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ANALYSIS OF THE FUTURE EFFECTS OF FUEL SHORTAGE AND INCREASED SMALL CAR USAGE UPON TRAFFIC DEATHS AND INJURIES

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16. Abstract

The literature was reviewed and accident data were analyzed to establish relations between automobile size and the frequency of occupant death and injury. On the assumption of four future scenarios for the size of automobiles, the consequences for car occupant deaths were calculated. The present effects of the 55 mph speed limit and results that may be achieved by strict enforcement were estimated. The effects of the potential reduction of commuter traffic on vehicle deaths were estimated. The question of how the elimination of sunday travel would affect motor vehicle deaths was addressed.

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PREFACE

The Automotive Energy Efficiency Project is concerned with the examination of technological options for improving the fuel efficiency of highway vehicles. This examination includes an analysis of the effects of existing and proposed mandated standards of fuel economy, safety and emissions on automobile design, estimation of the impacts of marketing and economic forces on automobile sales, and overall projections of fuel consumption for proposed automotive design alternatives. Also of interest are related effects on future air quality, highway safety, and on the costs of owning and operating automobiles. As a part of this project, research is being conducted to determine the impacts of the energy shortage in terms of such effects as changing auto size, reduced speed limits, and less overall automobile travel on the levels of future highway deaths and injuries.

Major contributions to this study were made by: J. Ball, P. Brown, J. Reidy, E. Sweeton and H. Wuerdemann. Support services were provided by P. Atticks, K. Costenoble, T. Mayer, C. Miller, H. Vince and M. Wallace. The author also wishes to acknowledge the helpful advice provided by Dr. H. J. Miser. The responsibility for the accuracy and interpretation of the results, however, rests with the principal investigator.

EXECUTIVE SUMMARY

1. OBJECTIVES

The objectives of this study were to estimate how the number of motor vehicle traffic accident deaths would change during the period 1975-1985, as a consequence of certain assumed changes in the following factors:

- The composition of the passenger car fleet in terms of large and small cars. Four scenarios describing future automobile sales by size class were given.
- Vehicle safety improvements reflecting current technological possibilities, but no drastic changes of current automobile design. The only improvement for whose effects sufficient quantitative information was available was the air cushion restraint system (air bag).
- Changes in travel volume and pattern, specifically the elimination of Sunday travel, and reductions of commuter travel.
- The 55 mph speed limit, as currently enforced, and if strictly enforced.

The effects of other highway safety programs, such as highway improvements or driver oriented measures were not included in this study.

2. SUMMARY OF RESULTS

2.1 EFFECTS OF CHANGING VEHICLE MIX

Four scenarios for the future development of the automobile market by size class were given; the two extreme ones being: "A," assuming by 1985 a return to the 1972 market shares of subcompact and standard cars, but a 50 percent increase in the market share of large luxury cars, e.g., Cadillac, with a corresponding reduction of compacts and intermediates; and "D," assuming essentially a doubling of the market share of compacts and subcompacts, a small increase for intermediates, and a reduction for standard and luxury cars together to 10 percent of the market.

Under Alternative A, the average fatality risk* for occupants of all cars in 1985 would be reduced by about 10 percent, compared to 1972; under Alternative D it would be higher by possibly as much as 15 percent. These changes include the effects of the current Federal Motor Vehicle Safety Standards (FMVSS).

2.2 VEHICLE IMPROVEMENTS

Various potential improvements of automobile design and construction reducing the occupants' injury and fatality risks are known. However, air cushion restraint systems (air bags) are the only ones whose effects can currently be quantified in terms of injury and fatality risk reduction. If air bags were installed in cars beginning with the 1978 model year, the average fatality risk for all car occupants in 1985 would be reduced by about 30 percent, compared with 1972, under Scenarios A, B, and C; and by about 15 percent under the extreme assumptions of Scenario D.

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*Although the fatality risk for a driver in a crash can conceptually be defined, no single number can be given for it, because "what is a crash" as operationally defined by accident records differs widely between states. Therefore, absolute figures for this risk differ widely between states, and no meaningful "nationally representative" figures can be given. However, the relations between this risk and many factors turn out to be surprisingly stable between various data bases. Therefore, it is meaningful to estimate the relative changes of this risk, due to changes in certain factors, even though no absolute figures can be given.

2.3 CHANGES IN TRAVEL VOLUME AND PATTERN

No quantitative estimates of the effect of changes in travel volume or travel pattern could be made, because the basic information on relations between exposure by quantity or quality and accidents is insufficient.

2.4 THE FIFTY-FIVE MPH SPEED LIMIT

No precise estimate of the effect could be made, because actual travel speeds are known only for very special traffic conditions. Making various assumptions, we estimate that the speed limit, as enforced, could be reducing the fatality risk for all car occupants in crashes by about 10 percent, but possibly by as much as 18 percent, or as little as 3 percent. If strictly enforced, the 55 mph speed limit could reduce the fatality risk by about 15 percent, possibly as much as about 20 percent.

3. OVERVIEW OF THE STUDY

3.1 THE EFFECTS OF VEHICLE SIZE

The Role of Vehicle Size

Vehicle size could influence accidents in two ways: (1) by changing the frequency of accidents, and (2) by changing the occupant injury and fatality risk in an accident.

A review of the literature resulted in the conclusion that, currently, no evidence exists that car size is—positively or negatively—related to accident frequency. Since no adequate exposure data were available, we did not analyze original accident data to study this question. We have to assume, implicitly, that accident frequency is not affected by changes in the small car/large car mix.

Vehicle size and occupant injury and fatality risk are related in different ways in single-car crashes, and in collisions between two vehicles. Therefore, we have to treat these kinds of accidents separately.

We found that approximately 48 percent of car occupants killed in motor vehicle accidents were killed in single-car crashes. About 8 percent were killed in collisions of more than two vehicles, and approximately 44 percent in collisions between two vehicles, of which 57 percent were killed in collisions between two cars, and 43 percent in collisions between a car and a truck.

In the following discussions we will use vehicle weight as a measure of vehicle size, as is commonly done, because in current cars size and weight are related. However, since size and weight have different effects in crashes[1], our results may no longer hold if the relation between weight and size changes in future vehicles.

The Risk of Fatal or Serious Injury in Single-Car Crashes

Studies of the fatal or serious injury risk in single-car crashes have been made, using North Carolina, New York State and Michigan data. All agreed that drivers of very light cars suffered a considerably higher

[1] B. O'Neill, H.C. Joksch, and W. Haddon, "Relationships between car size, car weight, and crash injuries in car-to-car crashes," Proceedings of the Third International Congress on Automotive Safety, July 15-17, 1974, San Francisco.

injury risk than those of very heavy cars. For the cars in the middle weight classes, however, considerable differences exist between the data bases. This might be partially due to differences in the selection of cases in the different data bases. To obtain more information we analyzed, in addition, original single-car crash data for Texas and Washington.

The results are shown in Figure 1. The risk of fatal or serious injury is consistently about 50 percent higher for drivers of small cars than for drivers of large cars. In the middle weight range, however, the relations between injury risk and weight differ widely: in two cases there appears to be a fairly smooth relation, in two others an abrupt change near the middle of the range.

Considering the great uncertainty of these results, an adequate description of our current knowledge of the relation between fatal and serious driver injury risk and car weight, would be that the risk is: 20 percent higher for subcompacts; 10 percent higher for compacts; 10 percent lower for standard size cars; and 20 percent lower for heavy cars, than for intermediate cars. If an analytical expression is required, the following is acceptable:

$$\text{Fatal or serious driver injury risk} = a \times 0.98^{w},$$

where w is the car weight in 100 lb.

The Risk of Fatal or Serious Injury in Car-Car Collisions

Using collision data for New York State and North Carolina, Mela[2] found the following expression for the frequency of fatal or serious driver injury in two-car collisions

$$16.6 \times 0.951^{w} \times 1.018^{w'}$$

where w is the weight (in 100 lb) of the car whose driver's injury frequency is considered, and w' is the weight of the other car.

[2] D. F. Mela, "How safe can we be in small cars?" Proceedings of the Third International Congress on Automotive Safety, July 15-17, 1974, San Francisco.

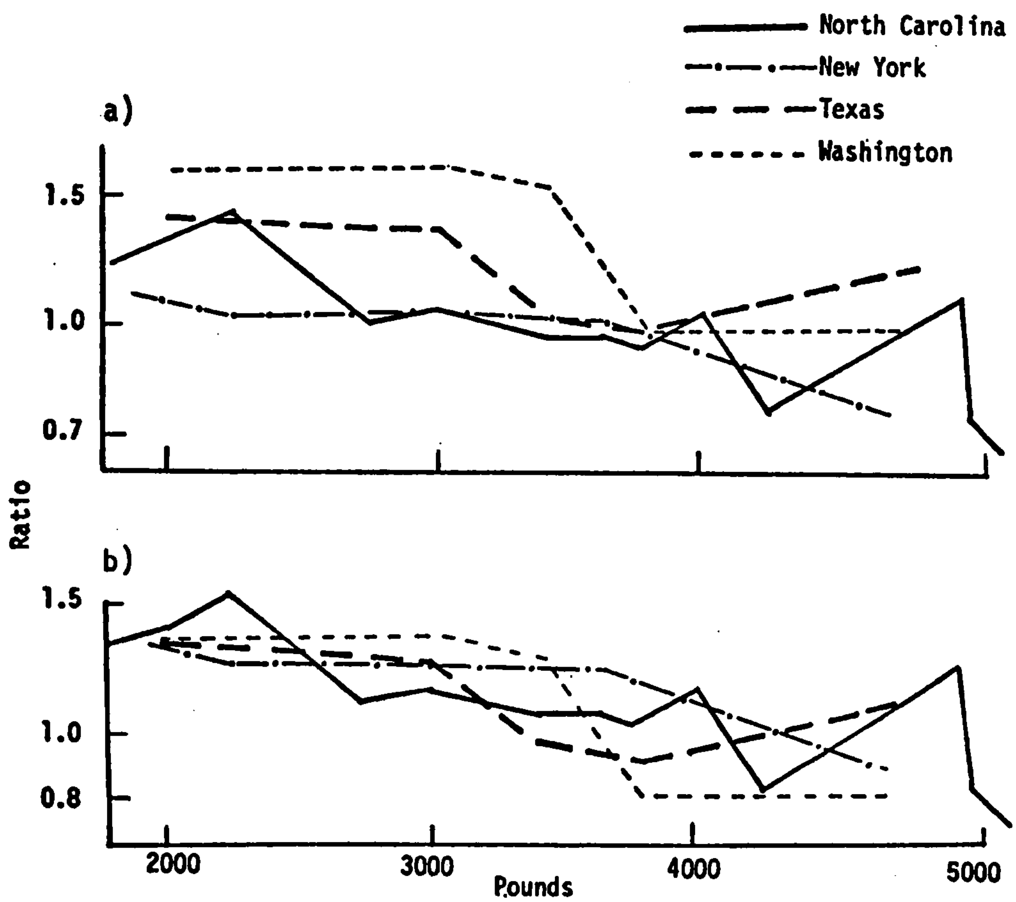


Figure 1. Relative frequencies of fatal or serious driver injury by weight of car. Absolute injury frequencies vary widely between states, presumably because of differences in definitions and reporting practices. Therefore, no absolute comparisons can be made. In part (a) of the figure, for each state the injury frequencies are given relative to that for standard size cars (=1). The wide scatter of these curves suggest the approach used in part (b): the "curves" for the different states are "matched" by multiplying them with empirical constants so that they fall into a narrow "band." This is scaled so as to give an average relative risk of 1 to standard-size cars.

However, the original data suggested that the formula reflected not only the direct influences of vehicle weight, but also indirect effects, such as driver age which is related to vehicle size and possibly to collision type. Therefore, new analyses were performed, controlling in the New York State data for the ages of both drivers involved, and in the North Carolina data for the type of collision. In addition, Washington State and Texas accident data were analyzed. In these cases, injury frequencies were standardized for car model year and driving environment differences, to reduce the effects of differences between cars of different model years, and of different uses of cars of different ages.

We retained the structure of the relation, $a \times b^{w} \times c^{w'}$, used by Mela, and fitted it by graphical methods to the various standardized data bases. The results are shown in Figure 2. With the exception of Texas, the results agree fairly well: for the effect of the primary vehicle's weight, w, the range of the effect reflected by the exponential bases 0.94 and 0.96 is a ± 20 percent deviation from the average effect of 0.95. For the weight of the secondary car, w', the range from 1.018 to 1.026 corresponds to a ± 25 percent deviation from an average effect of 1.022. The greater deviation of the Texas data from the others is not surprising, because in this analysis subcompact cars had to be excluded.

Multi-Vehicle Crashes

We found no information in the literature on fatality or injury risk to automobile drivers in collisions of more than two vehicles. Therefore, Texas and Washington data were analyzed. Due to the small number of such collisions, only very crude results could be obtained. It appeared acceptable to assume that the weight of the primary vehicle has a quantitatively similar effect as in two-car collisions. No attempt was made to estimate the influence of the weight of the two or more other vehicles.

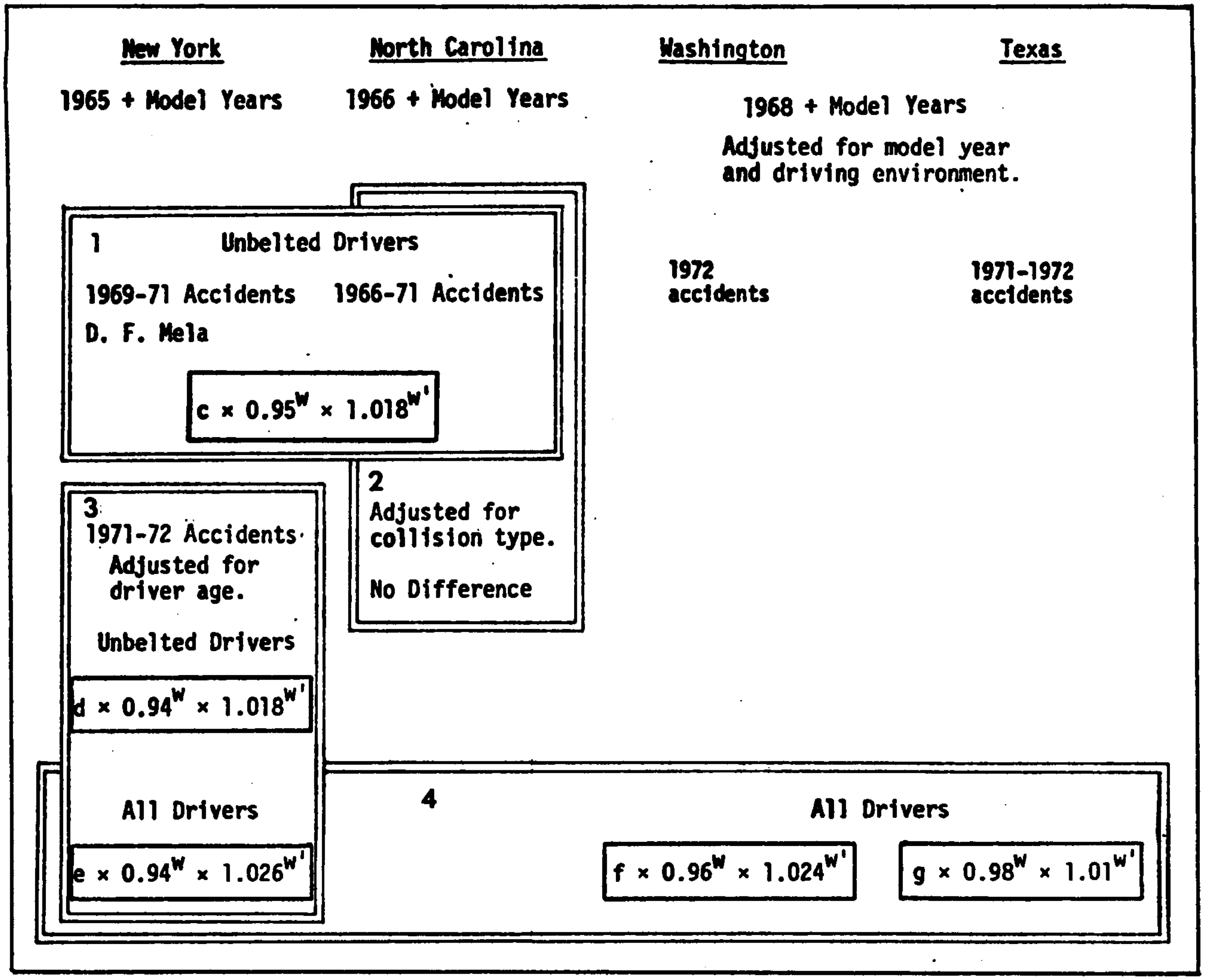


Figure 2. Summarization of relations between driver frequency and automobile weight in different data bases. Results are arranged by state in four columns. The double bordered "box" 1 shows Mela's formula and the data bases which it represents. Box 2 indicates that controlling for differences in collision types between automobile size classes does not result in a different formula. Box 3 shows the results for more recent New York accident data. Box 4 encompasses the results for "all" drivers (without regard for seatbelt use) in 1971 and 1972 accidents. W is the weight of the primary car (whose driver's injuries are counted), and W^1 the weight of the other car (in 100 lbs).

Car-Truck Collisions

No information on the role of car size in car-truck collisions was found in the literature. Again, Texas and Washington data were analyzed. The results turned out to be crude, but they are compatible with the assumption that the weight of the primary vehicle plays quantitatively a similar role as in two-car collisions.

Physical arguments suggest that truck size has a strong influence on the car occupant's injury risk in a car-truck collision. However, since the scenarios studied make no assumptions as to a changing future truck population, we did not study the potential effect of truck size.

Fatalities versus Fatal or Serious Injuries

The studies in the literature and our own analyses described above dealt with fatal or serious injuries, which are more numerous than fatal injuries. Since fatal injuries might be influenced by vehicle size in a different way than serious injuries, we studied this by calculating the ratios of fatal injuries to fatal or serious injuries, by car weight. The results are shown in Figure 3. In single-car crashes, the relations between this ratio and vehicle weight contradict each other so we have currently to assume that there is no relation. For car-car and car-truck collisions, fatal driver injuries vary more with vehicle weight than fatal or serious injuries. A factor of 0.98^{W} describes this differential variation adequately.

Interaction Between Vehicle Size and Speed

Physical arguments suggest that the relative injury risks in collisions between two cars should depend on their travel speed. Our analysis of Washington and Texas data, however, did not suggest such a relation. This may be due to the crudeness of the available data, or to a greater complexity of the collision process than was assumed in our arguments.

