Discussion and Summary of Findings

No data are available that allow a conceptually sound and numerically precise estimation of airbag effectiveness. NASS CDS data would allow a sound evaluation, but the case numbers are too small to achieve a meaningful precision.

Because of this lack of data, evaluations of airbag effectiveness have to be based on special crash types, or to rely critically on certain assumptions. Evaluations for special crash types can be conceptually sound, but case numbers are smaller, and the results may not hold for other crash types. When relying on assumptions, the results are only as good as the validity of the assumptions. To rigorously assess the validity of the assumptions, one needs exactly the data one would need for a direct evaluation of airbag effectiveness. However, certain assumptions may be plausible on the basis of past studies, or other evidence.

Therefore, we used a number of alternative approaches, two relying on selected crash types, two relying on certain assumptions. The differences of the results demonstrate that it is not sufficient to select one approach that appears promising. Even if the results appear numerically precise and the patterns plausible, they may give only a very one-sided picture of the situation.

The first approach has frequently been used. It studies vehicle occupant fatality rates per registered vehicle year. In its simplest implementation this approach assumes that differences in the fatality rates are due to vehicle differences, be it in crash risk or crashworthiness. This is clearly an implausible assumption, and sometimes attempts are made to control for the influence of other factors, though this is not rigorously possible.

Using this approach we encountered several problems. Combining files with car registration data with files with airbag availability was not simple, and non-negligible numbers of registered cars were "lost." When combining the registration data and accident data, again vehicles were "lost." If these losses are not randomly distributed over the car population, rates will be biased--to what extent we do not know.

We tried to account for driver, crash, and environmental factors influencing the fatality rate by statistical modeling, but had no success. When studying the effects of airbags for right-front-seat passenger, using their fatality rate per registered vehicle year, another assumption has to be made: that right-front-seat occupancy is the same in airbag cars as in other cars. Since we found no airbag effect for right-front-seat occupants, this assumption is probably wrong.

Our second approach used only collisions between two cars. One group consisted of collisions between airbag cars and nonairbag cars, the other, "comparison," group consisted of collisions between nonairbag cars. This approach requires no assumptions, but it relies on a very special type of accident in which airbag effectiveness may differ from that in other crashes, and the number of cases is small. The small number of cases limited the statistical modeling needed to separate the effects of airbag from those of other factors, and it limited the precision of the estimates.

The third approach used only accidents where a driver and a right front seat passenger were present. Again, two groups were compared: cases where the driver had an airbag, and the passenger not, and cases where both had no airbag. As in the previous approach no critical assumptions are needed, but again, the type of crashes is selective and not necessarily representative of all crashes, and the case numbers are small, limiting the statistical modeling that can be done, and the numerical precision achievable.

The fourth approach compared the distribution of impact points on cars where the driver was killed. The critical assumption was that airbags had no effect if the impact was at the driver's door (9 o'clock). For right-front-seat occupants the assumption is that airbags have no effect in 3 o'clock impacts. Though these assumptions appear plausible, it may well be that airbags have an effect in such impacts if there is little or no compartment intrusion, and the airbag deploys.

Though our analyses consistently showed the effectiveness of airbags, it appears to differ widely among cars and crash conditions, so that an average or overall figure would not be too meaningful. Therefore, more detailed findings are presented.

Figure 7-1 shows the factor by which airbags reduce the driver fatality risk in all impacts. Approaches B (comparing the distribution of impact points) and C (comparing driver and right-front-seat passenger) show similar values and trends with car weight. There is no effect for light cars, possibly even an increase (does the presence of an airbag reduce belt use in light cars?), a small effect, about 5% for midweight cars, and a large effect, 10% - 25% for heavy cars. For collisions between two cars (D), the trend is also clear, but in the opposite direction; for light cars the effect is 60%, for heavy cars only 20%. This discrepancy may reflect that airbags have very different effects in different crash types (this is also suggested by the data in Table 5.2-4; there is no effect in single vehicle accidents, but a clear effect in other accidents for frontal impacts).