Collisions with Pedestrians and Bicyclists

We found no consistent evidence in the Texas and Washington data that the frequencies of fatal, and fatal or serious injuries to pedestrians and bicyclists depend on the weight of the car.

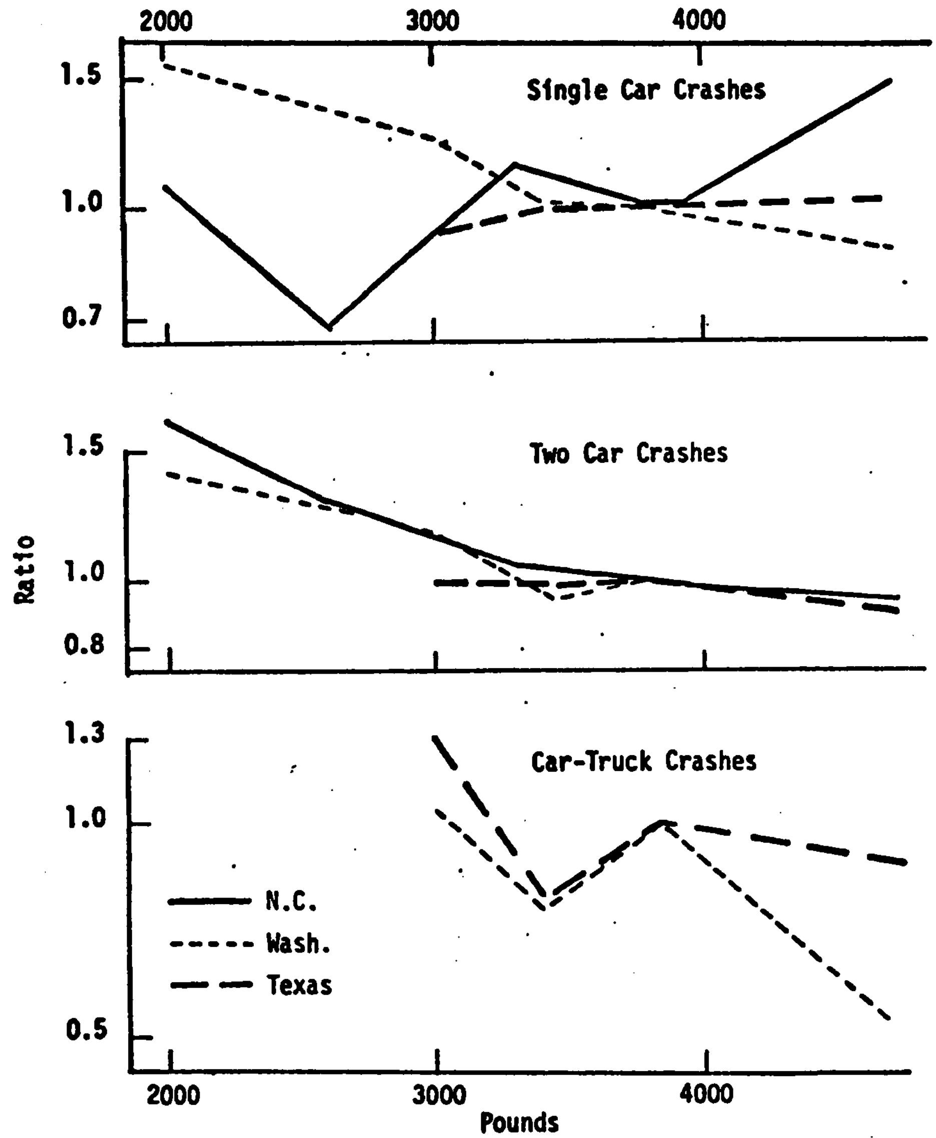


Figure 3. Ratio of fatal driver injuries to fatal or serious driver injuries. Because these ratios differ widely between the states studied, they are scaled to be "1" for standard size cars. The resulting ratio shows how the frequency of fatal injuries changes differently from the frequency of fatal or serious injury with vehicle type.

Summary of the Effects of Automobile Weight in Accidents Involving Automobile

We concluded that there is no known influence of automobile size on accident frequency. There appears to be no influence on the severity of pedestrian and bicycle accidents. Our best estimate of the effects on injury and/or fatality frequency in other crashes, once a crash has happened, are summarized in Table 1.

TABLE 1

Variation of the frequency of passenger-car driver injury (without regard to seatbelt use) with weight (w) of the car, and weight of the secondary car (w') in two-car crashes (w in 100 lb)

Accident Type	Fatal Injury	Fatal or Serious Injury
Single-Car Crash	0.98^{w}	0.98^{w}
Two-Car and Multi-Car Crashes	$0.93^{w} \times 1.02^{w'}$	$0.95^{w} \times 1.02^{w'}$
Car-Truck Crashes	0.93^{w}	0.95^{w}

The injury risk in other accidents, such as collisions with railroad trains, animals, etc. was not studied in relation to vehicle weight because of their low frequency.

3.2 PROJECTING THE RESULTS OF A CHANGING VEHICLE MIX

The Scenarios

Four different scenarios representing market shares of five automobile classes were analyzed. They are presented in Table 2. Scenarios A, B, and C are relatively similar, Scenario D is drastically different.

TABLE 2

TSC projections of automobile market classes for various scenarios (percent)

Year	Subcompact	Compact	Intermediate	Standard	Luxury*
1972 A, B, C, D	19	13	21	35	12
1974 A, B, C, D	22	17	24	29	8
1975 A, B	21	16	22	31	10
C	20	15	22	32	11
D	25	20	24	24	7
1980 A, B	20	12	20	33	15
C	19	10	19	35	17
D	40	25	25	6	4
1985 A	20	10	20	33	17
B, C	19	9	18	35	19
D	40	25	25	6	4

*The luxury car class includes a sizable number of larger and more expensive "standard" vehicles, e.g., some Mercurys, Dodges, Buicks, Oldsmobiles and Pontiacs.

The Model for Projecting the Car Occupant Fatality Risk

A mathematical model was used which considered:

- The current automobile population by age and size;
- Future automobile sales by size;
- The "mortality" of automobiles by age;
- Injury frequency related to car age;
- Effects of the FMVSS by model year;
- Seatbelt use by vehicle age and model year;
- Injury risk in single-car crashes;
- Injury risk in two-car collisions;
- Injury risk in car-truck collisions;
- Changes in the frequencies of single-car, car-car, and car-truck accidents

to calculate changes in the average injury risk to all automobile drivers in any year, relative to that in a base year.

Projections of Changes in Car Occupant Fatality Risk

The fatality risk model was applied to predict changes in the fatality risk under the assumptions of future automobile market shares corresponding to Scenarios A, B, C, and D, but using the same values for all other factors. Figure 4 shows the results by crash type and for all crashes. The differences between the results of Scenarios A, B, and C are well within the range due to the uncertainties of the basic relations; only Scenario D gives different projections. Sensitivity analyses were performed, changing the relations between fatality risk and car weight in single-car crashes, and in collisions. The influence of these changes was small under Scenario C (which is also representative for A and B), but could be considerable under Scenario D; however, it is unlikely that the uncertainty of the basic relations will affect the basic conclusion that there will be an increase in risk under Scenario D.

The increase in fatality risk under Scenario D will not continue indefinitely. It is partially due to the presence of older, heavier cars in the car population, into which smaller cars enter. Once the old, heavy cars are phased out, there will not only be a leveling off of this trend, but a small decline in the fatality risk.

3.3 VEHICLE IMPROVEMENTS

Potential Vehicle Improvements

We found a considerable body of engineering knowledge concerning the way to improve the crashworthiness of automobiles. However, only occasionally were estimates given on how they might affect the frequency of car occupant death or injury. It would be a major effort to quantify the effects of these potential improvements.

There exist quantitative estimates of the effects of air cushion restraint systems (air bags) on car occupant injury and fatality risk. With 60 percent lap-belt usage, NHTSA and TSC estimate[3] occupant fatalities

[3] National Highway Traffic Safety Administration and Transportation Systems Center, Analysis of Effects of Proposed Changes to Passenger Car Requirements of MVSS 208. August, 1974

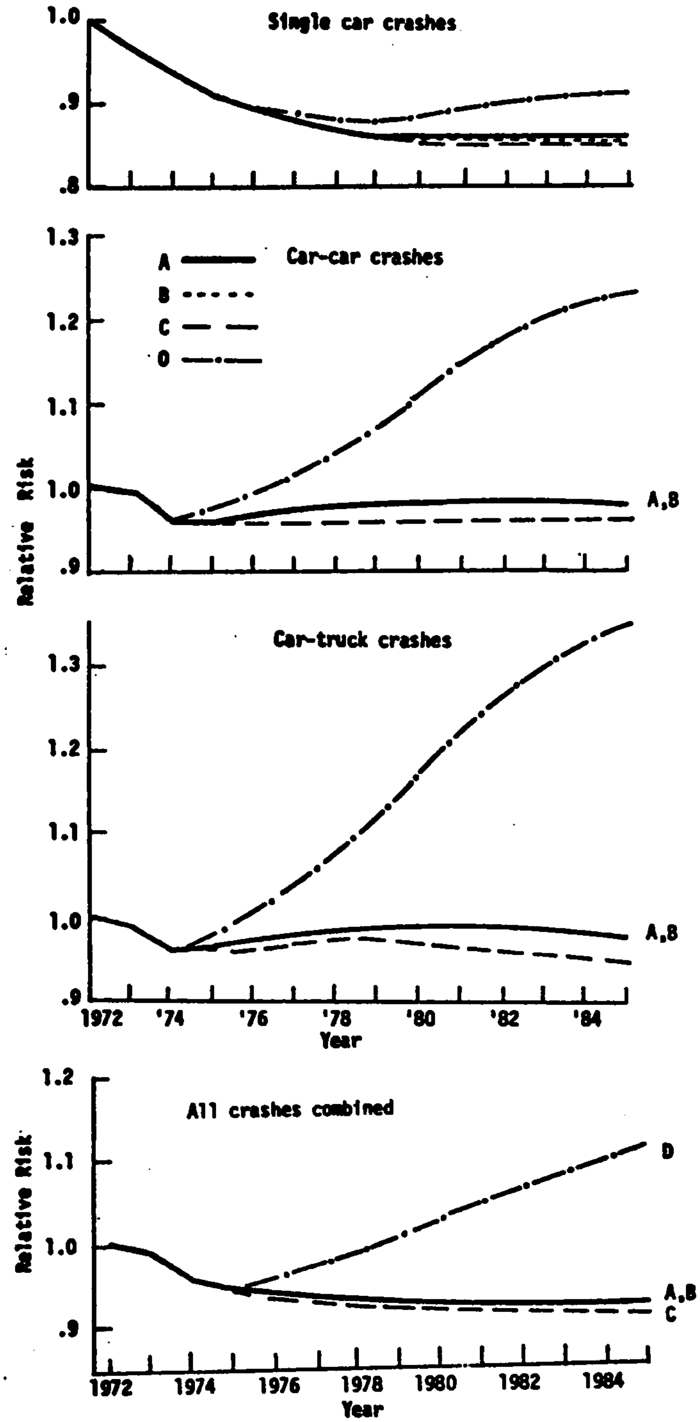


Figure 4. Projections of the average (over all cars) risk of fatal or serious injury to a driver of a car in a crash, under the scenarios A, B, C and D.

would be reduced by 41 percent, injuries by 35 percent. With only 20 percent usage, which reflects approximate current usage, we estimate reduction of the fatality risk to be 35 percent. We conjecture that this reduction is independent of car size.

Projecting the Effects of Air Bags

We found that sales of air bags in 1974 and 1975 were so low as to have no noticeable impact on traffic deaths. GM's projected sales for 1976 and 1977 will not have a noticeable impact on overall figures either. Assuming that as a consequence of FMVSS 208, air bags would be installed in all cars of model years 1978 and later, we incorporated their NHTSA-estimated effects into the fatality risk model. The results are shown in Figure 5, together with the projections without air bag installation. It shows that even under conservative assumptions, air bags would more than compensate for the increase of fatality risk resulting from even a drastic increase in the frequency of small cars.

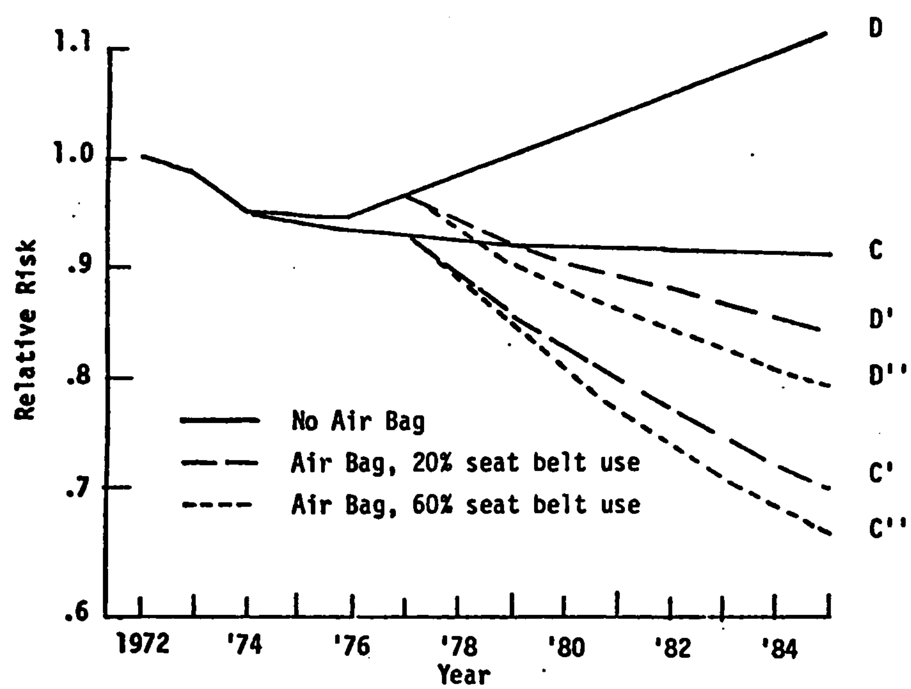


Figure 5. Projections of automobile occupant fatality risk, relative to 1972, under assumptions of no air bags, and installation of air bags in all cars from the 1978 model year on.

3.4 CHANGES IN TRAVEL VOLUME AND PATTERN

Changes in Travel Volume

The overall measure of motor vehicle travel is Vehicle Miles of Travel (VMT). We found that annual motor vehicle accident deaths are not proportional to annual VMT. Changes in the number of these deaths resulting from a certain change in VMT depend strongly on the following: on which type of highway, perhaps which segment of highway, and probably at which time those changes in VMT occur. Therefore, not even an approximate estimate of such a change can be made. Under highly restrictive implied assumptions, we estimated that an x percent uniform change in VMT would result in approximately a $0.75x$ percent change in the number of traffic deaths.

Elimination of Sunday Travel

Though traffic deaths on Sundays and holidays accounted for 21 percent of all traffic deaths, one cannot conclude that elimination of Sunday and holiday travel would reduce traffic deaths by that amount. A closer look at the purpose of travel on Sundays and holidays suggests that many, if not most, trips could be shifted to other days. Even if one knew which fraction of Sunday and holiday travel were shifted to other days, the current state-of-the-art is insufficient to predict how this addition to the normal traffic would affect the number of deaths.

Reduction in Commuter Travel

Home-to-work travel accounts for 23 percent of all VMT, or 21 percent on Mondays through Friday. It is concentrated in the hours 6-9 a.m. and 4-6 p.m. Figure 6 shows how the hourly percentage of traffic deaths is related to the hourly percentage of VMT. During the morning rush hours (6-9), traffic volume appears to have little influence on the number of fatal accidents. Thus, one can expect that a reduction in commuter travel will have no appreciable impact on traffic deaths in the morning. With the exception of the hours 7-9, the daily relation between fatal accidents and VMT is approximately linear, indicating

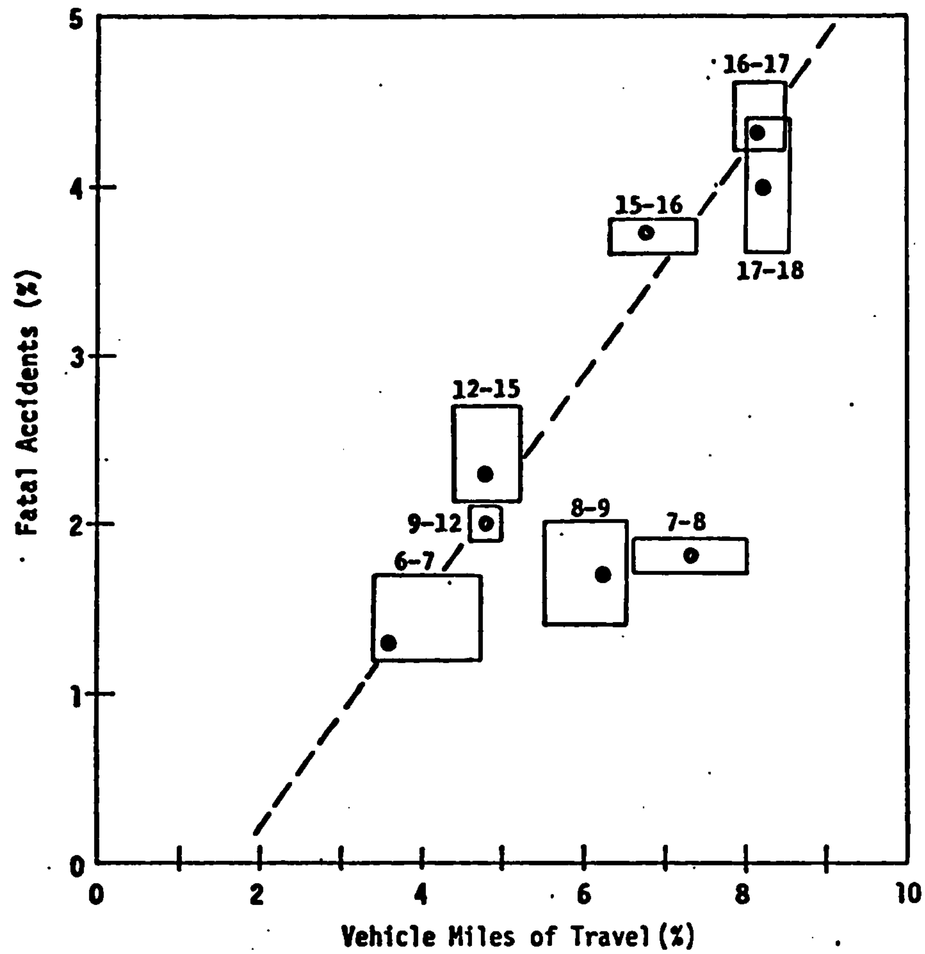


Figure 6. Hourly fatal accidents versus hourly VMT (both as percent of the daily total, to make different data bases comparable), Monday through Friday. The dots are median values, the "boxes" represent the middle tertile of the values from several data bases. The broken line illustrates a suggested relation except for the 7-8 and 8-9 hours. (Hours counted from 0 - 23.)

that a reduction of VMT during the period 4-6 p.m. by 1 percent would correspond to a reduction of traffic deaths by 2/3 of one percent. If we assume this, and ignore the possibility that more accidents during this period might be caused by the 60 to 65 percent noncommuters, we obtain the values in Table 3 for the changes in total traffic deaths corresponding to certain changes in commuter travel during the hours 6-9 and 15-18.