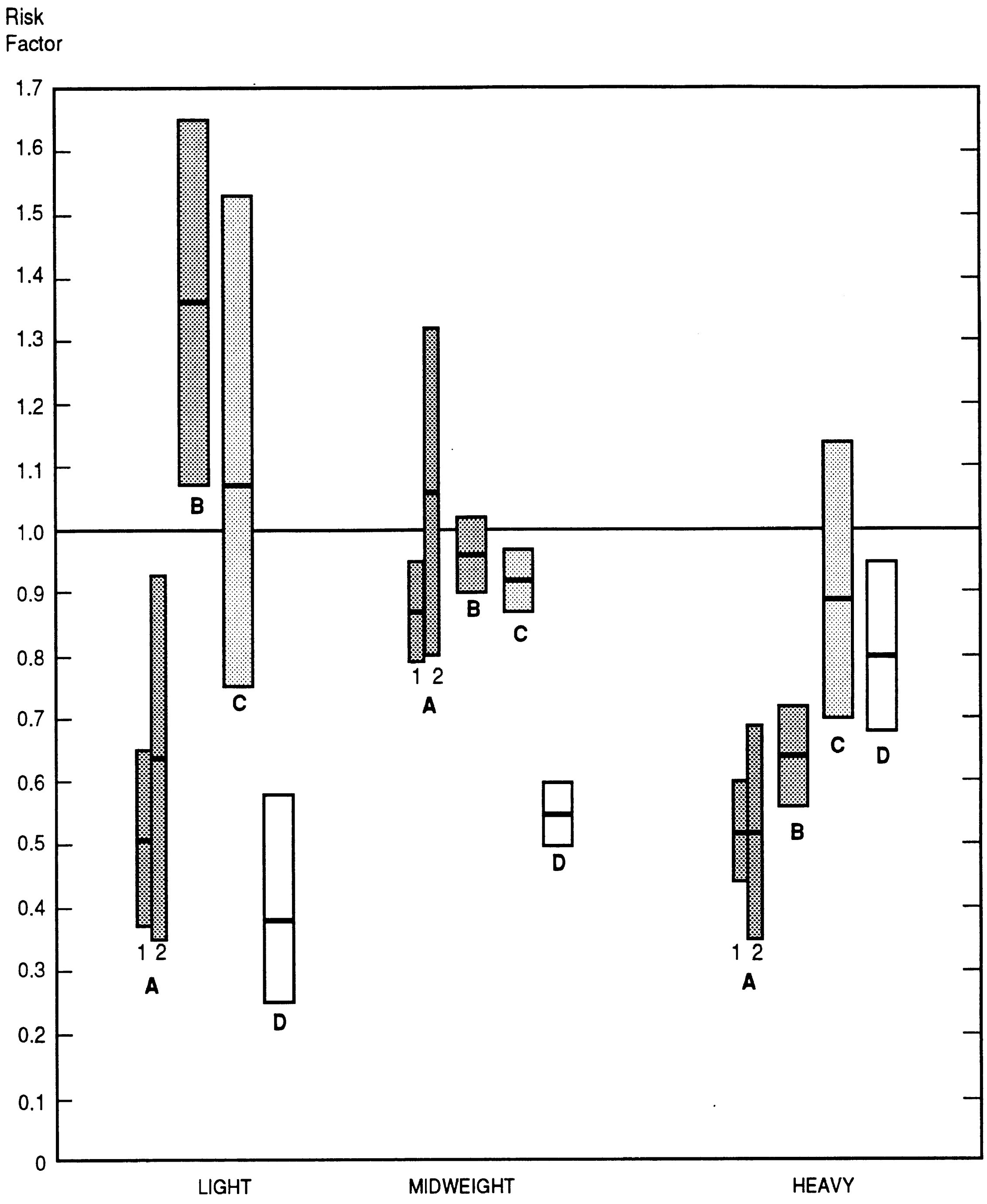

Figure 7-1. Risk factors for all impacts combined, by car class. A represents estimates based on driver fatality rates per registered vehicle year, A1 using unweighted averaging, A2 a regression model for standardizing. Estimates B are based on the distribution of impact points on the vehicle in fatal accidents. Estimates C are based on comparing fatalities of drivers and right-front-seat occupants in the same car. Estimates D are based on comparisons of driver fatalities in collisions between two cars. The bars represent ± 1 sigma ranges.

The estimates based on fatality rates per registered car (A) show no consistent pattern. One would expect a pattern similar to B and C, but they show a large effect for light cars, a similar effect for heavy cars, and only little effect for midweight cars. In our opinion, these estimates are questionable.

Figure 7-2 shows estimates for frontal impacts, for which airbags are designed. Now the picture becomes more consistent. The patterns for approaches B and C are basically the same as in Figure 7-1, only the effects are larger, as one would expect: 15% for midweight cars, and 10% - 50% for heavy cars. For approach D, collision types are distinguished. D1 represents front-front collisions, D2 front-left, and D3 front-other. D1 shows a trend which agrees with those resulting from approach B and C, though the effect appears to be larger: 45% for midweight, and 60% for heavy cars. Estimates D2 and D3 show no trend, but very large effects ranging from 55% - 65%, with one exception, heavy cars. For them the risk appears increased, but the error is so large that even a substantial decrease is not unlikely.

We will speculate why effects for D2 and D3 are larger than for D1, and the other estimates. As discussed in section 4.3, delta-v can be up to 30% less in angle collisions than in front-front collisions, given the same travel speeds. Thus, the greater reductions in D2 and D3 may reflect greater effects in low delta-v involvements. This agrees with our finding that in a front-front collision the driver of the car with a high mass ratio (low delta-v) gets the greatest benefit (58% versus 2% for cars with a low mass ratio) from airbags.

Figure 7-3 shows the risk factors for all impacts by driver age. No clear trend with age is apparent; only a very slight indication that middle age drivers benefit more than others from air bags.

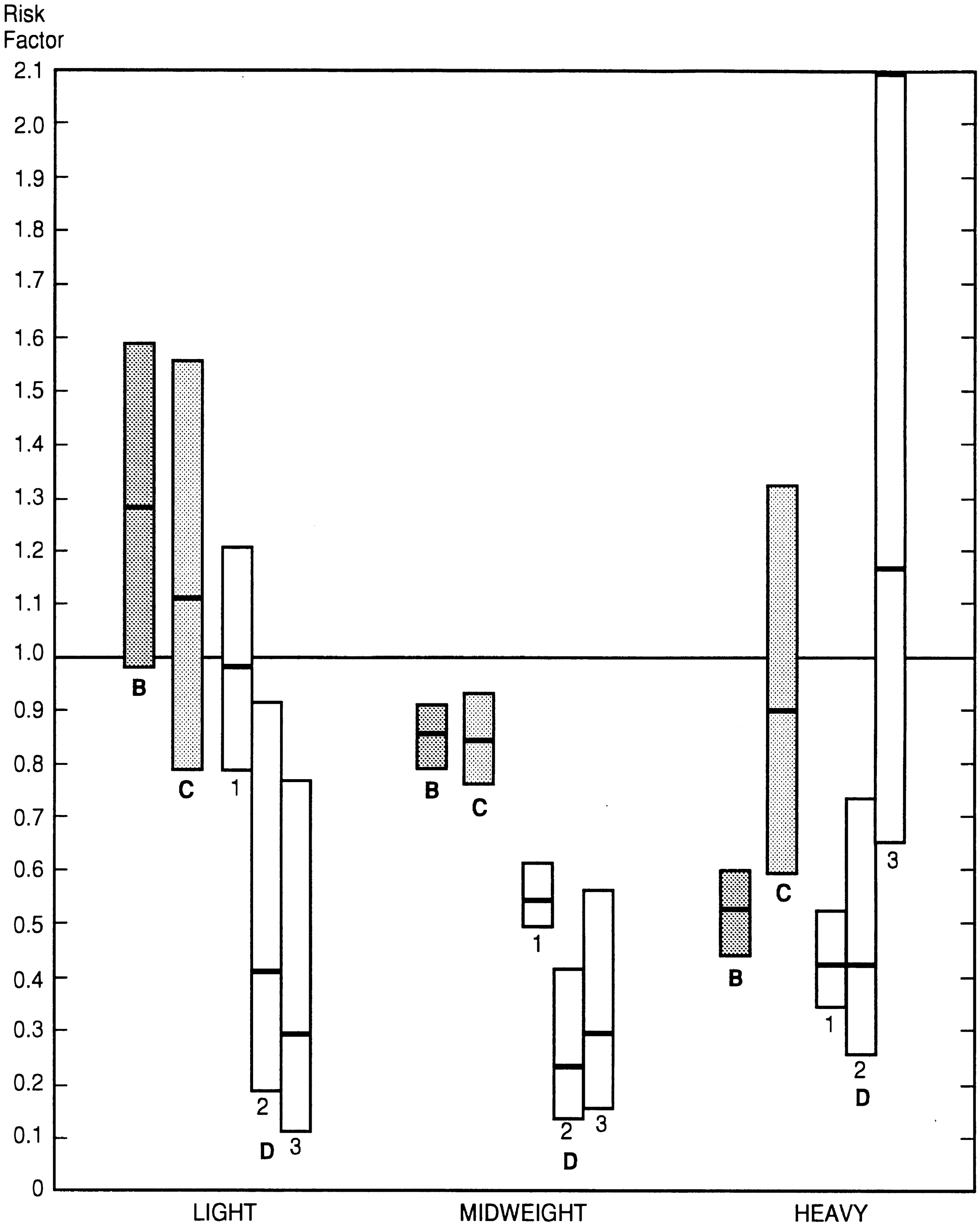

Figure 7-2. Risk factors for frontal impacts, by car class. B, C, and D are defined as in Figure 7-1. D1 is for front-front collisions, D2 for front-left collisions, and D3 for front-other collisions. The bars represent ± 1 sigma ranges.