TABLE 3

Reduction (%) of VMT and estimated reduction (%) in fatal accidents resulting from a reduction in commuter travel

	Reduction in Commuter Travel		
	10%	20%	30%
Reduction of VMT	1.4	2.8	4.2
Reduction of Fatal Accidents	0.3	0.6	0.9

3.5 THE FIFTY-FIVE MPH SPEED LIMIT

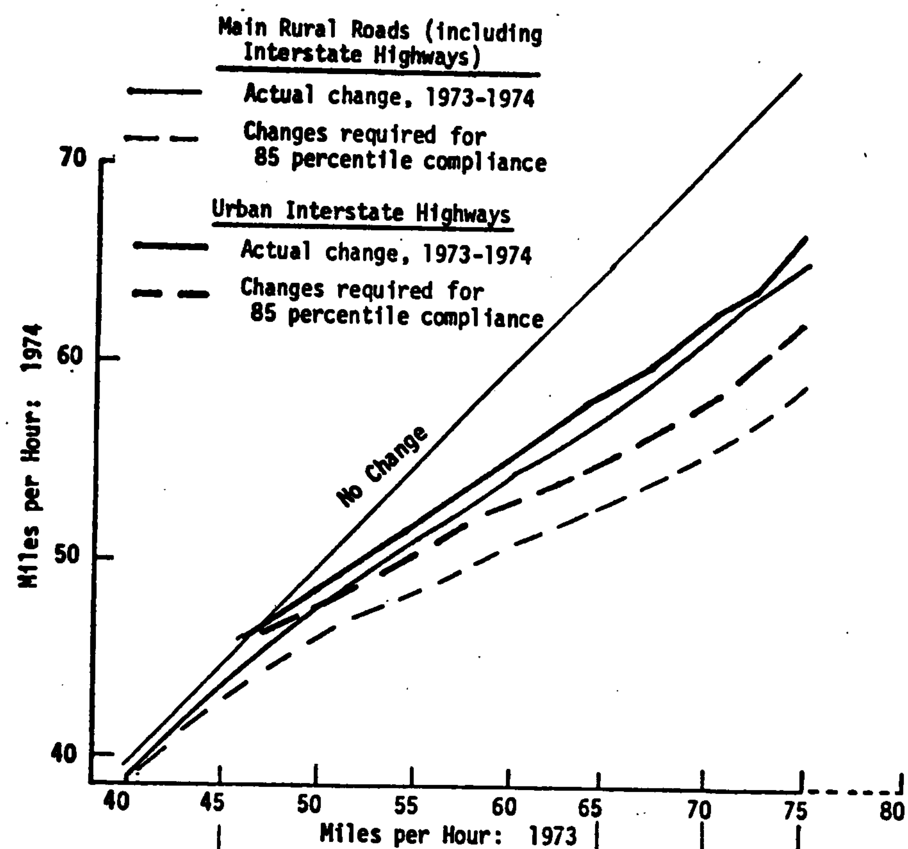
Travel speed can affect traffic accidents in two ways: (1) it may influence the frequency of accidents, and (2) it affects the fatality risk in an accident. We found that the known relation between travel speed and accidents is of such a form that it cannot be used to estimate the effect of an absolute change in travel speed. Therefore, we could only estimate the second effect.

Figure 7 shows how actual travel speed in free flowing traffic on main rural roads changed in 1974 compared with 1973, based on actual speed measurements. It also shows how far speeds would have had to be reduced so that 85 percent of all drivers would be in compliance with the 55 mph speed limit (which we use as an operational definition of "strict" enforcement). We also explored the case of "literal" compliance, where all drivers previously travelling above 55 mph would slow down to 55 mph, and drivers travelling at 55 mph or less would not change their speeds. Below each speed range are figures which indicate how far the three different speed reductions would reduce the risk that an accident would be fatal. Estimates in the range 75-80 mph are highly uncertain. We applied these risk reductions to the number of fatal accidents in each speed range which gave the value shown in Table 4 where we used a "best" estimate, B, a "high" one, A, and a "low" one, C.

TABLE 4

Reduction (%) of the number of fatal-accident involvements resulting from the speed changes shown in Figure 7. The first number assumes no reduction in the speed range exceeding 80 mph (excessive speeding which might not be influenced by the 55-mph limit), the second number (in parentheses) assumes the same reduction for the range above 80 mph as for the 75-80 mph range

Speed Changes		Distribution of Fatal Accidents		
		A	B	C
Actual, 1973-1974		12-(18)	12-(14)	7-(9)
85 Percent Compliance	55 mph	17-(24)	16-(20)	12-(14)
Literal Compliance	55 mph	12-(20)	11-(15)	8-(10)



	Change of Fatal Accident Risk due to Speed Reduction (relative to 1.0)							
Actual Speed Change	1.0	1.0	.9	.8	.7	.6	.5	(.4)
85 Percent Compliance	1.0	1.0	.8	.7	.6	.5	.4	(.25)
Literal Compliance	1.0	1.0	1.0	.9	.7	.5	.3	(.2)

Figure 7. Comparison of travel speeds in 1973 and 1974 as actually measured in free-flowing traffic on straight, level highway sections and a required-to-achieve 85% compliance with the 55 mph speed limit.

Below the graph is shown how the risk that an accident is fatal is reduced (from 1.0 "before") in each speed range, for the actual speed change, the change required for 85% compliance with the speed limit, and for "literal" compliance, assuming that all speeds above 55 mph are reduced to 55 mph, but speeds below 55 mph are not affected. The values for the 75-80 mph range are based on extrapolations and are uncertain.

First, we made the assumption that the risk in accidents at speeds exceeding 80 mph would be changed as in the range 75-80 mph. An alternative assumption was that there was no reduction in travel speeds above 80 mph, implying that the "speeders" disregard any speed limit. A comparison of the results shows that this change has a major impact on the conclusions (as shown in the numbers in parentheses of Table 4).

We reviewed a study of North Carolina accidents. It was assumed that drivers would exceed the 55 mph speed limit by the same amounts they had previously been exceeding existing speed limits. The result was that the number of vehicles involved in fatal accidents would be reduced by only 3 percent.

These results are comparisons between 1973 and 1974. To project the future effects of a continuing 55 mph speed limit, one would have to make projections of future travel speeds. Though there has been a continuous trend of increasing travel speeds over the last decade, it appears unrealistic to extrapolate this into the future, because the trend appeared to level off in 1970. Therefore, it appears more plausible to assume that no increases or only small increases in travel speed above the 1973 values would occur if the 55 mph limit were rescinded.

4. THE RELIABILITY OF THE RESULTS

Though our analysis is based on all available relevant studies, and on new results derived from original data, the accuracy and reliability of the results is very limited. The main reasons are: (1) that the number of fatal accidents in any single data base is quite small; (2) that "accidents" in relation to which injury risks are calculated are not uniformly defined; (3) that data bases are not comparable; and (4) that many important factors are not known or only very roughly known. In addition, there are some areas where even a basic conceptual understanding of the relations is lacking, e.g., the effect of speed, traffic density and traffic mix. Therefore, the results may reflect the real world changes with much lower reliability than one would expect from the internal consistencies and discrepancies of the various data bases. An indication of the magnitude of this "external" error is given by discrepancies between results from different data bases: It is frequently 20-25 percent of the estimated effect, and sometimes even larger.

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1. OVERVIEW

The objective of this study was to estimate how the number of motor vehicle accident deaths would change over the ten years 1975-1985 with possible changes in four factors:

1. The composition of the passenger-car fleet. The study included four possibilities, ranging from a slightly increasing proportion of standard-size cars sold compared to the years 1972-1975 to a doubling of the proportion of subcompact and compact cars sold by 1980.

2. Vehicle improvements. Only the effects of air-cushion restraint systems could be quantified. Two alternatives were considered: no use, and mandatory installation from the 1978 model year on.

3. Reduction in travel. Four cases were studied: eliminating Sunday travel, and reducing commuter travel by 10, 20, and 30 percent.

4. The 55-mile-per-hour speed limit. Three possibilities were examined: enforcement as in 1974, strict enforcement, and the limit rescinded with returning to 1973 speeds preceding the fuel shortage.

1.1 RESULTS

There are many difficulties and uncertainties associated with the relevant available data and the models that can be derived from them (as the main body of the report describes). However, for the purposes of this overview, it suffices to say that the best estimates obtainable by combining these data and models with CEM's best judgment yield these results. (A more detailed explanation of these results begins on the next page.)

1. The composition of the passenger-car fleet. Several alternative future developments of market shares of subcompact, compact, intermediate, full size, and heavy cars were studied, the most extreme assuming a doubling, compared with 1972, of the market share of subcompacts and compacts at the expense of standard and heavy cars. Under this extreme assumption, the average fatality risk for all car occupants in accidents

in 1985 would be higher than in 1972, possibly as much as 15 percent. Under the other alternatives, it would be about 10 percent lower.

2. Vehicle improvements. Various improvements of cars to reduce occupants' fatality risk are known, but "airbags" are the only ones whose effect can currently be quantified. If airbags would be required from the 1978 model year on, the average fatality risk for all car occupants in crashes in 1985 would be reduced by about 30 percent, compared with 1972, under most assumptions on automobile mix, by about 15 percent under the extreme assumption of a doubling market share of compact and subcompact cars.

3. Reduction in travel. No quantitative estimates of the effect of potential reductions in automobile travel on automobile occupant deaths could be made.

4. The 55-mile-per-hour speed limit. No precise estimate of the effects of the 55 mph speed limit could be obtained. We estimate that it reduced the average fatality risk of all car occupants in crashes in 1974 by about 10 percent, but possibly by as little as 3 percent. If literally enforced, the 55 mph speed limit could have reduced the fatality risk by about 15 percent.

1.2 DETAILED ANALYSIS OF RESULTS*

The Four Factors Considered Separately

1. The composition of the passenger-car fleet. Different classes of cars have differing risks of occupant deaths, once a crash has occurred, and may conceivably have differing risks of crash involvement, for comparable exposures. No evidence for the latter was found. Therefore, only the effect of a changing vehicle mix on the overall fatality risk of car occupants in crashes was studied. Of the four possibilities considered, all but the one with a doubling of the proportion of subcompact sales yielded comparable results; thus, the relative risks can be summarized as in Table 1-1.

*All figures quoted are ratios of the risks of a fatality for the whole population of car occupants related to 1972 experience.

TABLE 1-1

Summary of relative risks

Accident type	Market share development	
	Doubling subcompacts and compacts by 1980	Other scenarios
Single car crashes	0.98	0.85 - 0.86
Car-car collisions	1.23	0.96 - 0.98
Car-truck collisions	1.35	0.95 - 0.98

Combining the changes in risk by crash type with the frequency of car occupant deaths by crash type - one-half in single-car crashes, one-third in collision of two or more cars, and one-sixth in car-truck collision, and in addition considering the uncertainty of some basic data, we obtain for the overall fatality risk for car occupants in crashes in 1985, relation to 1972,

- for the doubling-subcompact-compact-sales scenario: 1.01 - 1.04,
- for the other scenarios: 0.88 - 0.91.

2. Air-cushion restraint. CEM's estimate is that cars equipped with air-cushion restraints reduce the risk of fatality in all crashes by 35%. For mandatory restraints for all new cars beginning in 1978, this changes the relative risk estimate for the total passenger-car fleet by 1985 of 0.84 for the doubling-subcompact and compact-sales case and 0.70 for the other cases.

3. Reduction in travel. Various factors (such as displacement of forbidden travel to unforbidden times, the relative insensitivity of risk ratios to the marginal changes resulting in the cases considered, and the relatively low sensitivity of occupant deaths to volumes of commuter travel) make it impossible to estimate separate risk ratios for the marginal travel reductions proposed for consideration. Rather, the changes in risk that would ensue from the proposed travel reductions appear to be so small as to be buried in the variability of the phenomena under consideration. In effect, therefore, the relative risk ratios for the changes considered here are too close to unity to be differentiated

from it, in view of the variability present in the rest of the problem.

4. The 55-mile-per-hour-speed limit. Relative to the risk of fatality for an accident at 40 mph, the risk ratio for an accident at 60 mph is 2, for one at 70 mph it is 4 and for one at 80 mph it is over 10. The year 1974 and its pattern of enforcement, as it continued through January 1975, saw a significant downward shift in the distribution of travel speeds. To represent strict enforcement case, we assume for the speed distribution that there is no change for speeds below 40 mph, but that 85% of the speeds are 55 mph or less. Combining these speed distributions with the risk ratio as a function of speed, we get the following results:

- For the actual 1974 speed reduction, the fatal risk ratio relative to the previous year may be as low as 0.88 to 0.93, but could be as high as 0.97.
- For strict enforcement of the 55 mph speed limit, the fatal risk ratio relative to 1973 is 0.83 to 0.88.

The future effects depend on which speeds would have prevailed in future years without the 55 mph limit, and how will it be obeyed in the future.

The Factors Considered Together

Considering all the factors together (which, practically, means uniting the results of paragraphs 2 and 4 above), we obtain these results (which assume mandatory air-cushion restraints and strict enforcement):

- For the doubling-subcompact-compact-sales case, the relative risk ratio declines to between 0.68 and 0.85.
- For the other cases, the average risk ratio declines even further to between 0.59 and 9.68.

In sum, depending on the composition of the fleet, in 1985, the relative risk ratio is reduced between 15 and 41 percent. The 1985 fleet in the doubling-subcompact-sales case contains about one-third subcompacts; for the other cases it averages one-fifth subcompacts.

In retrospect, the compositions of the fleet exhibit contrary influences, some reducing the risk ratio as much as 10 percent, others increasing it (the most notable of the latter being the subcompact in car-truck crashes), which can increase it by as much as 45 percent. Imposition of the

55 mph speed limit reduced it to an unknown extent up to 12 percent; strict enforcement could reduce it by 15 percent, to possibly 20 percent. The dominant influence could be the mandatory installation of the air-cushion restraint system which would reduce the risk ratio by 23 percent in 1985 (and by 35 percent once the entire automobile population is equipped with it). Thus, strict enforcement of the 55 mph speed limit and mandatory installation of the air-cushion restraint system would more than compensate for the effects of increasing sales of small cars.

Some other subsidiary conclusions are worth noting:

- The predicted tendency of the subcompact car fleet to raise the risk ratio arises partly from the presence of this car in a fleet still dominated by heavier older cars; if the fleet were entirely composed of subcompacts, the risk would increase less.
- The relative insensitivity of the risk ratio to levels of commuter traffic is a surprising result that clearly calls for further inquiry.

The results of this study are based on data and models of varying reliability, and the structure of the analysis is forced into relative crudity by this fact. Thus, it is clear that all of the phenomena and questions studied here warrant much further study; initial steps to this end are detailed in the body of the report.

2. OBJECTIVE AND SCOPE OF THE STUDY

The ultimate objective of this study was to estimate how the number of motor vehicle accident deaths would change over the next ten years under various assumptions on the use of small cars, on travel speed reductions, and on changes in vehicle use, which might result from a limited availability of gasoline.

As a basis for such estimates:

- Relations between automobile weight and the frequency and severity of accidents had to be established;
- Potential automobile improvements which might affect this relation had to be identified;
- A model had to be developed to calculate deaths and injuries as functions of the automobile population characteristics;
- Relations between accidents (and their severity) and automobile use in quantitative (vehicle miles of travel) and qualitative (speed, time of day and week) terms had to be established; and
- An approach to estimate the impact of changing automobile use on accidents and their severity had to be found.

The Transportation Systems Center provided the following "scenarios" for which estimates and projections were to be made:

- Four alternative compositions (in terms of "subcompact," "compact," "intermediate," "standard," and "luxury" cars) of car sales from 1972 through 1985.
- Assuming optional and mandatory installation of air cushion restraint systems.
- Reduction of travel by
  - elimination of all Sunday travel;
  - a 10 percent reduction in commuter traffic;
  - a 20 percent reduction in commuter traffic;
  - a 30 percent reduction in commuter traffic.
- The 55 mph speed limit
  - enforced as currently done;
  - strictly enforced;
  - rescinded and previous speed patterns resumed.

The scope of the study was limited to considering cars of essentially current design and construction, and improvements and minor modifications, but no basic changes or major modifications. Time and available funds limited the extent to which new data could be developed and the depth of the analyses. Most analyses had to be based on published or easily available information.

3. STRUCTURE OF THE APPROACH

3.1 THE ELEMENTS OF THE APPROACH

We approached the problem in the following steps:

- Establishing relations between automobile size (weight) and accidents (Section 4)
  - By reviewing the literature (Subsection 4.2)
  - By analyzing new accident data (Subsection 4.3)
  - And combining the results (Subsection 4.4)
- Applying the previously developed CEM accident model to project, using the relations established in the first step (Section 5)
  - How changes in future sales of larger versus smaller cars would affect the overall car occupant fatality risk (Subsection 5.1)
  - How certain potential automobile improvements--including the air bag--would affect the overall car occupant fatality risk (Subsection 5.2)
- Reviewing the literature and CEM's past work in relation to the way changes in the quantity and quality of automobile travel influence the number of traffic deaths (Section 6)
  - What is known on the relation between VMT and traffic deaths (Subsection 6.1)
  - What is known on the relation between speed and accidents (Subsection 6.2)
- Estimating how changes in automobile use would change the number of traffic deaths (Section 7), specifically
  - What the effects of the 55 mph speed limit in 1974 were, and what they would have been, had it been strictly enforced (Subsection 7.1), using, to a large extent, previous work by CEM and actual speed data
  - What the effects of eliminating Sunday travel would be, analyzing the purposes of Sunday travel (Subsection 7.3)
- Finally, we identified potential interactions between the various effects studied (Section 8).

These steps were not always, for practical reasons, performed in the indicated order. The tabulations for identifying potential interactions were, e.g., generated together with the tabulation for analyzing the vehicle size-injury relations.

3.2 THE CHOICE OF METHODS

The objective is to estimate total national effects of the changes considered. The data on which the relations used are based, however, are for a few states or even smaller areas. There are many factors which cause real or apparent differences between the relations for different data bases, many of which one cannot adjust for. In addition, the known factors may be only crude measures of important characteristics, e.g., vehicle weight represents the weight itself, vehicle size,and possibly also complex design characteristics. Therefore, it is speculative to assume that relations valid for a few recent years will hold in the future.

Considering this, the best one can expect to do is to use "best estimates" from the available data and to perform parameteric analyses to determine how plausible changes of critical parameters influence the results. Therefore, we did not perform thorough statistical analyses where a relation was known to exist, e.g., in the case of two-car collisions (subparagraph 4.2.2.2) or the relation between travel speed and injury frequency (subsection 6.2). Here we used simple graphical methods for making numerical estimates rather than a statistical analysis, because the differences between the data bases are more important than the statistical accuracy of the result within each of them. In addition, we presented the result in the form of graphs or simple table only. They present much more detailed information than aggregate statistical measures, such as a correlation coefficient, and visually show obvious systematic deviations from the hypothetical relation, or suggest possible deviations. However, where relations had not been previously established but could be plausibly expected, we did apply more sophisticated statistical analyses, if the data did not show obvious relations (e.g., in 4.2.2.1 and 4.3.7).

Most of the effects studied will occur in future years. The current state-of-the-art, however, is such that even *ceteris paribus*, it is not possible to confidently project motor vehicle traffic deaths as a function of a few independent variables. The best one can do is to make illustrative projections of absolute numbers. On the other hand, the state-of-the-art is sufficient to make projection of changes in the risk of fatal, or fatal or serious injuries due to changes in several parameters with a greater degree of confidence. Therefore, we will make our projections in terms of relative risks, and use absolute numbers only for illustrative purposes.

4. AUTOMOBILE SIZE AND ACCIDENTS

4.1 SIZE AND WEIGHT

"Size" and "weight" of automobiles are sometimes used synonymously, since for existing cars the size (measured by overall length or wheelbase) and weight (measured by shipping weight or curb weight) are correlated. However, this correlation is loose: for a given size, the weights of different automobile models vary by about 500 lbs. Also, "size" and "weight" have to be distinguished for conceptual reasons, as discussed by O'Neill, Joksch and Haddon [1].* "Size" is primarily a protective property of a car because it allows for occupant deceleration over a longer distance, thereby reducing peak deceleration. "Weight" is primarily a hostile characteristic because it decreases the deceleration of the heavier vehicle and increases that of the lighter vehicle in a two-vehicle collision, although it has no direct effect in most single-car crashes. The exact roles of size and weight depend on how the size is utilized for energy absorption and how the weight is distributed in the car. Over the years, both weight and size of most car models have increased, but not necessarily uniformly, which suggests that the protective and hostile characteristics may have changed differently from the direct changes in weight and size.

To separate these effects would have been far beyond the scope of this study. Considering the uncertainty introduced by not separating these effects, and the numerical uncertainty of the result obtained, a conventional classification† of cars into "subcompacts," "compacts," "intermediates," "standard" and "heavy" was used. A definition of these classes, primarily in terms of weight, is given in Appendix B.

4.2 AUTOMOBILE SIZE AND ACCIDENTS - REVIEW OF THE LITERATURE AND PUBLISHED DATA

The relation between automobile size and accidents has two aspects: (1) the frequency of accident involvement, and (2) the frequency of death or injury, including the severity of injuries, once an accident

*References appear in Appendix G.

†There exists, however, no commonly used unambiguous definition of these classes.

has occurred. The frequency of accident involvement is measured by accidents per "exposure" unit, such as 100 million vehicle miles of travel, or more commonly, per 100,000 vehicle registration years. The frequency of injury is measured by the number of injured occupants per crash-involved car, the severity by using the classes* "fatal injury," "fatal or serious," "any injury," or similar classes such as "fatal," "fatal or A," "fatal, or A or B," "fatal, A or B or C."† Usually, only driver injuries are considered, because the exposure basis for other occupants is unknown: their presence is rarely reported if they are not injured.

These measures of accident frequency and accident severity are subject to considerable uncertainties, mainly:

- The conceptual inadequacy of vehicle miles of travel or vehicle registration years or measure of exposure;
- The incomplete reporting of accidents; and
- The gross and subjective classification of injuries.

Vehicle miles of travel or vehicle registration years are inadequate because the risk of getting into an accident depends greatly upon when and where a mile is traveled, and the risk per registration year varies greatly depending upon the numbers of miles traveled annually, and when and where they are traveled. If usage patterns differ between car classes, differences in accident involvement between car classes will result which are not due to characteristics of the cars themselves.

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*More refined measures of injury severity, such as the Abbreviated Injury Scale (AIS) are used only in a few special accident investigation programs.

†A, B, and C injuries were defined as: A - "a bleeding wound, distorted member, or any condition requiring the victim to be carried from the scene of an accident;" B - "abrasion, bruise, swelling, limping, or obviously painful movement;" C - "complaint of pains without visible sign of injury, or momentary unconsciousness." Recently, the definitions have been changed to: A - "incapacitating injury;" B - "nonincapacitating evident injury;" and C - "possible injury." Thus, many injuries previously classified as A should now be classified as B, and similarly with B and C. However, the old definitions are still used by many police agencies reporting accidents. This makes it very difficult, if possible at all, to compare injury figures over time or between jurisdictions, as evidenced by the data presented in Appendix A.

All states require reporting of accidents resulting in death or personal injury. The amount of property damage above which reporting is required if no injury occurred, however, varies greatly between states: from $25 (in Texas) to $400 (in Connecticut); details are given in Appendix A. To what extent drivers comply with these requirements and which fraction of accidents is investigated by the police is unknown. Moreover, the property damage reporting threshold can make an accident reportable for one type of car which would not have been reportable had another car model been involved.

The injury classifications used in mass accident data are very crude; this is obvious from the definitions used, and from comparisons of the distribution of injury severity in various states.

Some of these problems are discussed in greater detail in Appendix A.

A consequence of these uncertainties is that estimates of both accident frequency and accident severity are of considerable uncertainty, which has to be considered when interpreting the results of any analysis of accident data. In addition to the stochastic variation, which can be estimated, unknown biases are likely to be present.

4.2.1 The Frequency of Accident Involvement

The literature on the relative frequencies of accident involvement of small and large cars has been reviewed by Mela [2]. His conclusion is that "the results of accident involvement rates are contradictory and there is no clear evidence that the likelihood of getting into a crash is related to car weight."

In a recent paper, Hart [3] claims that there are differences in the crash involvement of large and small cars. However, in our opinion, his arguments are not strong enough to require a revision of Mela's conclusions.

An interesting point has been raised by Epstein and O'Day [4]. They find that in Oakland County, Michigan, in 1969 there were 1.2 times as many collisions between two large cars, 2.7 times as many between two small cars, and only 0.4 times as many between a large and a small car, as one could expect if large and small cars were randomly mixed in collisions.

New York State data [5], however, show only small, though consistent deviations of the actual pattern from that to be expected in a random mix. The largest deviations are for collisions between two cars of less than 2,500 lbs -- +14 percent, and for collisions between two cars or more than 4,000 lbs. -- +7 percent. All other deviations are less than 4 percent.

This "clustering" of small and of large cars is probably due to current usage patterns (the New York State data also show more frequent collisions between two young, and between two old drivers than to be expected, and CEM found in Virginia and Texas accidents more frequent collisions between cars of the same age than to be expected) and not to physical properties of the vehicles.

4.2.2 Injury Frequency

Several studies have estimated the injury frequency of drivers and/or occupants by car model [6, 7, 8] or car weight class [9]. These earlier studies do not distinguish between single-car, two-car and other crashes. Therefore, their results reflect not only the characteristics of each car model, or weight class, but also the effects of interactions with the other vehicles in the vehicle population. Thus, they cannot be used as a basis for estimating how injury frequency would change with a change in the composition of the vehicle population. To study this, one needs separate information for single-car, two-car and other crashes.

4.2.2.1 Single-Car Crashes

Campbell and Reinfurt [10] calculate an "injury index" for injury to unbelted drivers in run-off-the-road crashes. The injury index standardizes for possible differences in speed and site of impact among different car models. Figure 4-1a shows the index for serious and fatal driver injury in relation to vehicle weight. The figure suggests that injury frequency decreases with car weight, but using certain statistical tests, Campbell and Reinfurt find that it cannot be concluded that there is a negative relationship between vehicle weight and serious injury in single-vehicle ran-off-road crashes.

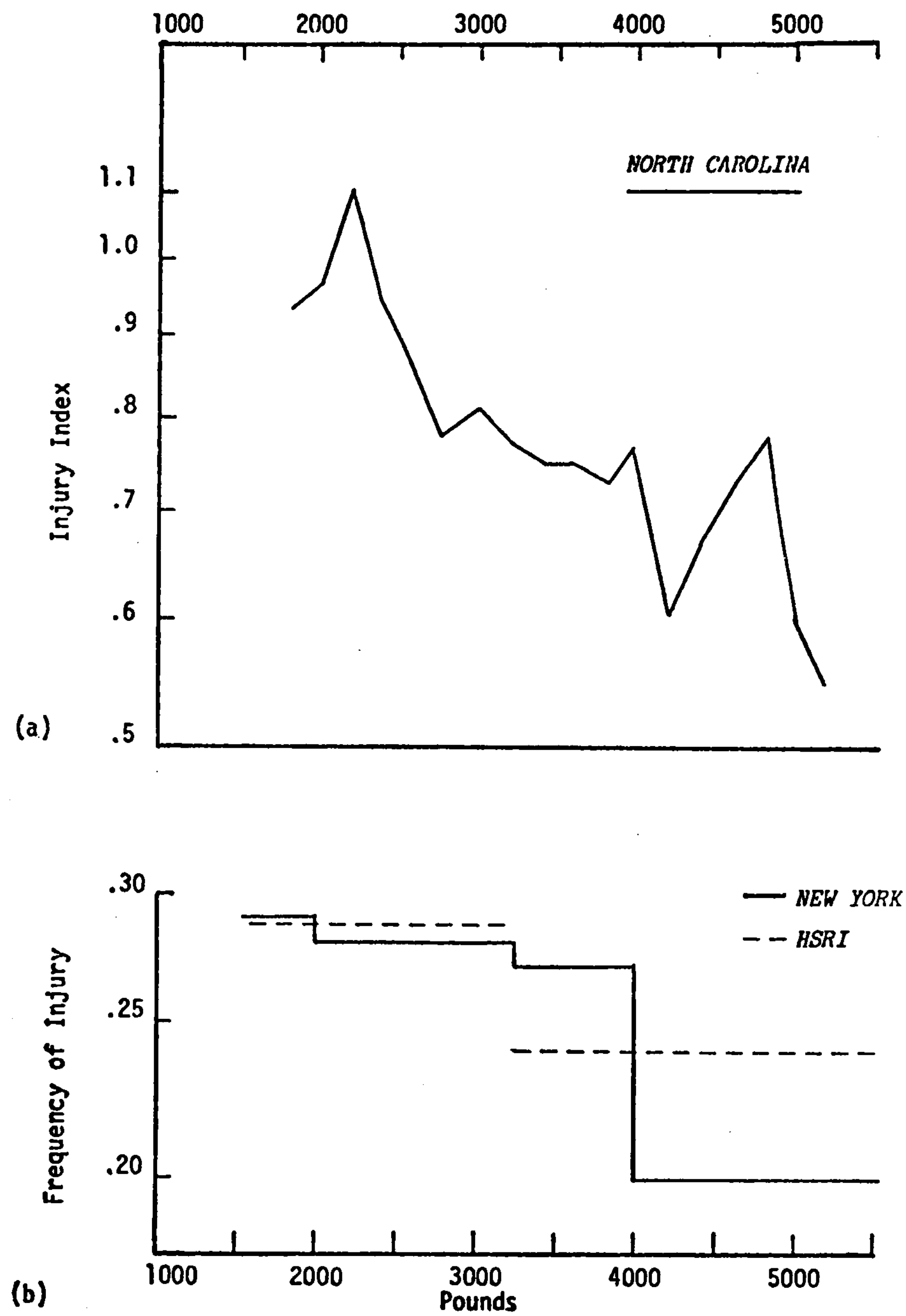

Figure 4-1. (a) Injury index for serious and fatal unbelted-driver injury in ran-off-road crashes, derived from North Carolina data by Campbell and Reinfurt. The index values are taken from a graph and are subject to some uncertainty.
(b) Frequency of fatal or serious unbelted-driver injury in New York State single-car accidents, and of an occupant's injury in single-car crashes in Washtenaw County, Michigan, both derived by CEM from New York State and HSRI data.

We performed a further analysis. The data for the various car models and model years were grouped into 9 weight groups and an average index for each group calculated. Figure 4-2 shows the results. In the range from 2500 to 4500 lbs weight, the relation between index and weight appears to be linear. Outside of this range, however, there are great deviations from this line. A closer look at the original data shows the following: the two points below 2500 lbs represent the one the "beetle" type, the other the "fastback" type. The point above 4500 lbs represents Cadillacs and one-sixth Lincolns. In the case of VW, the uncommon design might explain the deviations from the "normal" index-weight relation, in the case of the Cadillac and Lincoln the higher driver age which makes them more susceptible to injury [11].

Excluding the three extreme points and fitting a straight line to the others, one obtains the regression equation 113 - 1.0 × weight (in 100 lb) as a best fit. A test value of $t = 1.8$ for the coefficient 1.0 indicates, however, that this 1.0 is not significantly different from

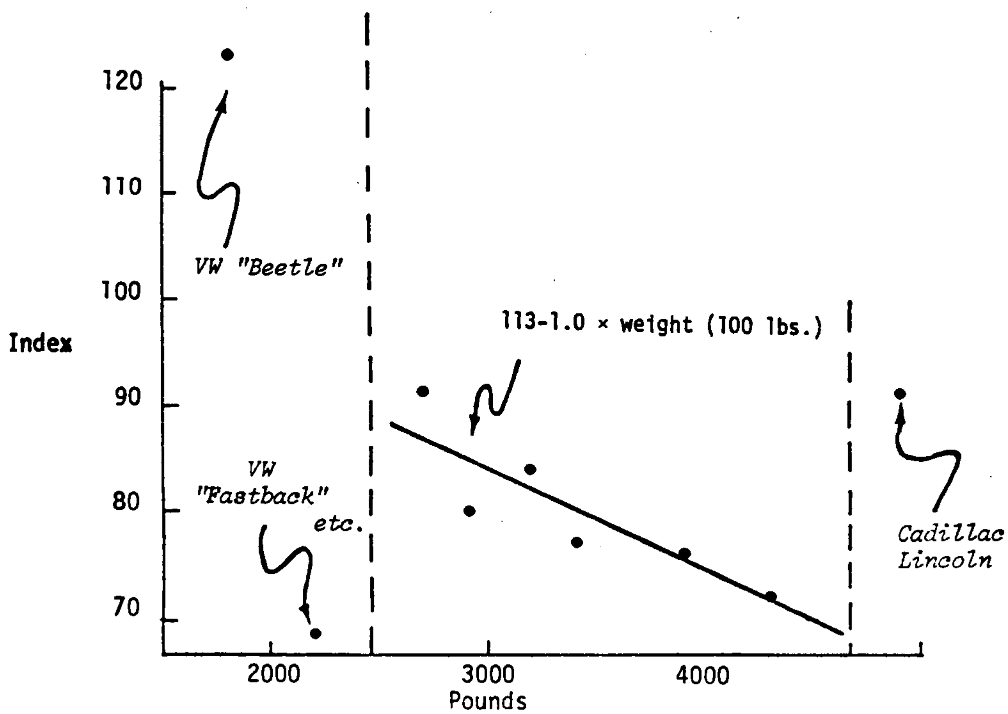

Figure 4-2. Injury index for serious and fatal unbelted-driver injury in ran-off-road crashes, by car weight in broad classes. Derived by CEM from Campbell's and Reinfurt's data.

0.0, which would mean that the six points could be considered as randomly fluctuating around a constant value, in this case 80. This conclusion contradicts the visual impression conveyed by Figure 4.2. Therefore, Kendall's rank-correlation test was applied; it tests only whether the index decreases (or increases) systematically with increasing weight. It results in S = 13, which indicates that the six points could have resulted from random fluctuations around a constant value of 80 with a probability of only 0.008. The different results of the two tests are not incompatible: they surely indicate that the assumption of linearity in the first test is too restrictive. However, for all 9 points, the rank correlation becomes non-significant.

Our overall conclusion is that for the most frequent weight classes, the North Carolina data show a clear relation between driver injury and car weight in single-car accidents.

We also analyzed New York State data provided by NHTSA on serious and fatal injury to unbelted drivers by vehicle weight and driver age. The frequency of serious and fatal injury, standardized for the driver age distribution, by automobile weight, is shown in Figure 4-1b.

O'Day, Golomb and Cooley [12] present graphs showing that in Washtenaw County, Michigan, of single-vehicle collisions, 41 percent involved injury for small cars (less than 3100 lbs) and 35 percent for large cars (over 3,300 lbs). Since injury to any occupant is considered, we have to adjust for differences in occupancy, graphically shown as about 1.58 for small cars and 1.64 for large cars. This can be done only with additional assumptions: (1) that there are either one or two, but never more occupants, and (2) that the probability of injury is the same, p, for each occupant. Then, with an average occupancy, a, per car, the probability, q, of at least one injury in a crash can be derived:

$$q = pa - p^2 (a-1) \quad . \tag{4-1}$$

Using this formula, we obtain the values shown in Figure 4-1b. Compared with the New York State data, the injury frequency differs less between small and large cars. This is not surprising considering that New York State data are for fatal or serious injuries only, the Washtenaw County data for any injury: the North Carolina data discussed above also show that the frequency of any injury varies less with car weight than the frequency of fatal or serious injuries.

Overall, the New York State and the North Carolina data agree that the frequency of fatal or serious injury to an unbelted driver is about 50 percent higher in small cars than in large cars. In the middle-weight group, however, there is a systematic difference: in the New York State data, the frequency varies little in the 2000-4000 lbs range, whereas in the North Carolina data the frequency declines steadily with vehicle weight. Part of this difference might be due to the data base: the North Carolina data include only run-off-the-road crashes, New York run-off-the-road and hit-fixed-object crashes. Also, North Carolina has only Volkswagen models in the lower weight classes, New York State also other makes and models.