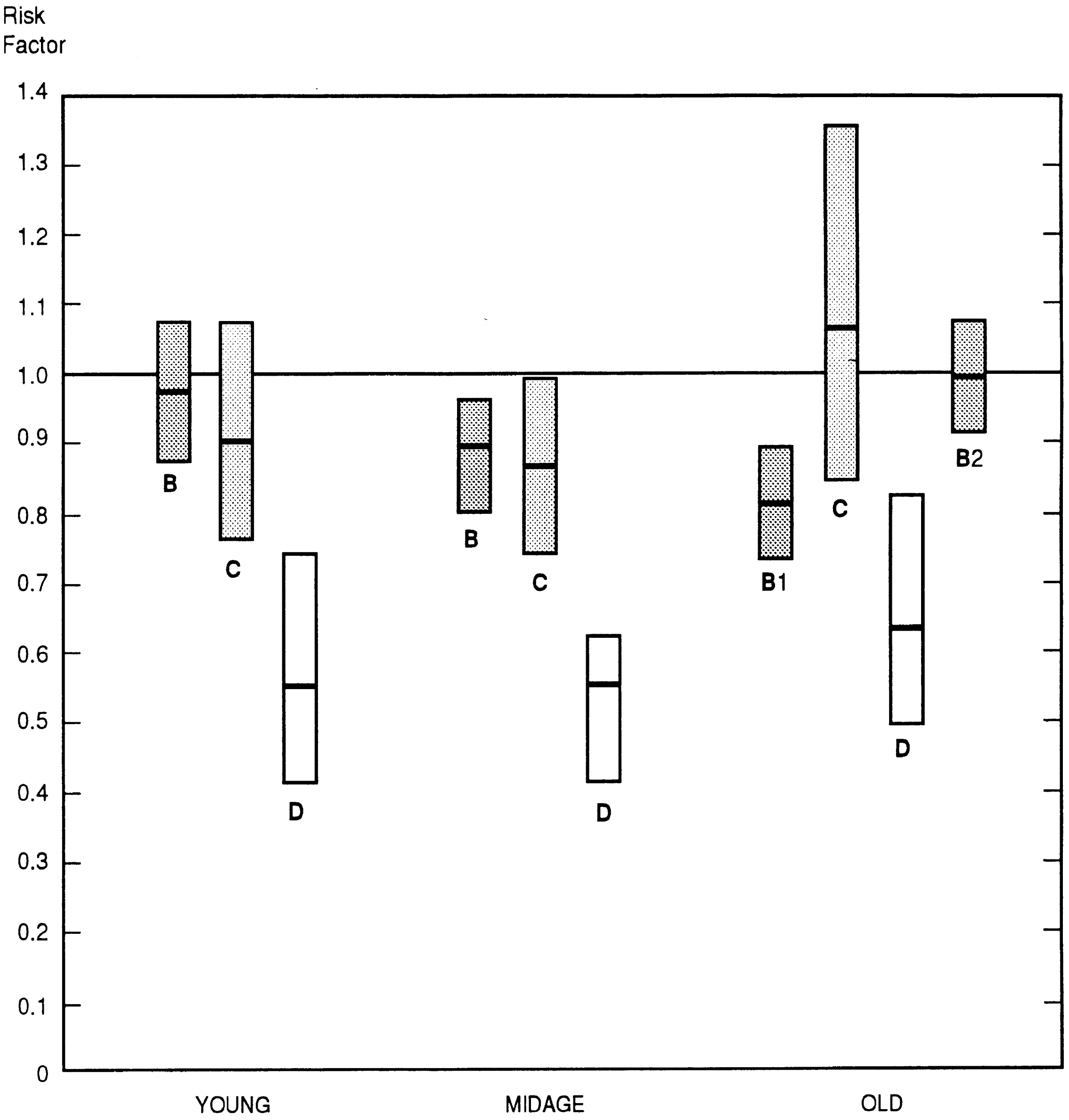

Figure 7-3. Risk factors for drivers for all impacts, by age. B, C, and D are defined as in Figure 7-1. B1 refers to drivers 46 to 65 years old, B2 to drivers over 65. The bars represent ± 1 sigma ranges.

Estimates for right front seat occupants are limited by the small number of cars with a passenger side airbag. Comparing fatality rates of right front seat occupants per registered vehicle year between airbag and nonairbag cars, we found no effect. However, we do not consider this to be a good approach, as already discussed. The analysis of the distribution of impact points showed a non-significant increase of the risk for right-front-seat passengers of heavy cars, and a very large and significant reduction for passengers in midweight cars: 75% in frontal impacts, 60% overall. There were too few light cars with a passenger-side airbag.

Airbags and seatbelts perform largely similar functions, though belts also prevent ejection, and provide protection in multiple impacts when bags have already deflated. Thus, to compare airbags and belts, and to estimate the additional benefit of airbags when belts are used is of interest.

Belt use is "soft" information in most accident data files; often, if not mostly, based on the statement of the persons involved, and nearly certainly exaggerated if a person is not injured, and questionable even if the person is not too seriously injured. Therefore, any analysis relying explicitly or implicitly on belt use information for surviving occupants will nearly certainly be biased to an unknown extent.

However, since the information on belt use by killed occupants is more likely to be correct, we performed one analysis which relied only on killed occupants (not even implicitly on surviving occupants).

A comparison of drivers of airbag cars using no belts, with drivers using belts in no-airbag cars had some striking results (Table 6.3-3). For heavy cars, there was little difference, for midweight cars the risk in airbag cars was about 50% higher, and for light cars it was nearly doubled. To some extent this was due to large risk increases in noncollision accidents (presumably involving ejection); more than doubling for heavy cars, more than an eightfold increase for light cars. Even for frontal impacts, only heavy airbag cars showed a--non-significant--reduction, in other cars the risk was still much higher than in nonairbag cars. If the belt use information for killed drivers is correct, airbags should definitely not be considered "passive protection."

A combination of airbags and seatbelts, however, appears to offer additional benefits (Table 6.3-1a). Over all impacts, airbags seem to offer no benefits for non-users of belts, but a 17% risk reduction for belt users. In frontal impacts, there is an 11% risk reduction for non-users, 30% for belt users. On the other hand, using belts in an airbag car reduces the overall risk by 32%, in frontal impacts by 35%. Thus, it appears that belts provide substantial protection, and that airbags must be considered "supplemental restraint systems." Again, it must be emphasized that these conclusions are critically dependent on the assumption that belt-use information for killed drivers is correct.

8. Recommendations for future research

The analyses of airbag effectiveness were limited by the number of airbag cars involved in fatal crashes in 1990 through 1993. When data on 1994 and 1995 crashes become available, the numbers will be much larger and more thorough analyses will be possible. The number of cars with passenger-side airbags will be greatly increased. For instance, one could obtain more precise estimates for effects in light cars--which currently appear doubtful--, one could distinguish collisions with different vehicle types, and one could attempt to estimate airbag effectiveness for very old drivers. One could also address the question of airbag "aggressiveness": under which conditions do airbags increase the fatality risk of children in the right-front seat? In addition to making estimates for special groups of drivers, vehicles, or crash conditions possible, the larger data base will allow more precise estimates for broader groups.

All approaches used had some limitations: they applied only to certain types of crashes, they relied on unverified assumptions, or they combined data which were not well matched. A new approach would combine two good data bases, FARS and the General Estimates System (GES) component of NASS. A very limited experiment has shown promising results. FARS is a national census of fatal accidents, GES provides nationwide estimates of all police reported accidents, based on a statistically designed sample. Thus, the data are conceptually compatible. They are also technical compatible, because data in both files share similar variables. From the combined data one can directly calculate fatality rates, given that a crash has occurred, without having to make assumptions which are difficult to validate. These rates can be calculated for car classes, crash conditions, driver classes, or other classes desired. Comparing these rates gives directly the effectiveness of airbags in crashes under the specified conditions. This is exactly what one wants to know. However, to calculate the error of the effectiveness estimates, more sophisticated than usual techniques are needed, because GES data are based on a complex sampling plan.

Our fourth approach allowed estimation of the interaction effects of airbags and seatbelts. However, if required the assumption that airbags have no effect on the driver fatality risk in 9 o'clock impacts (3 o'clock for right front seat occupants). The validity of this assumption could be checked by analyzing the combined FARS and GES data. If found valid, the fourth approach can be applied to the much larger data base of 1990 - 1995 fatal crashes. This would allow study of the interaction of airbags and seatbelts for a wide range of conditions, e.g., for old drivers, collisions with different types of vehicles, non-collision crashes, and other conditions of interest.

Appendix A-1. Estimating relative fatality risks from FARS data

FARS contains only fatal accidents. No comparable data base for nonfatal accidents exists. Thus, fatality risks in accidents cannot be directly estimated on a national basis. However, for certain persons in accidents, relative fatality risks can be estimated, using only FARS data.