4.2.2.2 Two-Car Crashes

Bivariate tabulations of the frequency of serious or fatal driver injury in two-car crashes, by the weights of the two cars involved (and crash configurations), had been made for New York State accidents (1969 through 1971) [5] involving cars of the 1965 and later model years, and North Carolina accidents (1966 through 1971) [10], involving cars of the 1966-1970 model years. On the basis of the New York tabulations Mela [2] derived the following formula

$$16.6 \times 0.951^{w} \times 1.018^{w'} \qquad (4\text{-}2)$$

for the risk of fatal or serious injury to an unbelted driver of a car of weight w (in 100 lbs) colliding with a car of weight w'. He also found that essentially the same equation represented North Carolina data.*

Despite the good agreement between the results from New York State and North Carolina, some doubts arose as to what extent they reflected differences between car classes, and to what extent the influence of other factors which might be correlated with car classes, e.g., speed or driver age, the possible influence of which was not eliminated in the

*Mela used the actual data, not the "smoothed" data presented in the study.

data bases. That such factors might have an influence was suggested by the observation that in New York State the frequency of injury decreased with the increasing age of the driver of the other car.

4.3 AUTOMOBILE SIZE AND INJURY FREQUENCY - ANALYSIS OF NEW DATA

The review of the literature found good information on the relations between vehicle size and driver injury in two-car crashes, less consistent information on this relation in single-car crashes, and none on other crashes. As Figure 4-3 shows, nearly 20 percent of all car drivers are killed in car-truck crashes, and between 5 percent and 10 percent in multi-vehicle crashes. Therefore, additional analysis of new data were performed to determine:

- How the injury frequency in single-vehicle crashes depends upon car weight;
- How the injury frequency in car-truck crashes depends upon car weight; and
- How the injury frequency in multi-car crashes depends upon car weight.

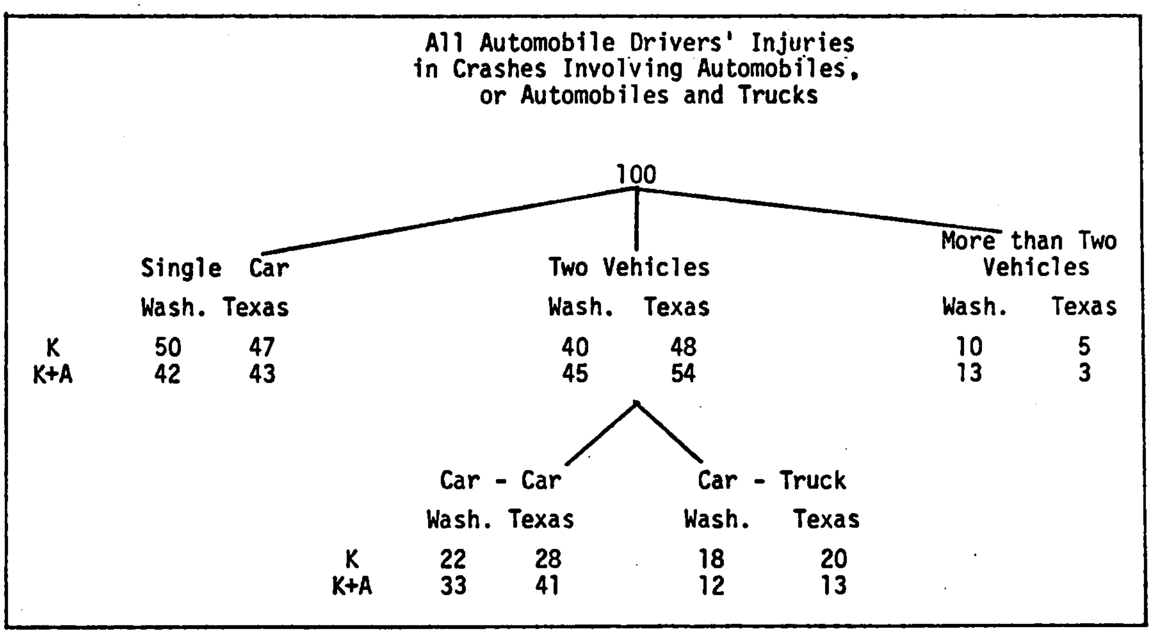

Figure 4-3. Distribution (in percent) of automobile drivers' deaths (K) and fatal or serious injuries (K+A) in crashes involving only automobiles, or automobiles and trucks. Data Base: Washington State 1972, Texas 1971 and 1972.

Additional work was also done on two-car crashes to provide a broader basis for the results. A closer look at results from North Carolina [10], and the observations made in Subparagraph 4.2.2.1 of this report suggest that the frequency of fatal injury may depend more strongly on car size than does the frequency of fatal or serious injury. Therefore, we also studied:

- Whether the frequency of fatal injury depends upon car weight in a manner different from the frequency of fatal or serious injuries.

Physical arguments (Appendix C) make it plausible that the differences in injury frequency for drivers of large and small cars may be less at lower speeds. Therefore, we also addressed the question:

- Whether the relation between injury frequency and car weight depends upon speed.

Finally, we studied whether pedestrian or bicyclist injury severity depended on the weight of the car involved in a pedestrian or bicycle accident.

As a basis for these analyses the following data were used:

1. Tabulations of driver injury severity in two-car crashes in New York State, 1971 and 1972 [13], based on 140,000 cars;
2. Tabulations of the frequency of unbelted-driver fatalities, and fatal or serious injuries in North Carolina crashes 1966 through 1971, based on 160,000 cars, which were generously made available by Dr. D. Reinfurt of the Highway Safety Research Center, University of North Carolina;
3. Original data tapes for Washington State accidents 1972, involving 150,000 cars; and
4. Original data tapes for Texas accidents in 1971 and 1972, involving 1,000,000 cars.

A more detailed description of the data bases is given in Appendix A. In addition to car size, other factors influence the frequency of driver injury (e.g., speed, and the model year of the car, the latter determining the applicability of the Federal Motor Vehicle Safety Standards). Small cars are more common in recent model years, to which the FMVSS's are applicable, which reduce the frequency of occupant injury. To avoid spurious results due to this relation between vehicle size and the effects of the FMVSS's and also possible consequences of a suggested "age-effect," [14, 15] cars were also distinguished by model year from 1968 through 1972. For most analyses, only the 1968 and later models were used. Thus, the 55 percent of all cars before 1968 were included in only a few cases.

To eliminate the effects of such a potential interaction between model-year and vehicle-size and suspected interaction between vehicle-size and speed, a "standardized" ratio of fatally or seriously injured drivers to drivers involved was calculated by first computing the ratio for each model year/driving environment combination (driving environment being defined by "posted speed" in the Washington accidents, and by highway type in the Texas accidents--Interstate Highway, open roads, city streets, and "other highways"), and then averaging these ratios according to the overall frequency of the model year/driving environment combination for each vehicle class. In a few cases, all of these combinations were given equal weight, which did not result in systematic differences against the correctly weighted results.

Although such a standardization procedure reduces systematic errors, it may increase the variance of this result. A full analysis would first have tested for the presence of interactions, and then used a standardization only for those factors which significantly interact with car class. This, however, was beyond the scope of the present study.

Whereas the studies reviewed in Subsection 4.2 were restricted to unbelted drivers, we used all drivers without regard to reported belt use. The reason was that reporting of belt use or nonuse is correlated to accident severity; therefore, using only unbelted drivers would introduce unknown biases. This approach was further justified by the observation that in New York State injuries to belted and unbelted drivers did not depend differently on vehicle size.

4.3.1 Single-Car Crashes

The standardized ratios of fatality or seriously injured drivers to crash-involved drivers were calculated for Texas and Washington. We also used the New York State, and the North Carolina data presented in

Figure 4-1. Neither of these two were standardized for potential model-year/car-class interaction, but North Carolina data are standardized for speed differences and the New York data for driver age differences. To make the various data easily comparable, all frequencies were expressed relative to that for full-size cars. The results are presented in Figure 4-4a. There are considerable discrepancies for the smaller and larger cars. A closer look at the curves suggests that if one attempts to match them over the entire weight range rather than for the most frequent vehicle class (full-size cars), a much better agreement can be reached. This is done in Figure 4-4b where the curves are shifted by an appropriate factor determined graphically. The overall

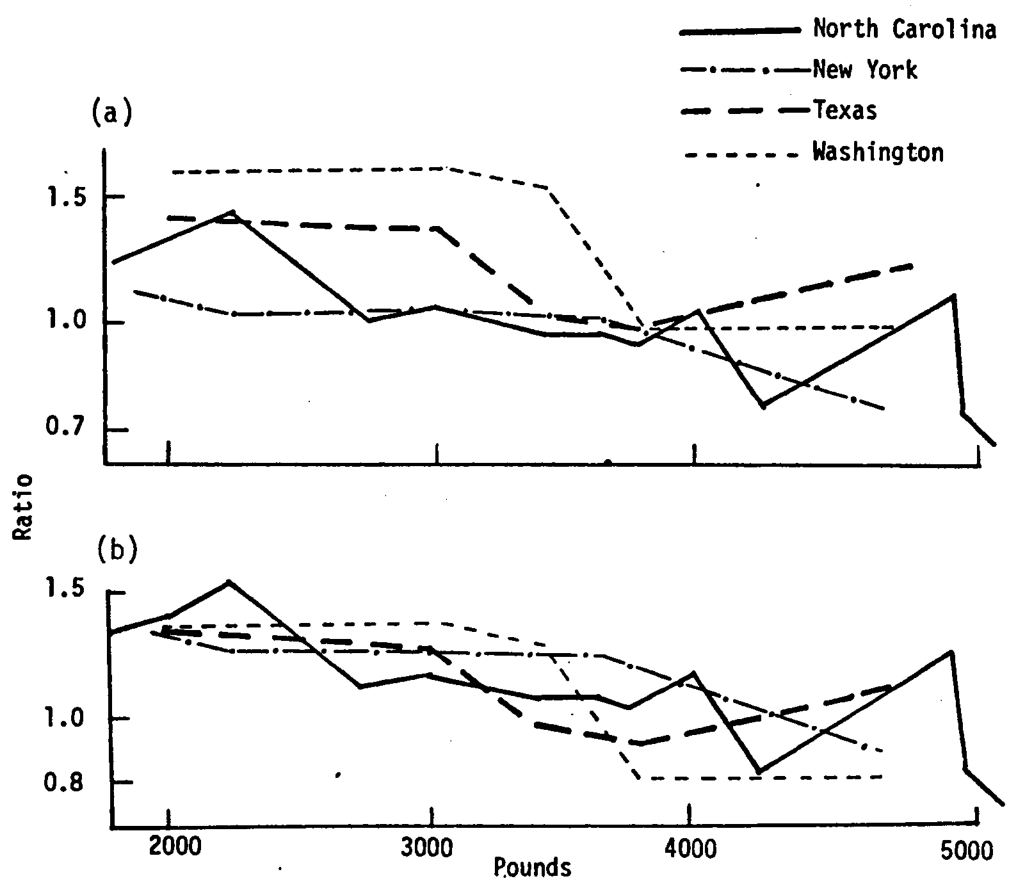

Figure 4-4. Frequencies of fatal or serious driver injury, by weight of car, relative to the frequency for full-size cars. "1" is the average value for full-size cars. In (a), the curves from the various data bases are matched at the value for full-size cars. In (b), the curves are visually matched over the entire range so as to fall into as narrow a band as possible.

picture becomes clearer, suggesting that the injury frequency in small cars is 50 percent higher than in larger cars, but the discrepancies between the various curves still remain large. It is not clear whether there is a monotonic decrease of injury risk with vehicle weight, or whether the risk changes little for weights up to 3,000 or even 3,500 lbs and changes relatively much between 3,000 and 4,000 lbs and remains again unchanged for higher weight. There is even a suggestion of a slight increase for heavy cars.* Contributing to these discrepancies might be the fact that the North Carolina and New York State data consider only unbelted, the Texas and Washington data all drivers† and the North Carolina data cover only run-off-the-road crashes, whereas the other data also cover other single-car crashes.

One can easily fit a straight line through the scatter of the curves. Since the vertical scale is logarithmic, this corresponds to a function of the form b^w. Trial and error suggest that

$$0.98^w \quad , \qquad (4\text{-}3)$$

where w is the car weight in 100 lbs, fits the data sufficiently well. It should be emphasized that this is a very gross approximation, and that the actual relation may be different, not only in the numerical parameter, but also in the mathematical structure of the relation.

4.3.2 Two-Car Collisions

4.3.2.1 New York State Accidents

As mentioned in Subparagraph 4.2.2.2, a look at New York State two-car collisions suggests that injury frequency decreases with the age of the driver of the other car, presumably because speed may be related to

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*One might speculate that this is an effect of the probably higher age of drivers of the heavy, usually expensive cars, and not of the car characteristics.

†However, there exists evidence, discussed in Paragraph 5.2.1, that seatbelts reduce injury frequency in large and small cars by the same percentage. Therefore, the relative risks for drivers of small and large cars would not be influenced by seatbelt use. However, if the frequency of seatbelt use is related to car weight, then the relation between injury frequency and car weight will be different for unbelted drivers and for all drivers.

age. Since vehicle size and driver age are correlated, a spurious vehicle size effect may appear. To eliminate such a possible effect, more detailed--disaggregated by driver age also--tabulations of New York State accident data were obtained from NHTSA [13]. These tabulations covered 1971 and 1972 accidents involving 1965 model year and more recent cars. Because of the different time periods covered, one might expect differences from Mela's results.

To eliminate the direct effects of driver age--injury susceptibility--and possible indirect effects--speed, collision type--the data were "standardized" as follows. The frequency with which collisions between different driver age groups contributed to all collisions were determined (Table 4-1). Then, within each vehicle-weight/vehicle-weight combination, the injury frequencies for the various driver age combination groups were weighted with the uniform frequencies given in Table 4-1.

TABLE 4-1

Frequency of collisions between drivers of different ages. New York State accidents

Driver age	Driver age		
	16-24	25-54	55 +
16-24	0.11	0.16	0.04
25-54	0.16	0.29	0.08
55+	0.04	0.08	0.03

The results are shown in Table 4-2, together with the unadjusted values. A closer examination shows only one clear difference: the adjusted values for very small cars (up to 2,000 lbs) are less than the unadjusted values.

To adjusted values, one can fit the equation

$$29.7 \times 0.937^{w} \times 1.018^{w'} \qquad (4\text{-}4)$$

using the structure of Mela's equation (4-2). The agreement between the bases--0.937 and 0.951, and 1.018--is good. The difference between the factors 29.7 and 16.6 is major. A closer look at the basic tabulations

TABLE 4-2

Frequency (%) of serious or fatal unbelted-driver injury in the primary car colliding with the secondary car.
New York State accidents 1971, 1972.
Numbers below the slash are actual frequencies, numbers above are adjusted for differences in driver age distribution.

Secondary car (lbs)	Primary car (lbs)				
	← 2000	- 2500	- 3250	- 4000 →	
	13.7/16.1	10.0/8.9	4.6/5.1	2.2/2.9	2.4/1.6
2000					
	15.5/20.0	13.1/11.7	4.3/4.6	4.4/4.4	1.7/1.8
2500					
	12.9/13.8	10.0/10.2	7.8/7.7	5.3/5.2	3.8/3.6
3250					
	13.5/15.4	12.3/12.1	8.0/7.8	5.9/5.6	3.8/4.0
4000					
	17.1/18.1	7.0/7.7	7.8/7.7	6.7/6.7	5.0/4.7

on which Mela's calculations are based shows that in 1970 and 1971 the injury frequencies were higher than in 1969--possibly due to an increase in the reporting threshold from $100 to $200 in 1970. Therefore, our accident data--1971 and 1972--have to show higher accident frequencies than his--1969 through 1971. In addition, if the difference in the bases 0.951 and 0.937 is primarily expressing a change in slope of the relation between injury and weight, and not in the absolute level, the factor 16.6 would have to be increased to 25.9 to maintain the same injury frequency at 3,000 lbs.

A closer look at the data shows that they deviate systematically from equation (4-4): both for collisions between small cars and between large cars, the observed injury frequency is slightly higher than the one calculated from formula (4-4). Between Mela's formula (4-2) and the data on which it is based, no systematic difference is apparent.

Table 4-3 shows the frequencies of fatal or serious injuries to all drivers--without regard to seatbelt use--in two-car collisions, adjusted for different age distributions of both drivers.

TABLE 4-3

Frequency (%) of fatal and serious driver injury (all, belted, unbelted or unknown belt status) in the primary car in collisions with the secondary car. (New York State accidents). Numbers above the slash are actual values standardized for the age distribution of both drivers, numbers below the slash are resulting from formula (4-5).

Secondary car (lbs)	Primary car (lbs)				
	←	2000	2500	3250	4000 →
	7.7/7.7	8.1/5.7	3.2/3.7	1.8/2.2	1.1/1.3
2000					
	8.8/8.7	6.4/6.5	3.8/4.2	2.5/2.5	1.9/1.5
2500					
	9.0/10.2	7.6/7.2	5.6/4.9	3.8/2.9	2.3/1.7
3250					
	12.0/12.6	8.7/9.3	6.1/6.1	3.9/3.6	2.9/2.1
4000					
	12.9/15.4	7.9/11.5	5.7/7.5	4.8/4.4	2.6/2.6

To fit an equation of the form $ab^{w}c^{w'}$ to the data, their logarithms were averaged over rows and over columns. The result is shown in Figure 4-5. The data points relating the logarithms of injury frequency to the weight of the primary car are very well represented by a straight line (a). There is a suggestion that the relation between the logarithms of injury frequency and weight of the secondary car might possibly be nonlinear (b); however, as a first approximation, a straight line appears sufficient. Combining the equations of the lines in Figure 4-5a and b, one obtains for the frequency of fatal or serious injury:

$$16.0 \times 0.936^{w} \times 1.026^{w'} \qquad (4\text{-}5)$$

The difference between the factors 16.0 in formula (4-5) and 29.7 in formula (4-4) expresses the overall effects of seatbelts. The perfect agreement between the bases for the effect of the weight of the primary car--0.936 and 0.937--suggests that safety belts reduce the injury

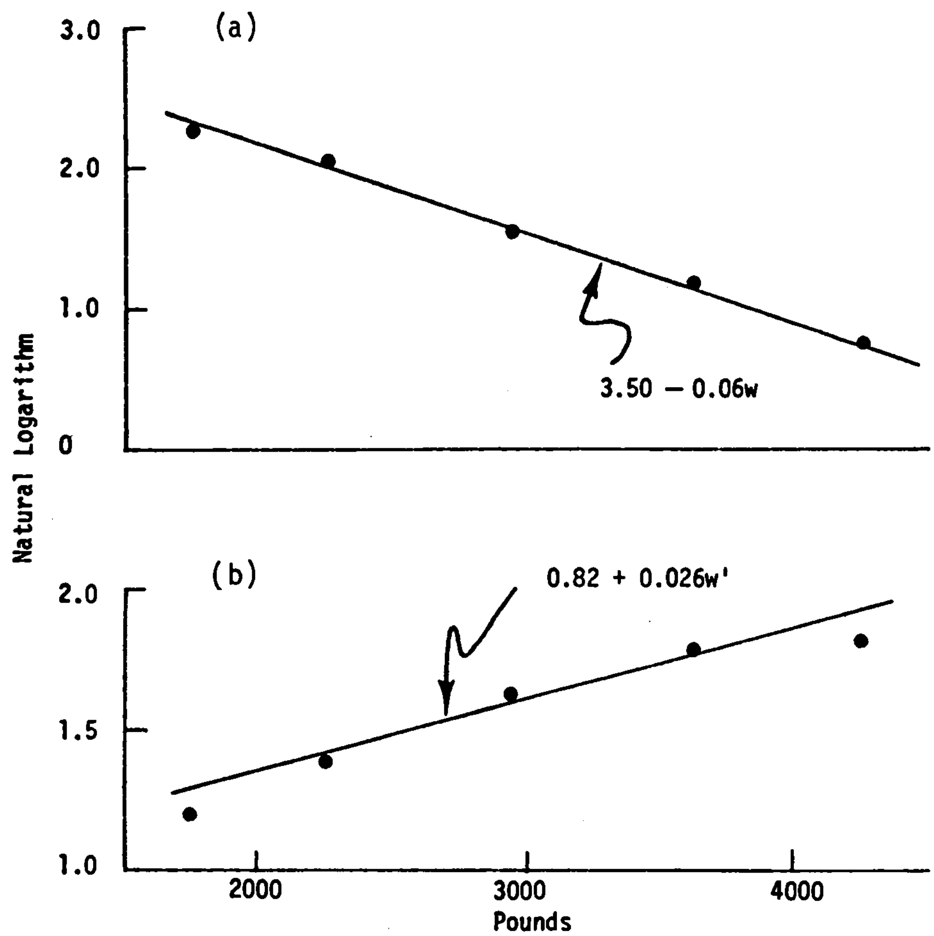

Figure. 4-5. Fitting equation (4-5) to the frequencies of fatal or serious driver injury in New York State two-car crashes. (a) shows the average (over the secondary cars) of the logarithms of the injury frequencies in the primary car by weight of the primary car. (b) shows the average (over the weight of the primary cars) of the logarithms of the injury frequencies in the primary car, by weight of the secondary car w and w' in 100 lbs.

risk in all car classes by the same factor. There is a difference* between the bases for the weight of the secondary car--1.026 and 1.018--and a closer look at Figure 4-5b suggests that 1.018 would represent the data for all drivers less well than 1.026. However, considering the possible nonlinearity (in the logarithm of the injury risk) of this effect, no further analysis was attempted.

Table 4-3 also shows the injury frequencies resulting from formula (4-5). In general, the agreement is good. The only obvious systematic deviation is that the formula overestimates the "aggressiveness" of heavy cars in collisions with small cars, which corresponds to the suggestion of nonlinearity in the logarithms discussed above.

4.3.2.2 North Carolina Accidents

For the North Carolina accidents, no disaggregation by driver age nor by speed was available, but separate tabulations for front-to-side and front-to-rear impacts were available.† Therefore, we standardized for the distribution of these three collision types. The results are shown in Table 4-4. The differences between adjusted and unadjusted values are small, and no pattern appears in the differences. Also, no pattern appears in the differences between the unadjusted values and Mela's formula. Therefore, no further analysis was performed.

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*When evaluating the differences of exponential bases in formulas such as (4-4) and (4-5), one has to keep the exponential nature of the relation in mind. Consequently, the difference between effects of 1.026^{W} and 1.018^{W} is approximately the difference between 0.026 and 0.018--about 50 percent and not 0.8 percent.

†Mr. O'Neill of the Insurance Institute for Highway Safety provided us with tabulations of the actual data rather than the "smoothed" ones which were published.

TABLE 4-4

Frequency (%) of serious and fatal unbelted-driver injury in the primary car colliding with the secondary car. North Carolina accidents. Below the slash are actual frequencies, above are the frequencies adjusted for differences in impact type distribution.

Secondary car (lbs)	Primary car (lbs) ←	2700	3100	3300	3700	4100 →
	6.3/6.0	3.9/3.9	2.6/2.5	1.8/1.7	2.3/2.3	2.3/2.1
2700	6.9/6.9	2.7/2.8	3.5/3.3	3.0/3.0	2.0/2.0	2.0/2.0
3100	6.7/5.8	5.2/5.1	4.6/4.4	3.9/4.0	3.0/2.7	2.9/2.4
3300	7.3/7.2	3.5/3.6	3.8/3.9	3.4/3.5	2.8/2.9	1.9/1.9
3700	5.9/6.0	5.1/5.2	3.6/3.6	3.4/3.3	2.4/2.3	3.0/2.8
4100	6.6/6.6	5.4/5.2	4.4/4.5	3.0/3.0	3.4/3.2	3.0/2.6

4.3.2.3 Washington State Accidents

Table 4-5 shows the standardized frequencies of fatal or serious driver injury in the primary car colliding with the secondary car. Since the number of cases was relatively small, pre-1968 model year cars were also included.

A graphic analysis of the data resulted in the formula:

$$2.2 \times 0.96^{W} \times 1.024^{W'} \qquad (4\text{-}6)$$

for the frequency of fatal or serious injury. The values resulting from this formula are also shown in Table 4-5. The general agreement is good. There is a slight suggestion that the formula underestimates the risk for drivers of subcompact cars. However, the number of cases is far too small to allow any conclusion. If one tried to improve the fit of the risk for drivers of subcompacts, the base 0.96 would be reduced--getting closer to the value for New York State and North Carolina--but systematic deviations would appear in the fit for other car classes with large sample sizes.

TABLE 4-5

Frequency (%) of fatal or serious driver injury in the primary car in collisions with the secondary car (Washington State Accidents). Numbers above the slash are the "standardized" actual values, numbers below the slash are resulting from formula (4-6). Numbers in parentheses are based on fewer than 5 casualties.

Secondary Car	Primary Car				
	Subcompact	Compact	Intermediate	Full Size	Heavy
Subcompact	(2.0)/1.6	1.2/1.1	1.0/0.9	0.9/0.8	(0.5)/0.6
Compact	1.7/2.0	1.1/1.4	1.0/1.2	0.8/1.0	(0.5)/0.7
Inter-mediate	3.4/2.3	1.0/1.5	1.5/1.3	0.8/1.1	(0.7)/0.8
Full Size	3.4/2.5	1.7/1.7	1.4/1.4	1.7/1.3	1.2/0.8
Heavy	(1.3)/3.1	1.4/2.1	1.9/1.8	1.3/1.5	(0)/1.0

4.3.2.4 Texas Accidents

A problem with the Texas accident data was that "Volkswagen" could not be unambiguously disaggregated into the different models and, therefore, was omitted from the analysis. This reduced the number of two-car collisions involving subcompacts so much that never more than two drivers of subcompacts were killed or severely injured in collisions with cars of a certain weight class. Therefore, no meaningful frequencies of fatal or serious injuries could be calculated and subcompacts had to be excluded from this analysis.

Table 4-6 shows the standardized frequencies of fatal or serious driver injury in the primary car colliding with the secondary car. A graphic fit of the data gave the formula:

$$1.2 \times 0.98^{w} \times 1.01^{w'} \qquad (4\text{-}7)$$

The frequencies resulting from this formula are also shown in Table 4-6. In general, the formula represents the trends of the data, but the differences are great in some cases. There is also a suggestion that the formula overestimates the "aggressiveness" of compacts, and underestimates that of full-size cars.

Since the structure $ab^w c^{w'}$ of formula (4-7) was assumed and not derived from the data, the differences between the coefficients of (4-7) and (4-4), (4-4) and (4-6), might well be due, at least partially, to the fact that the coefficients of (4-7) are derived from a shorter range of w and w', due to the exclusion of subcompacts.

TABLE 4-6

Frequency (%) of fatal or serious driver injury in the primary car in collisions with the secondary car (Texas accidents). Numbers above the slash are the "standardized" actual values, numbers below the slash are resulting from formula (4-7).

Secondary Car	Primary Car			
	Compact	Intermediate	Full Size	Heavy
Compact	0.7/1.0	0.9/0.9	0.7/0.8	0.6/0.7
Intermediate	1.0/1.0	0.9/0.9	1.0/0.9	0.7/0.7
Full Size	1.2/1.1	1.0/1.0	1.0/0.9	0.9/0.8
Heavy	0.8/1.2	0.6/1.1	1.0/1.0	1.5/0.8

4.3.3 Multi-vehicle Crashes

Figure 4-6 shows the standardized frequencies of fatal or serious car driver injury in multi-vehicle crashes, by weight class of car, relative to that for full-size cars (=1). With the exception of subcompacts in Washington State, the trend is as intuitively expected. It can sufficiently well be represented by

$$0.97^w \qquad (4\text{-}8)$$

The base 0.97 of w was chosen as the average of the bases of w in two-car crashes--0.96 for Washington, 0.98 for Texas. This suggests, until better information is available, that cars in multi-vehicle crashes be treated similar to those in two-car crashes.

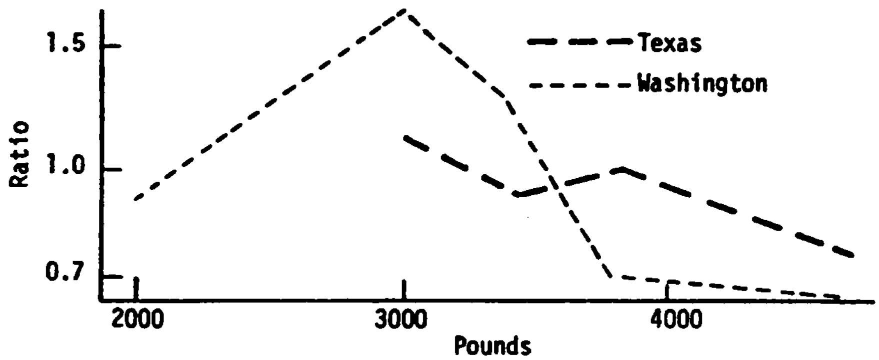

Figure 4-6. Relative frequency of fatal or serious driver injury in multi-vehicle accidents, by weight of the car, relative to "1" for full-size cars.

4.3.4 Car-Truck Crashes

Figure 4-7 shows the "standardized" frequencies of fatal or serious car driver injury in car-truck crashes, by weight of car, relative to that for full-size cars (=1). The overall trend is as intuitively expected with the exception of the values for heavy cars in Texas accidents. Except for this, a formula

$$0.97^{W} \tag{4-9}$$

can acceptably approximate the data. This numerical value 0.97 would indicate that the "protective" properties of car size vary with car weight in car-truck crashes in a similar manner as in car-car and multi-vehicle crashes.

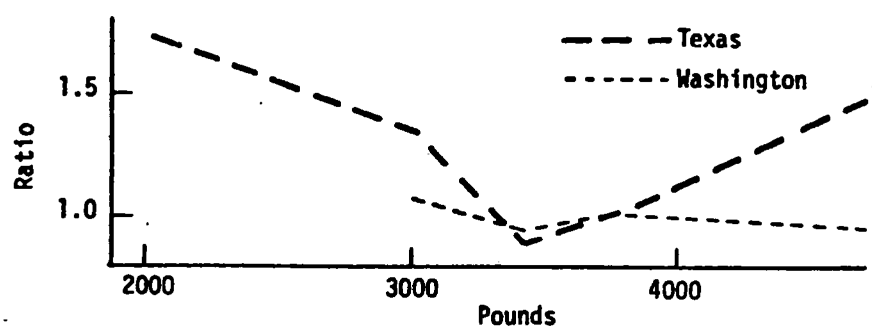

Figure 4-7. Relative frequency of fatal or serious car driver injury in car-truck collisions, by weight of car, relative to "1" for full-size cars.

4.3.5 Comparing Differences Between Cars in the Frequency of Fatal Injuries with that of Fatal or Serious Injury

The preceding analyses dealt with the frequency of fatal or serious injury. As discussed above, it appears plausible that the frequency of fatal injuries might vary with vehicle weight in a different manner than the frequency of fatal or serious injury. Therefore, a repetition of the preceding analyses for fatal injuries would have been desirable. However, in the case of two-car crashes, the number of fatal driver injuries for most combinations of car classes was too small to allow a meaningful analysis. Therefore, the ratio of fatal to fatal or serious injuries, by weight class of the primary vehicle only, was studied. To be consistent, the same was done for single-car crashes and car-truck crashes (fatalities in multi-vehicle crashes were so few that no meaningful analysis was feasible), even though in this case a direct analysis of only fatal injuries would have been equally possible. This approach of using the ratio of fatal to fatal or serious injuries also offered the advantage of relying on the more completely reported fatal and serious accidents and not the less reliable number of all reported accidents. Figure 4-8 shows the ratios of fatal to fatal or serious driver injuries, relative to that ratio for full-size cars. Actually, the ratios of the *standardized* ratios were used. For the North Carolina data, standardization was by averaging the ratios for the model years over model years.

For single-car crashes, the various data bases show contradicting trends; to what extent this might be due to the restrictions of the North Carolina data for run-off-the-road crashes we do not know. Figure 4-8 gives no reason to assume that the frequency of fatal driver injury in single-car crashes varies with weight in a different manner from that of fatal and serious injury.

For two-car crashes, there is a good agreement between the North Carolina and Washington State results; the Texas data show a slight difference for intermediate cars. The curves suggest that the frequency of fatal injury decreases faster with increasing vehicle weight than the frequency of fatal or serious injury. Though a formula of the type $ab^{w}c^{(w^2)}$ would fit the data better than ab^{w}, it appears sufficient to use the latter as an approximation. The reason for this choice is that

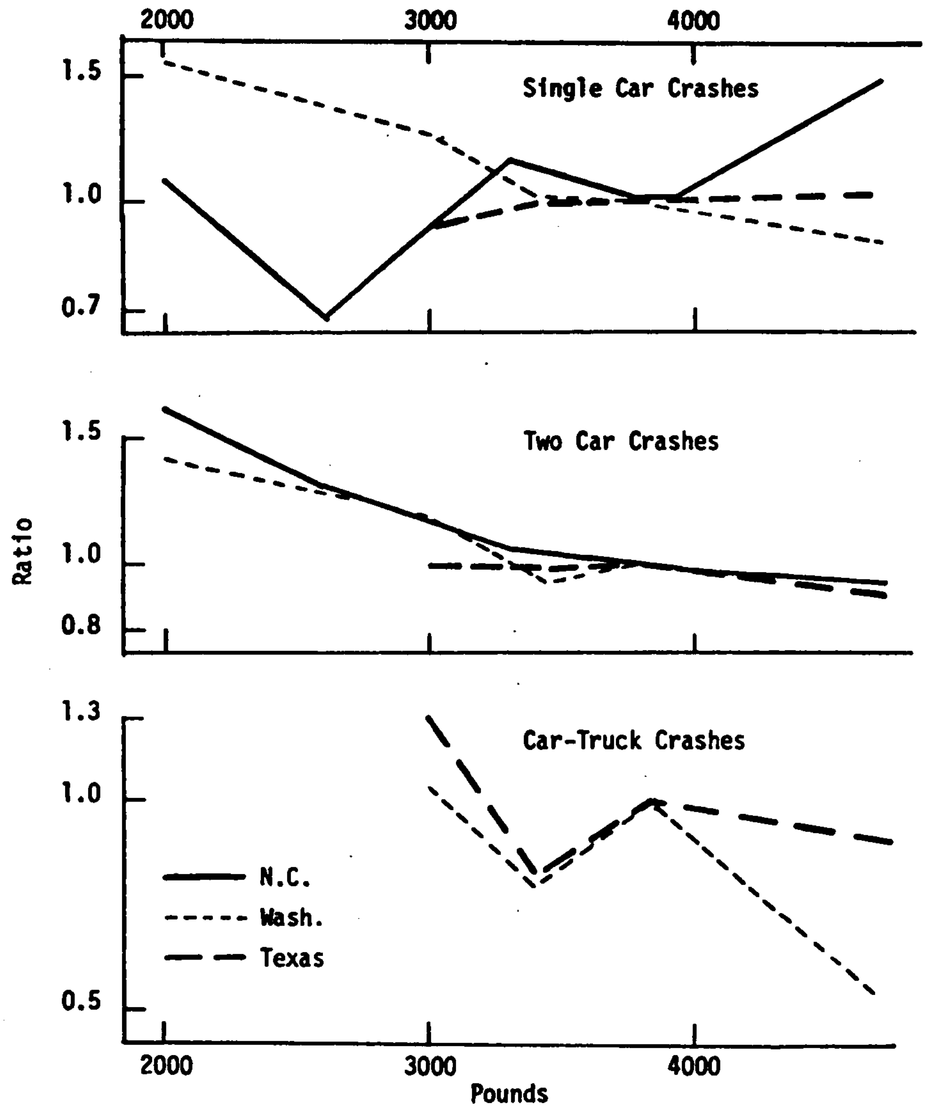

Figure 4-8. Ratio of fatal driver injuries to fatal or serious driver injuries, relative to the ratio of full-size cars, by weight of car and type of crash.

the simpler formula can easily be combined with formulas (4-2) through (4-9). A graphic analysis gives

$$0.98^{w} \qquad (4\text{-}10)$$

for the change in the ratio of fatal to fatal or serious injury in relation to vehicle weight.

In the case of car-truck collisions, there is good agreement between the Texas and Washington data that the frequency of fatal car driver injury decreases faster with car weight than that of fatal or serious injury. The same as above,

$$0.98^{w} \tag{4-11}$$

represents the overall trend sufficiently. It is, however, puzzling that in both states full-size cars have a higher ratio of fatalities to fatal or serious injuries than intermediate cars.