Assume two cars colliding, and let p_1 be the probability that driver 1 is being killed, p_2 that driver 2 is being killed. These probabilities can depend on each driver's characteristics, including age, the delta-v his or her car experiences, the collision configuration, and other factors. We consider only cases where at least one driver is killed. Cases where no driver is killed can appear in FARS if another occupant is killed. Because the fatality risks of other occupants can differ very much from that of drivers and depend on other factors, their inclusion would complicate any analysis immensely.

The counts for a class of accidents one wants to study (the definition of the class may include the characteristics of the two drivers) can be arranged in a table as follows:

	Driver 2	
Driver 1	**Killed**	**Survived**
Killed	x_2	x_1
Survived	x_3	

If there are a total of N collisions, the counts are:

$$x_1 = p_1(1-p_2)N$$
$$x_2 = p_1p_2N$$
$$x_3 = p_2(1-p_1)N$$

In principle, one can calculate p_1, p_2, and N from the three counts x_1, x_2, x_3. If x_2 is small compared with x_1, and x_3, the error of the results become large, and for $x_2 = 0$ the calculations break down, even if x_1 and x_3 are sizable numbers.

What one can estimate more reliably is

$$p_1/p_2 = (x_1 + x_2) / (x_2 + x_3),$$

or the odds-ratio.

$$\frac{p_1}{1-p_2} / \frac{p_2}{1-p_2} = \frac{x_1}{x_3}.$$

In Appendix A-3 we will provide some empirical evidence that in the case of collisions between two cars, p_1/p_2 is a relatively simple function of the ratio of the two car masses, the strongest factor influencing the relative fatality risk.

To evaluate the effect of an airbag on a driver's fatality risk, we compare collisions where driver 1 had an airbag, driver 2 had a belt, with collisions where both drivers had belts. Let x_1, x_2, and x_3 be the case counts for the first type collisions, y_1, y_2, and y_3 those for the second type collision, and let f be the factor by which the airbag reduces the fatality risk. Then

$$
\begin{aligned}
x_1 &= fp_1(1-p_2)N \\
x_2 &= fp_1p_2N \\
x_3 &= p_2(1-fp_1)N \\
y_1 &= p_1(1-p_2)N' \\
y_2 &= p_1p_2N' \\
y_3 &= p_2(1-p_1)N'
\end{aligned}
$$

holds, from which one obtains

$$f = \frac{x_1+x_2}{x_2+x_3} / \frac{y_1+y_2}{y_2+y_3}.$$

The same argument can be applied to certain occupants of the same car. For instance, one can compare driver and right-front-seat occupants, in cars where the driver has an airbag, and in cars where the driver has only a belt.

Appendix A-2. Estimating errors, smoothing and averaging

To derive an error estimate for the risk factor f it is convenient to use its logarithms.

$$\log(f) = \log(x_1 + x_2) - \log(x_2 + x_3) - \log(y_1 + y_2) + \log(y_2 + y_3),$$

from which it can be obtained via

$$\mathrm{var}(f) = f^2\,\mathrm{var}(\log(f)).$$

Since the x_i and y_i are independent, it suffices to derive the variance for the two first terms; that for the other two terms is analogous. The standard approach is to develop the functions into a Taylor series and retain only the linear terms. With m_i being the means of the x_i, one has

$$\begin{aligned}
&\log(x_1 + x_2) - \log(x_2 + x_3)\\
&= \log(m_1 + m_2) - \log(m_2 + m_3)\\
&+\log\Big(1 + \frac{(x_1 - m_1) + (x_2 - m_2)}{m_1 + m_2}\Big) - \log\Big(1 + \frac{(x_2 - m_2) + (x_3 - m_3)}{m_2 + m_3}\Big),\\
&\approx \log(m_1 + m_2) - \log(m_2 + m_3) + \frac{(x_1 - m_1) + (x_2 - m_2)}{m_1 + m_2} - \frac{(x_2 - m_2) + (x_3 - m_3)}{m_2 + m_3}
\end{aligned}$$

Rearranging the terms so that those with x_2-m_2 are combined, one gets

$$\log(m_1 + m_2) - \log(m_2 + m_3) + \frac{x_1 - m_1}{m_1 + m_2} + (x_2 - m_2)\Big(\frac{1}{m_1 + m_2} - \frac{1}{m_2 + m_3}\Big) + \frac{x_3 - m_3}{m_2 + m_3}$$

Now, the three terms containing the x_i are independent, and the variance for the expression is

$$\frac{\mathrm{var}(x_1)}{(m_1 + m_2)^2} + \mathrm{var}(x_2)\Big(\frac{1}{m_1 + m_2} - \frac{1}{m_2 + m_3}\Big)^2 + \frac{\mathrm{var}(x_3)}{(m_2 + m_3)^2}$$

Under the conventional assumption of Poisson-distributed x_i, $\mathrm{var}(x_i) = m_i$. Combining the terms of the expression gives

$$\frac{m_1 + m_3}{(m_1 + m_2)(m_2 + m_3)}.$$

The m_i are unknown, however, the x_i are used as estimates of the m_i. A similar expression holds for the other terms in the expansion of log(f), those containing the y_i. Combining all terms one obtains the estimate

$$\mathrm{var}(\log(f)) = \frac{x_1 + x_3}{(x_1 + x_2)(x_2 + x_3)} + \frac{y_1 + y_3}{(y_1 + y_2)(y_2 + y_3)}.$$

This estimate is only an approximation, and it is not easy to determine when it overestimates, and when it underestimates the variance.

Estimating the variance of log(f) is much simpler than estimating the variance of f. The reason is that for values of the x_i and y_i, which are not very large, f has a very asymmetric distribution; its lowest value is zero, but its largest value can be infinite. Even if the probability for the values zero and infinity is negligible, the distribution can be very skewed.

This can have undesirable effects. To illustrate them, we use simple ratios; for double ratios the situation is similar, but more complex. Assume that we have in one group of accidents 4 fatalities in airbag cars, 2 in others, giving a ratio of 4/2 = 2. In another group, the ratio may be 2/4 = 0.5. The average of these ratios is (2 + 0.5)/2 = 1.25. If one had used the inverse ratios 2/4 = 0.5, and 4/2 = 2, one would have obtained the same average, 1.25. This clearly advises against averaging ratios, except if they are close to one. In this example, one can avoid the difficulty by aggregating numerator and denominator, obtaining (2 + 4)/(4 + 2) = 1. In many cases, however, this is undesirable because it does not eliminate certain confounding effects.

A preferable way of dealing with the matter is to use logarithms. The distribution of the logarithm of a ratio is more nearly symmetric, and effects of asymmetry are vastly reduced. In our example, in the first case the logarithms of the ratios are log4 - log2, and log2 - log4, with an average 0, corresponding to an average ratio of 1. In the second case, the logarithms of the ratio are log2 - log4, and log4 - log2, again with an average 0.

Averaging and aggregation is closely related to standardization. Assume that we have accident involvements classified by car mass, and that we have the fatality risks p_i for airbag cars, and q_i for others, in class i, and ratios $f_i = p_i/q_i$

Car mass:	light	medium	heavy
	p_1, q_1, f_1	p_2, q_2, f_2	p_3, q_3, f_3

Of course, the best way is to present the data as detailed as shown here. However, it can happen that all three f_i are subject to fairly large errors, so that differences among them are not meaningful, and one would rather present an overall average, or an overall average may be desirable for other reasons.

Unfortunately, averaging is not unambiguous. A weighted average with weights according to the variances of the f would have the minimum error, but it could be strongly influenced by a single class, usually that with the largest number of cases. Weighting according to the number of cases, or of registered vehicles corresponding to a class could give an unbiased estimate of the actual estimate for that composition of the accident population or the vehicle fleet, but it would be seriously confounded, e.g., if airbags are predominantly available in heavier vehicles. Aggregating the data for all classes and calculating f from the totals is equivalent to weighting according to certain case numbers in the study population. While we also present these latter estimates as descriptive of the current situation, comparisons among them can be seriously misleading.

Some of these problems are avoided by calculating a "standardized" factor f, which is equivalent to a weighted average with weights corresponding to a "standard" population. This is an estimate of the effect one would find in the standard population. We used a simple version of this approach, by simply averaging the values of the $f_{i.}$. Usually, the data were disaggregated into three age classes for persons, three classes for mass ratios, and three classes of vehicle mass. For the latter, the coarser of NHTSA's two classifications was used, for the former we defined classes so that very roughly one third of the cases fell into each.

When forming averages of the f_i we also calculated the standard deviations of the f_i, and of their average. They combine two effects: the random variability of the f_i, and any difference between their means. Therefore, they are more realistic than error estimates based on a linear approximation and the assumption of a Poisson distribution, and we used them whenever possible.

When data were classified according to two or more factors, some cell frequencies were so low that ratios of the form 0/n or n/0 resulted. Some averages could not be calculated, and estimates of standard errors became unrealistically low. This problem is well known. Simple remedies that have been used in the past include adding 1/2, or 1/n, n total number of cells, to each cell. More recently, pseudo-Bayesian approaches have been developed. We use that proposed by Bishop et al.[3] In the case of a two-dimensional array, let x_{ij} be the cell counts, $n = \sum x_{ij}$. One has to assume a prior probability distribution λ_{ij} for a distribution of the total of n observations over the cells i, j. The pseudo-Bayesian estimator "shrinks" the actual counts x_{ij} toward the $\lambda_{ij}\, n$, according to the formula

$$y_{ij} = \frac{n}{n + \hat{K}}(x_{ij} + \hat{K}\lambda_{iij}),$$

where

---

[3] Y.M.M. Bishop, S.E. Fienberg, P.W. Holland. Discrete Multivariate Analysis: Theory and Practice, MIT Press 1975. Chapter 12.

$$\hat{K} = \frac{n^2 - \sum x_{ij}^2}{\sum(x_{ij} - N\lambda_{ij})^2}.$$

If the x_{ij} follow a multinominal distribution, then the y_{ij} are in a certain sense "better" estimates of the expected cell frequencies than the observed values x_{ij}. While the y_{ij} are biased toward the $\lambda_{ij}n$, the bias is so chosen that it does not overcompensate the reduction in variance achieved, thus resulting in a better estimate.

If the prior distribution λ_{Ij} is chosen properly, there will be no zeros among the y_{ij}, and the numerical difficulties with 0/n, and n/0 disappear. As prior we usually used the distribution resulting when aggregating over one factor, if necessary aggregating over two factors. Experimenting with different priors showed that the y_{ij} were relatively little affected by changing the prior, as long as it had a reasonable similarity to the overall pattern of the data.

A-3. Modeling the effects of factors influencing the fatality risk

The model for the probabilities of drivers' deaths developed in A-1 suggested to search for a statistical model which allowed to estimate the probabilities of death for the two drivers as functions of other factors--confounding factors in our case.

The strongest single factor influencing the fatality risk is delta-v. In a first approximation, a driver's fatality risk increases with the fourth power of delta-v, reaching 1 at a delta-v of about 70 mph.

Another factor strongly influencing the fatality risk is a person's age. In a crash of a given severity, the fatality risk increases with age, especially rapidly at higher ages. Unfortunately, no simple formula for this relation appears to be known.