The number of fatal driver injuries is too small to allow an analysis of a bivariate table considering the weights of both cars in two-car crashes to look for a possibly different influence of the weight of the second car upon fatal, and fatal or serious injuries. However, to make a gross analysis, we plotted the ratio of fatal to fatal or serious driver injuries (in this case using the actual numbers and no standardization) versus the weight of the secondary car, as shown in Figure 4-9. Texas and Washington State exhibit contradictory trends. Therefore, we have no empirical reason to assume that the "aggressivity" of the secondary car is different for fatal and for fatal or serious driver injury in the primary car.

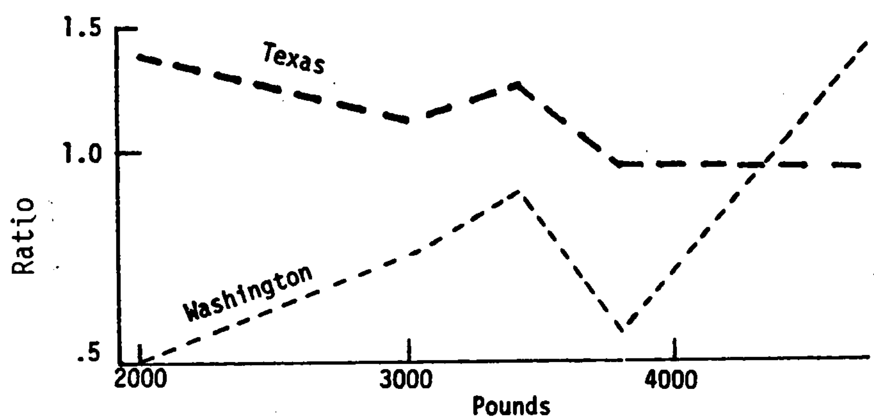

Figure 4-9. Ratio of fatal driver injuries, to fatal or serious driver injuries in the primary car in two-car crashes, by weight of the secondary car. The ratio is relative to that for full-size cars (=1) in Texas, relative to heavy cars (=1) in Washington.

4.3.6 The Influence of Speed

The physical arguments presented in Appendix C suggest that the differences in injury frequency between cars of different sizes might increase with the speed in an accident. The relevant physical factor is impact speed; however, it is not available in most accident data. If at all, travel speed before the accident is given in accident data files. In the Texas and Washington data files used by us, not even this information is given (it is also not known how reliable it is in the files where it is given). However, in the Washington file, "posted speed" is given in the majority of cases. In reality, "posted speed" is usually a gross indication of actual travel speeds, except at times of traffic congestion or adverse weather conditions. In the Texas file, not even this information is given. Therefore, we defined a "driving environment" by highway type. "City streets" have usually travel speeds of up to 35 mph, "open roads" of 55 up to 60 mph, and "Interstate Highways" of 60-70 mph. This matching of speed and highway type is used in Figures 4-10 through 4-12.

Separately for single-car crashes, two-car crashes, and car-truck crashes for each speed range and car class, the ratio of the number of drivers killed or seriously injured to that for full-size cars was calculated (by model year, and averaged over model years for standardization). Figures 4-10 through 4-12 show the ratios. There is no agreement between the results obtained from Texas data and those obtained from Washington State data. Therefore, we have no empirical reason to assume that the differences in injury frequency between car classes depend on speed. However, the Washington State data suggest consistently that these differences increase with travel speed; it is puzzling that heavy cars also become "worse" in relation to full-size cars with increasing speed. Further investigations are desirable.

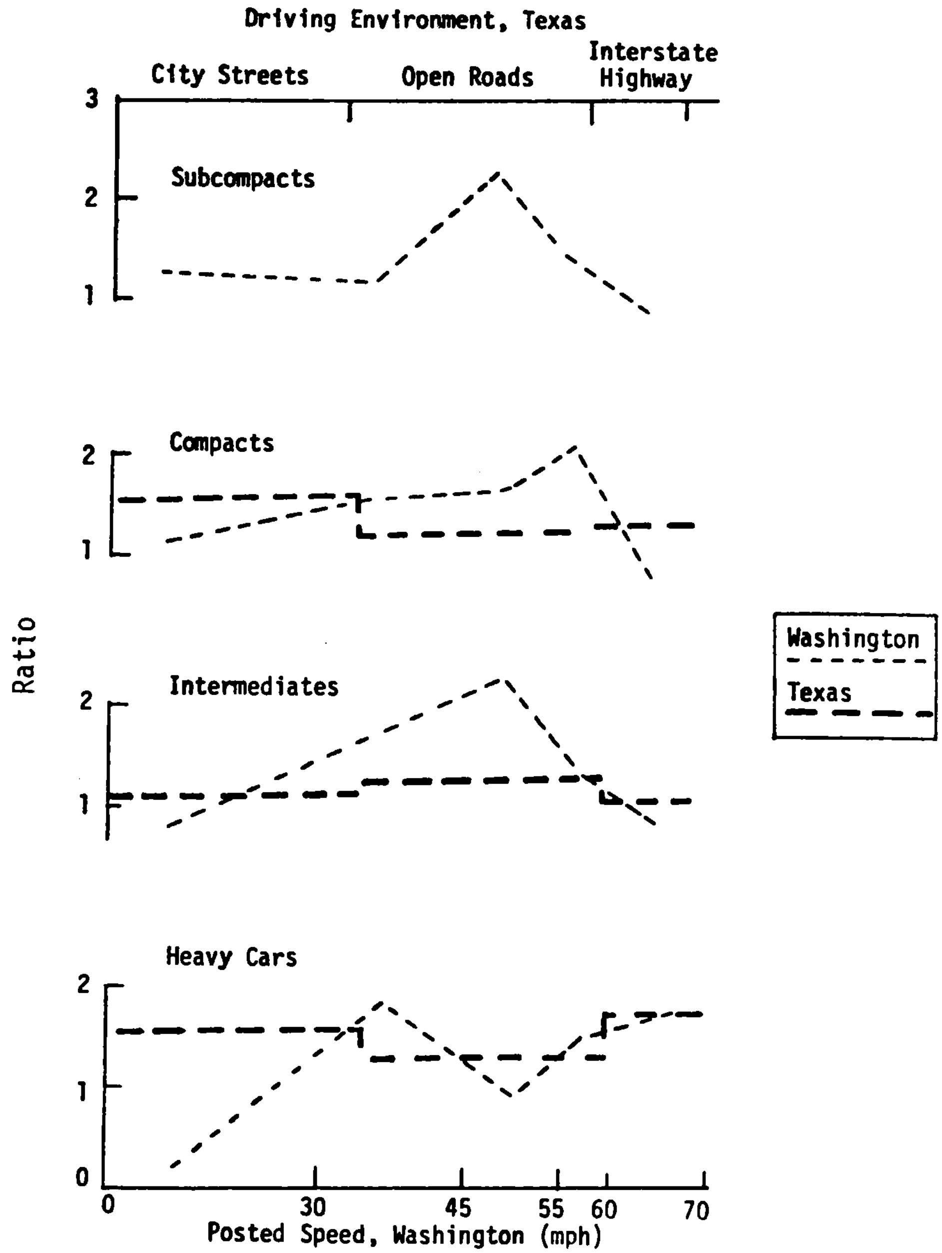

Figure 4-10. Frequency of fatal or serious driver injury in single-car crashes, by car class, relative to that for full-size cars (=1), by driving environment, described by highway type or posted speed.

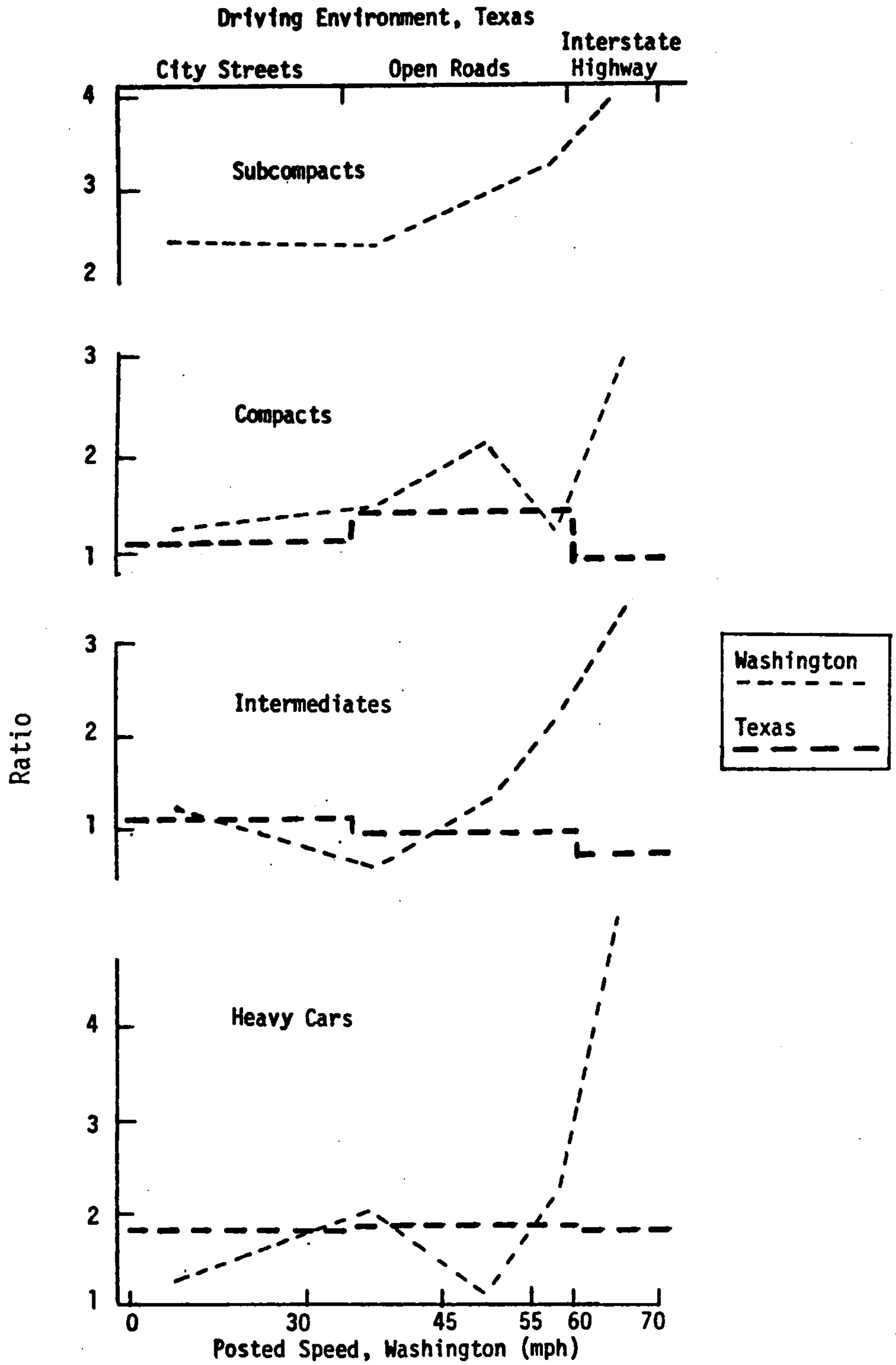

Figure 4-11. Frequency of fatal or serious driver injury in two-car crashes, by car class, relative to that for full-size cars (=1), by driving environment, described by highway type or posted speed.

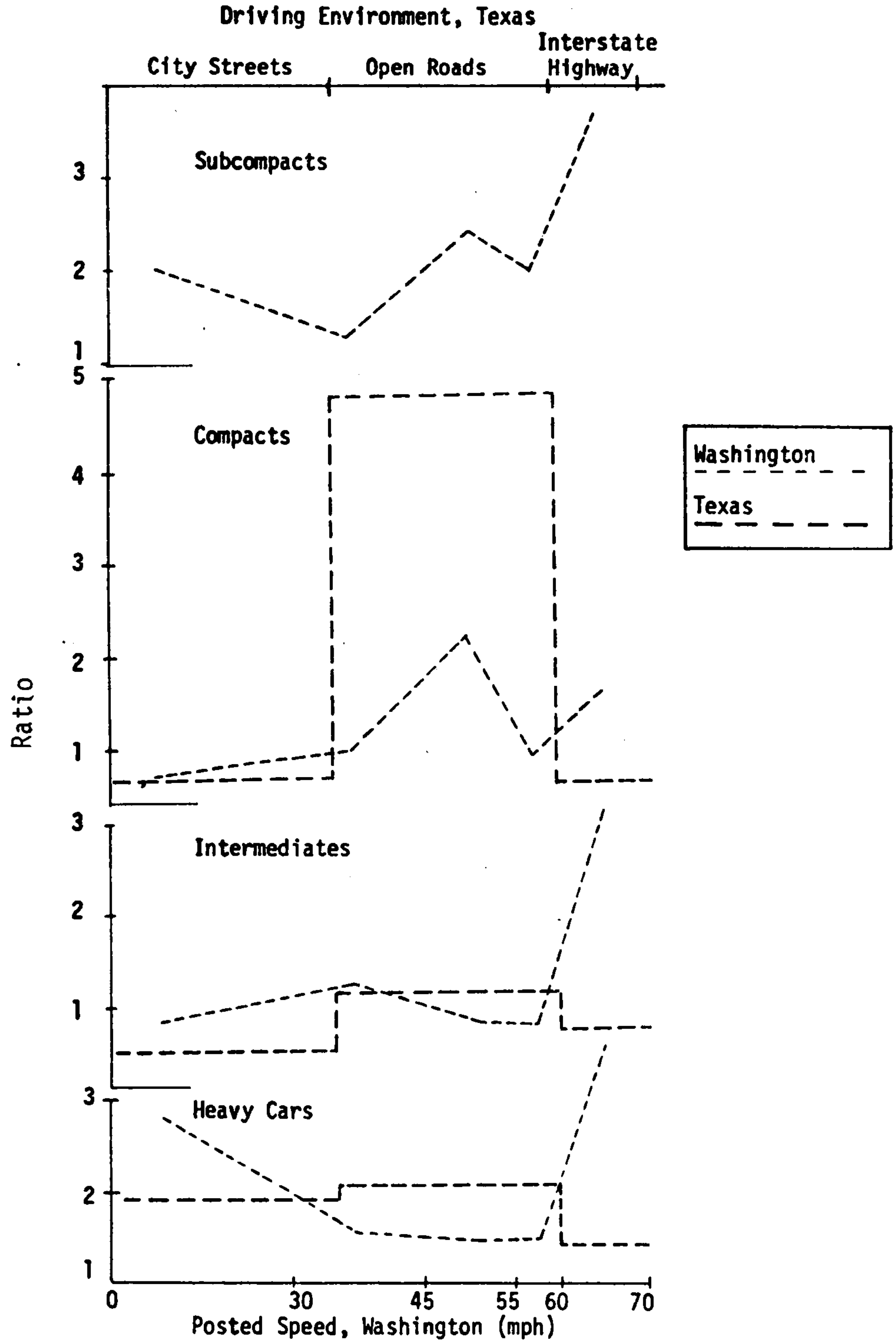

Figure 4-12. Frequency of fatal or serious car driver injury in car-truck crashes, by car class, relative to that for full-size cars (=1), by driving environment, described by highway type or posted speed.

4.3.7 Injuries to Pedestrians and Bicyclists

In order to determine whether a changing automobile population mix might influence pedestrians' or bicyclists' injuries and deaths, Texas and Washington state accidents involving one motor vehicle and a pedestrian or a bicycle were analyzed.

Figure 4-13a shows the frequency of fatal pedestrian injury by vehicle class, Figure 4-13b the frequency of fatal or serious injuries. (All pedestrian or bicycle accidents involve an injury to the pedestrian or bicyclist.) In addition to the observed frequency, the 95 percent confidence range for the frequency is indicated by vertical bars.

The Texas data show a consistent decrease of the frequency of fatal injury with passenger car weight, contrary to what one would intuitively expect, but are compatible with the hypothesis that there is no influence of vehicle weight.* The Washington State data, however, agree with the intuitive expectation: the frequency of fatal pedestrian injury is lower for subcompacts and compacts than for intermediate and full-size cars; the much lower frequency for heavy cars is based on only one pedestrian death. Again, the observed frequencies are compatible with the hypothesis that the "true" frequency is independent of car weight. However, because of the order--two low values for smaller, two high values for the larger cars--further tests were performed. One test developed by Bartholomew [16] for 2 × n tables where an order of the n expected frequencies is hypothesized, and ridit analysis, developed by Bross [16] were applied. Both showed no deviation from a random arrangement.

For fatal and serious injury, both states show no significantly lower injury frequency for subcompacts than for other cars, and within the other cars a suggestion of a decreasing trend.

For fatal bicycle accidents, both states' data (Figure 4-14) do not suggest any relation between frequency and passenger car weight. For fatal or serious injury, both states show an increase in frequency

*The low number of accidents involving subcompacts is due to the exclusion of VW's in Texas.