In a collision, delta-v is determined by the speeds of the two vehicles and their masses. If both vehicles move in the same (or opposite) direction,

$$\Delta v_i = v_o \frac{m_j}{m_1 + m_2}, \quad j = 3 - i,$$

where v_o is the closing speed.

If the relation

$$r_i = a(\Delta v_i)^4$$

(or with any other exponent instead of 4) holds, then

$$r_1 / r_2 = (\Delta v_1 / \Delta v_2)^4 = (m_2 / m_1)^4$$

follows. This means that the travel speeds have no effect on the relative fatality risks in the two cars, at least in the range in which the relation holds (delta-v below 70 mph).

To check this relation, we selected front-front collisions of nonairbag cars, grouped them by mass ratio, and plotted the logarithm of the fatality risk ratio against the mass ratio. The result is shown in Figure A.3-1. The points are indeed close to a straight line, and the slope is approximately -4.

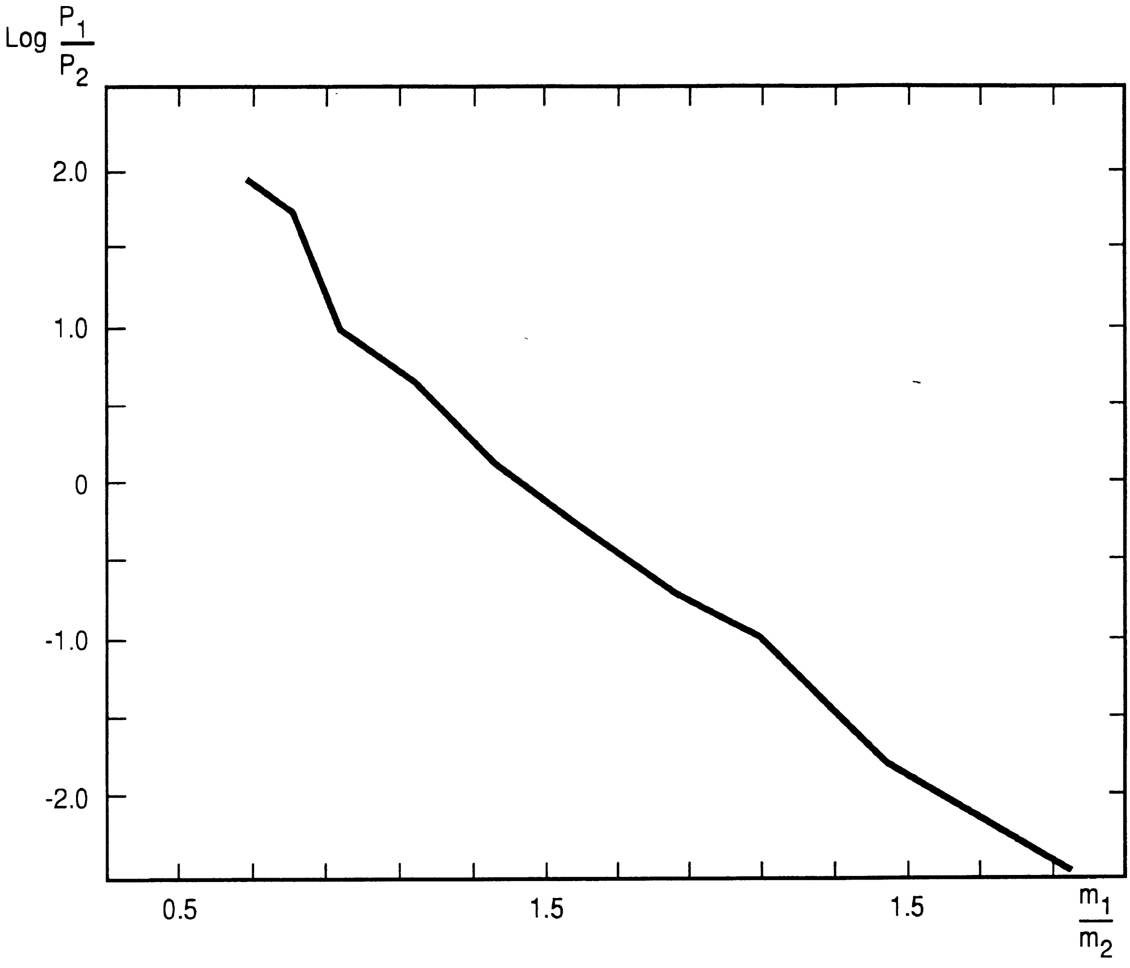

Figure A.3-1. Relation between the ratio of the probabilities of deaths for the drivers in a collision between two nonairbag cars, versus their mass ratio.

We also selected frontal collisions between an airbag car, and a nonairbag car and did the same. The points were more scattered, but could be reasonably well represented by a line parallel to that for collisions between nonairbag cars, the offset indicating an about 25% reduction of the fatality risk.

These findings encouraged us to search for an analytic model. First, we tried to improve the model. Though the line in Figure A.3-1 is approximately straight, it is not exactly so. We experimented with the speed limit, as a proxy for travel speed, and the mass of the case vehicle as additional variables. None of these had a clear effect.

Age turned out to be a critical factor. Since we had no formula for the relation between age and fatality risk, and to develop one would have gone far beyond the scope of this project, we categorized age. Because both drivers' ages influence the relative fatality risk, the number of "cells" resulting from a classification is at least 4, better 9, and preferably 16. A result was that the data became "thin'" and the results very dependent on the way the data were classified.

To avoid this problem, we experimented with an approach that did not aggregate cases, but treated each collision as one observation. A common way to do this in a situation where the dependent variable is 0/1 (surviving/killed) is to use a logistic regression model. This did not give satisfactory results. First, a logistic model with linear terms does not adequately reflect the empirical relation between delta-v and fatality risk, second, even more important, in our situation we have three potential outcomes: the nonairbag driver killed, the airbag driver killed, and both drivers killed. Available logistic regression routines implicitly impose a structure on the model which does not reflect the realistic probability structure developed in A-1. Therefore, after a few experiments this approach was abandoned.

It appears possible to develop a statistical model that incorporates the probability model developed in A-1, uses the empirical relative between delta-v and fatality risk, and includes the two ages, an airbag effect, and interactions of the airbag effect with other factors. Such a model could use individual collisions as observations and thus avoid the loss of resolution resulting from aggregation. It would have to be fitted to the data by a maximum likelihood routine. This, however, would have by far exceeded the scope of this project.

A-4. Airbag deployment

Airbags can have an effect only if they deploy. FARS reports airbag deployment. Table A-4.1 shows reported airbag deployment. The high percentage of "unknown or not applicable" in cars equipped with airbags, and practically no reporting of "not deployed" should raise doubts about the reliability of reporting. However, it is plausible to assume that reported deployments are real and provide a lower bound for the number of actual deployments. Thus, the airbag deploys in at least 42% of frontal impacts, whereas in side impacts it deploys in at least about a quarter of all cases.

TABLE A.4-1 Reported Airbag Deployment in Car-Car Collisions, by Impact Type and Restraint Type. Entries are row percent, for each class of driver.

	DRIVER SURVIVED			DRIVER KILLED		
IMPACT TYPE RESTRAINT TYPE	DEPLOYED	NOT DEPLOYED	UNKNOWN OR NOT APPLICABLE	DEPLOYED	NOT DEPLOYED	UNKNOWN OR NOT APPLICABLE
Front						
Belt	0.3	0.1	99.6	0.2	0.1	99.7
Airbag	42.0	1.1	56.6	49.3	1.4	49.3
Unknown or Other	6.3	0.0	93.7	7.4	0.0	92.6
Left						
Belt	0.2	0.2	99.6	0.2	0.0	99.8
Airbag	26.2	0.0	73.8	22.2	1.2	76.6
Unknown or Other	0.0	0.0	100.0	0.0	0.0	100.0
Right						
Belt	0.0	0.1	99.9	0.3	0.1	99.6
Airbag	17.8	1.7	80.5	30.6	1.4	68.0
Unknown or Other	0.0	5.6	94.4	0.0	0.0	100.0
Rear						
Belt	0.2	0.2	99.6	0.4	0.0	99.6
Airbag	5.1	0.0	94.9	0.0	0.0	100.0
Unknown or Other	0.0	0.0	100.0	0.0	0.0	100.0

A closer look at the data by speed limit shows that in frontal impacts reported deployment increases from 39% to 40% to 49% for speed limits of 35 mph or less, 40 to 50, and 55 or more for frontal impacts; for left side impacts, the increase is less consistent; from 18% to 16% to 32%.

Speed effects can confound the pattern observed in the table. That the percentage of air bags deployed in frontal impacts (and even more so in right-side impacts) is higher when the driver is killed does not have to indicate a negative effect of the airbag, but may be due to differences in speed between cases where the driver is killed and not killed.

To what extent the “unknown or unapplicable” cases contain cases where deployment occurred but was not reported, and to what extent the airbag did not deploy because of low deceleration is not known.

GLOSSARY

Definitions of frequently used terms

Impact type

Frontal: Initial impact clock position 11,12,1
Right side: Initial impact clock position 2,3,4
Rear impact: Initial impact clock position 5,6,7
Left impact: Initial impact clock position 8,9,10

Driver age

Young: up to 25
Medium: 26 to 45
Old: over 45
(some analyses use "very old" for drivers over 65)

Car weight (or mass) Classes

Light: up to 2,450 lbs.
Medium: over 2,450 to 3,450 lbs.
Heavy: over 3,450 lbs.

Fine car weight classification

Mini compact: under 1,950 lbs.
Subcompact: 1,950 - 2,449 lbs.
Compact: 2,450 - 2,949 lbs.
Intermediate: 2,950 - 3,449 lbs.
Full size: 3,450 - 3,949 lbs.
Large: 3,950 or more lbs.

Mass ratio

High: 1.25 or higher
Medium: 0.80 to 1.25
Low: under 0.80

Standardized: Averaged with equal weights over groups defined by combinations of driver and/or passenger age(s), car weight(s), mass ratio of cars, calendar year, model year, impact point, crash type, and other factors, depending on the context.

Relative risk:	Depending on context: Ratio of the probabilities that a driver in one of two colliding cars will be killed to that that the driver of the other car will be killed. Ratio of the probabilities that a driver will be killed, and that a right front seat occupant of the same car will be killed. Ratio of the probability that a driver will be killed in a collision with a certain impact point, to that for a collision with a baseline impact point (typically 9 o'clock).
Risk factor:	Relative risks can be estimated for all crashes, classes of drivers, classes of cars, classes of crash conditions, or classes defined by combinations of such factors ("cells," see below.) Ratio of two relative risks, the numerator for cars equipped with airbag, the denominator for cars without airbags. The percentage reduction of fatalities in airbag cars is represented by 100(1-RF). Risk factors can be calculated for all crashes, classes of drivers, classes of cars, classes of crash conditions, or classes defined by combinations of such factors ("cells"). They may also be "standardized" to represent the effect for a "standard" distribution of accidents over "cells."
Cell:	A group of accidents or accident involvements (a collision of two vehicles constitutes two involvements) defined by factors such as driver and/or occupant age(s), vehicle weight(s), mass ratio, calendar year, model year, impact point, speed limit, etc. Cells are used in the analysis only if there are cases in both the airbag and the nonairbag cell, with the same other factors.
Error:	Though usually calculated like a standard error, it may not have the statistical properties of one. See the text for definition and interpretation in each case.