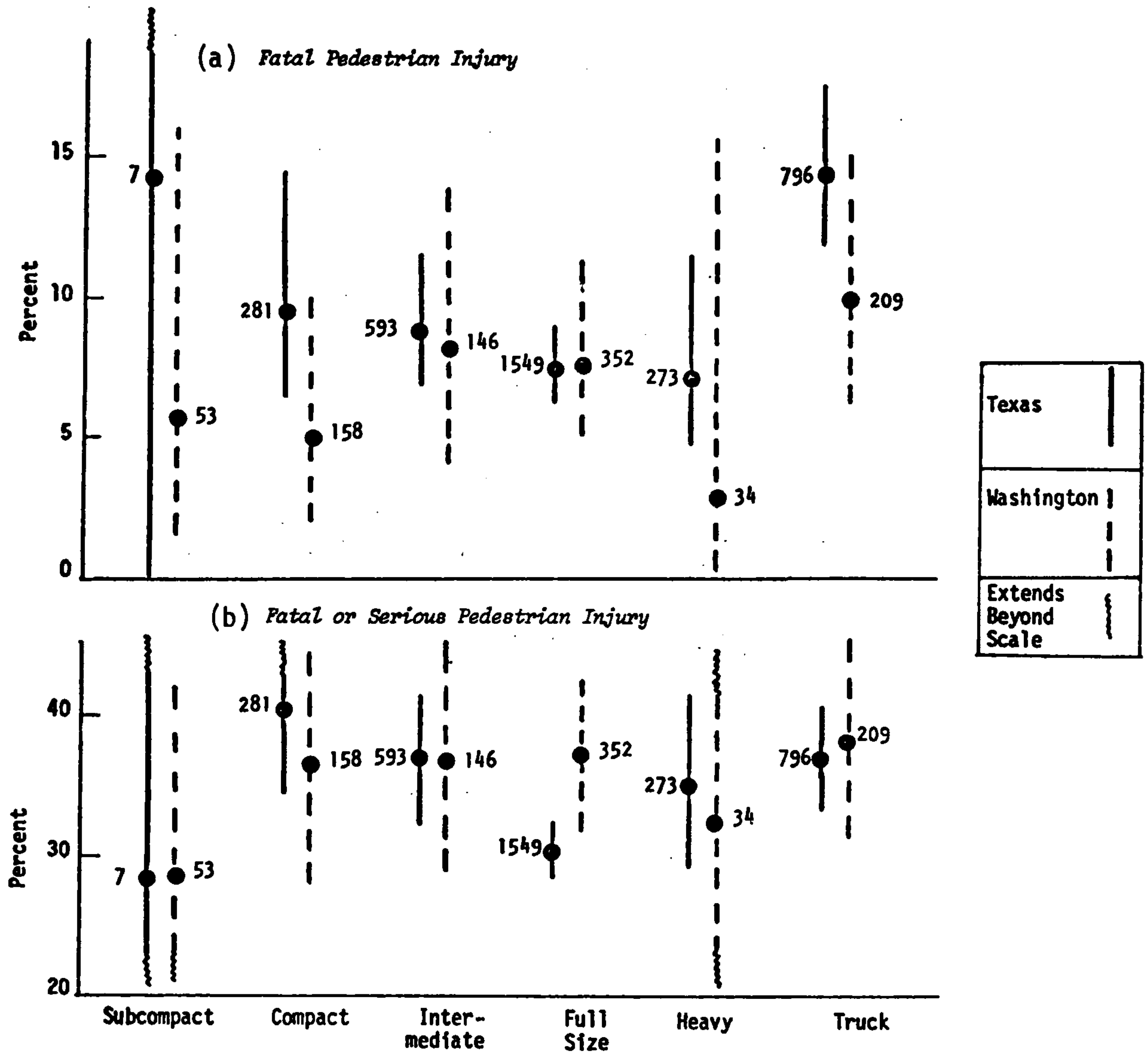

Figure 4-13. Frequency of pedestrian injury [(a) fatal, (b) fatal or serious] by size of motor vehicle involved. The dots are the actual numbers, the vertical lines indicate the 95 percent confidence limits for the actual frequency. Next to the dots are the total number of accidents from which the injury frequencies are derived.

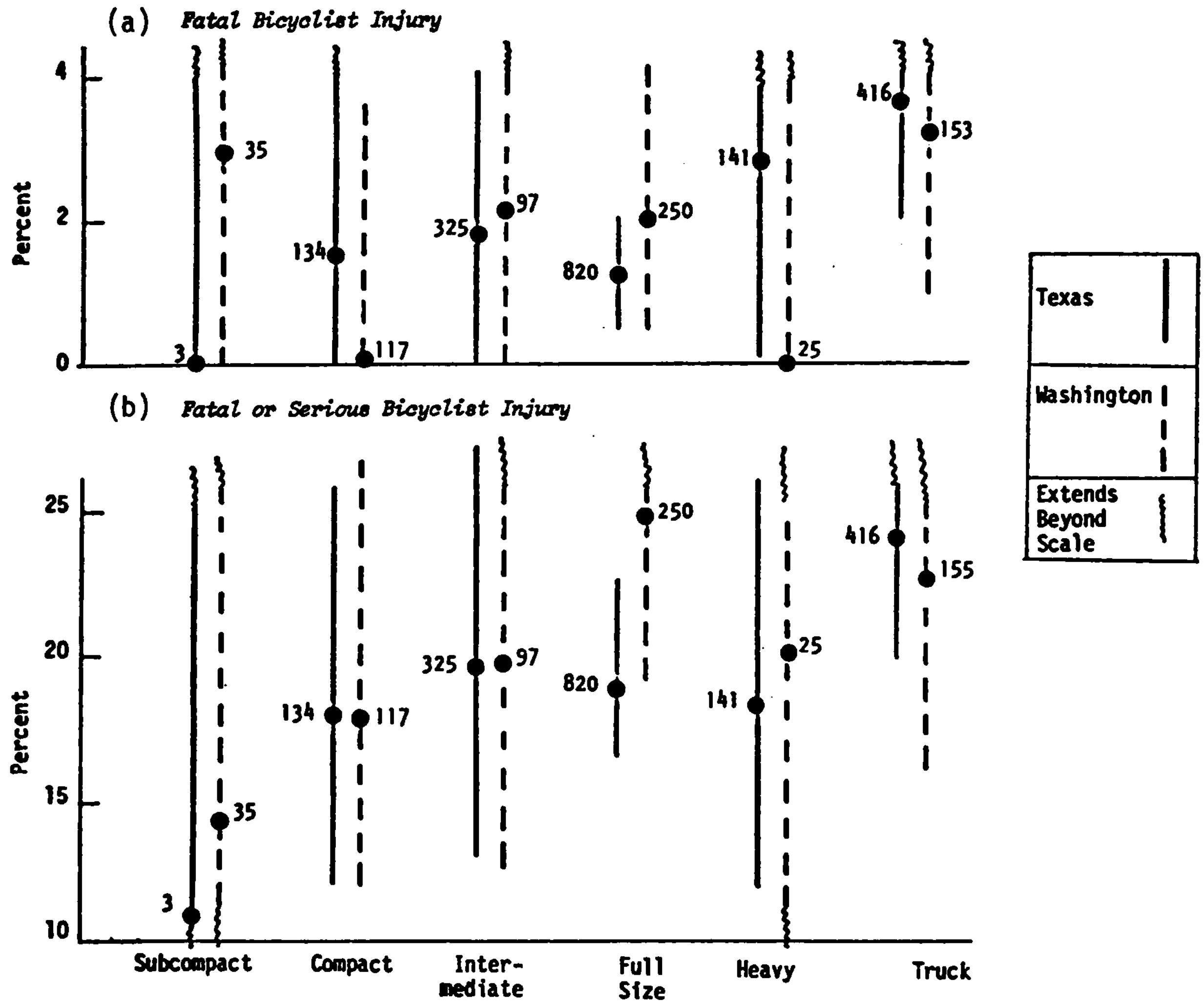

Figure 4-14. Frequency of bicyclist injury [(a) fatal, (b) fatal or serious] by size of motor vehicle involved. The dots are the actual numbers, the vertical lines indicate the 95 percent confidence limits for the actual frequencies. Next to the dots are the total number of accidents from which the injury frequencies are derived.

from subcompact to full-size cars and slightly lower values for heavy cars, but the differences are not significant.

These data do not require abandoning the hypothesis that passenger car weight has no influence on pedestrian or bicyclist injury severity. However, in order to be detectable as significant in this data base, differences would have to be very large. Since there is a suggestion in the data that subcompacts cause less severe injuries than other cars, a thorough study of the problem appears worthwhile.

4.4 SYNTHESIS

4.4.1 Single-Car Crashes

We found that for single-car crashes the frequency of fatal or serious driver injury was 50 percent higher in small cars than in large cars. However, the exact nature of the relation between injury frequency and car weight (w) remained unclear. A function of the form $a \times 0.98^{w}$ gave a sufficient approximation. However, a relation of the type shown in Table 4-7 appears to be an equally good approximation (1.0 for intermediates was chosen for symmetry; since we are using only relative risks, the absolute value is unimportant).

TABLE 4-7

Alternative description of the relative frequency of fatal, or fatal and serious driver injury, by vehicle class.

Subcompact	Compact	Intermediate	Full Size	Heavy
1.2	1.1	1.0	0.0	0.8

The frequencies of fatal, and of fatal or serious injuries did not appear to depend differently on car weight.

4.4.2 Two-Car Collisions

The results of the various analyses of the frequency of fatal or serious driver injury are summarized in Figure 4-15. We suggest that "best estimates" be based on the lowest row of formulas, because they are derived from 1971 and 1972 accident experience, which is the most recent available. We also suggest that little weight be placed on the formula for Texas accidents, because it was derived for compacts through heavy cars only, omitting subcompacts. The "average" formula, $0.95^{w} \times 1.02^{w'}$, for New York State and Washington State gains additional support from being identical with a formula derived by Mela for North Carolina, and earlier New York State accidents.

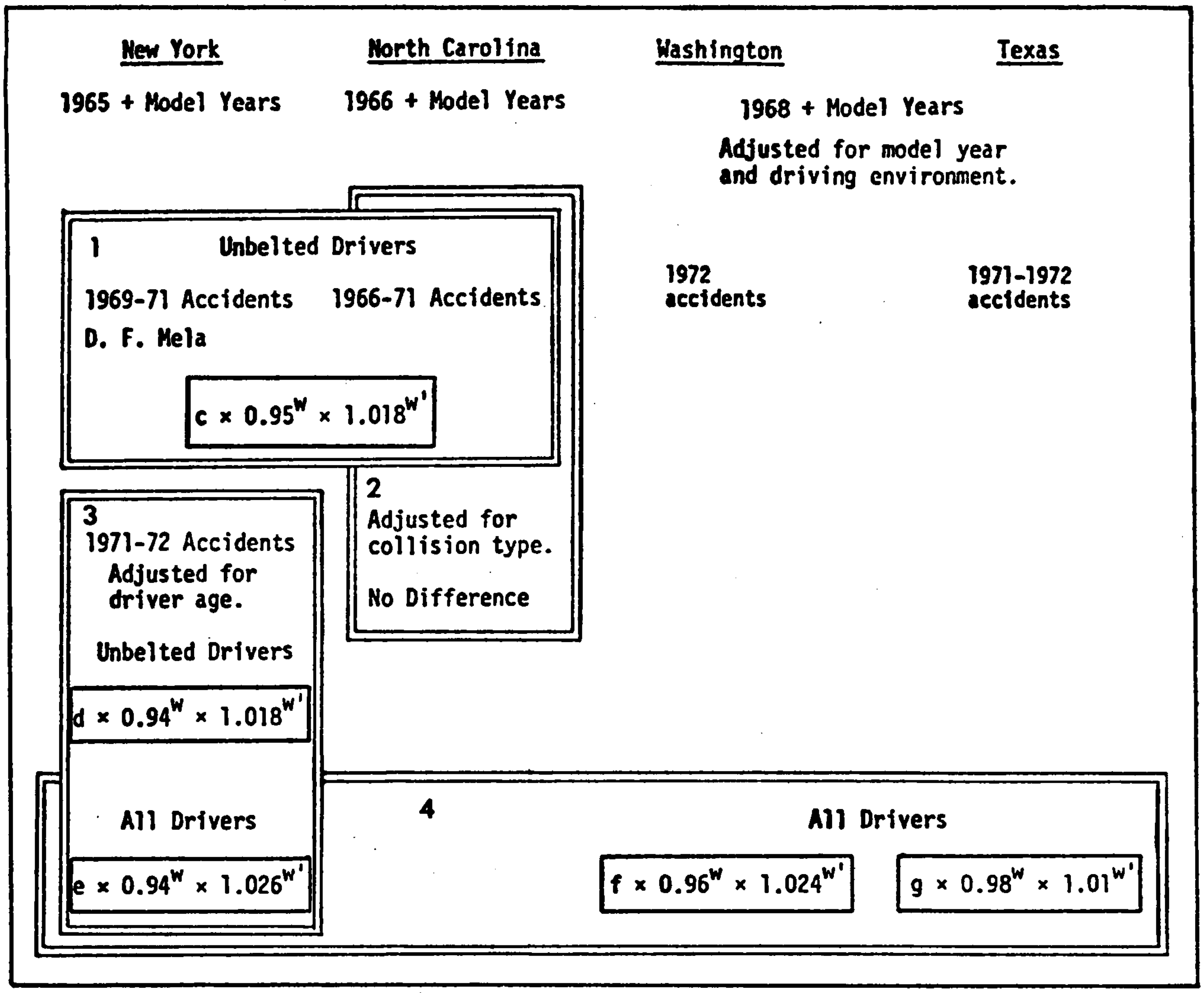

Figure 4-15. Summarization of relations between driver frequency and automobile weight in different data bases. Results are arranged by state in four columns. The double bordered "box" 1 shows Mela's formula and the data bases which it represents. Box 2 indicates that controlling for differences in collision types between automobile size classes does not result in a different formula. Box 3 shows the results for more recent New York accident data. Box 4 encompasses the results for "all" drivers (without regard for seatbelt use) in 1971 and 1972 accidents. W is the weight of the primary car (whose driver's injuries are counted), and W^1 the weight of the other car (in 100 lb).

We found a clear suggestion that fatal injuries depend differently--by a factor of approximately 0.98^W--on vehicle weight than do fatal or serious injuries. There is no indication that the weight of the secondary car affects this difference. Combining this with the formula for the frequency of fatal or serious injuries, we obtain for the change in fatal injury risk with car weight $0.98^W \times 0.95^W \times 1.02^{W'} = 0.93^W \times 1.02^{W'}$.

4.4.3 Car-Truck and Multi-vehicle Collisions

For car-truck and multi-vehicle collisions, we found that in Washington State and Texas accidents the variation of the frequency of car driver injury could be adequately described by 0.97^W. This equals the "average" of the terms 0.96^W and 0.98^W, reflecting the influence of the primary car's weight in two-car collisions in Washington State and Texas. This suggests that the weight of the primary car exerts the same influence on driver injury frequency in car-car, car-truck, and multi-car collisions. Since we assumed a function 0.95^W for this influence (based on New York State and Washington State accident data), we will assume the same for car-car and car-truck accidents.

Obviously, the weight of the truck in a car-truck collision should play an important role too. However, not enough is known about this [17]*. Therefore, we can use our relation, at best, for situations where the share of trucks in traffic and their characteristics do not change.

For multi-vehicle collisions--which are probably mostly multi-car collisions--we can expect that the weight of the "other" cars plays a role in determining injury frequency too. Therefore, we suggest that multi-vehicle collisions be treated as two-car collisions, which is no less justified than using the only simple alternative that the weights of the other cars have no influence.

Since we found that in car-truck and multi-vehicle crashes the ratio of fatal to fatal or serious injuries varied approximately with 0.98^W, combining this with 0.95^W we obtain 0.93^W for the variation of

*See Section 2.3.2 of Reference 17.

the frequency of fatal injuries with car weight.

4.4.4 Summary of Best Estimates

Table 4-8 summarizes the "best estimates" derived in Paragraphs 4.4.1 through 4.4.3 for the dependence of the frequency of fatal, and fatal or serious driver injury upon automobile weight.

TABLE 4-8
Variation of the frequency of passenger car driver injury (without regard to seatbelt status) with weight (w) of the car, and weight of the secondary car (w') in two-car crashes.
(w in 100 lb)

Accident Type	Fatal Injury	Fatal or Serious Injury
Single-car Crash	0.98^{w}	0.98^{w}
Two-car and Multi-car Crashes	$0.93^{w} \times 1.02^{w'}$	$0.95^{w} \times 1.02^{w'}$
Car-Truck Crashes	0.93^{w}	0.95^{w}

We have found no empirical evidence that these relations depend upon speed (though such a dependence can plausibly be expected on the basis of physical arguments). Neither have we found empirical evidence that automobile weight influences the severity of pedestrian or bicyclist injuries in automobile-pedestrian and automobile-bicycle collisions.

4.4.5 Reliability and Limitations of the Results

Figure 4-4 shows clearly the great uncertainty of our knowledge of the relation between car size and occupant injury risk in single-car crashes. This uncertainty is not so obvious in Figure 4-15 which shows the various relations obtained for the frequency of car occupant injury in two-car crashes, but it is there: the "protective" aspect of car size shows a three times as large effect in the New York State data, as in the Texas data, and it is still 50 percent higher than in the Washington State data. In the case of multi-vehicle and car-truck crashes, the numerical coefficients of the relations were arbitrarily selected to match those for car-car crashes, and they represented the actual data sufficiently well.

To what extent these numerical discrepancies are due to differences in the quality of the data bases, and to which extent to differences in the actual crash experience, be it due to differences in basic physical factors or only to differences in reporting requirements and practices, we do not know. Currently, however, we have no reason to assume that the data from any single state are better or more representative than those from others.

The great numerical uncertainties of the results are not surprising if one considers that the number of crashes and casualties from which to calculate an injury frequency goes rapidly down if one classifies accidents by car class and accident type. Especially in the extreme classes of very light or very heavy cars, where the size effects are largest, there are only very few cars involved. On the other hand, the majority of cars is concentrated in the intermediate and full-size classes which differ relatively little in size and weight.

To improve the numerical accuracy of relations between car occupant injury frequency and vehicle weight, however, would be of relatively little practical value. Any more extensive analysis of data should attempt to separate the effects of weight and of size, in order to provide a more meaningful basis for policy planning and decisions. Obviously, all empirical relations which do not distinguish between weight and size might lead to the fallacious conclusion that light cars are undesirable under the aspect of traffic deaths, though in reality only small but not necessarily light cars are undesirable.*

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*A serious problem with large but light cars is that the current automobile population contains a large percentage of heavy cars. During a transitional period, large and light cars would be at a disadvantage relative to existing large and heavy cars.

5. EFFECTS OF A CHANGING AUTOMOBILE POPULATION

In this section the results of the previous sections on the relation between automobile size and injury frequency are used to estimate how changes in the composition of future automobile sales--in terms of car size or weight classes--will affect the frequency of car occupant injuries in an "average" (for the entire automobile population) crash.* The relations found in Section 5. apply to drivers; however, we will apply them to other car occupants as well. This appears defensible because drivers account for 60 percent, and front seat occupants, who are, except for the steering assembly, in a physical environment similar to that of the driver, for 90 percent of all occupant deaths [18, 19].† We will calculate the average risk of a fatal injury, because only fatal injuries are uniformly defined nationwide. However, some results of the sensitivity analysis on the risk of fatal injuries will also provide a best estimate for the change in risk of fatal or serious injuries.

We will further estimate how introduction of the "air bag" with the 1978 model year would influence the average injury risk.

Finally, we will make "illustrative" projections of the changes in the absolute number of automobile occupants' deaths. These projections are "illustrative" only because they result from a trend model based on the years 1950 through 1972, which cannot incorporate the effects of recent drastic changes in important factors, namely, the gasoline shortage beginning in the middle of 1973, the recent great increase in gasoline prices, and the 55 mph speed limit. However, the projections will give an indication of the trend to be expected.

5.1 CHANGES IN THE COMPOSITION OF NEW CAR SALES

5.1.1 Scenarios

The Transportation Systems Center's projection of the composition of future car sales in terms of size-price classes for four scenarios is shown in Table 5-1. A simplified description is that in Scenario A,

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*We found no evidence that the severity of pedestrian or bicyclist injuries would change, and we assume that there will be no change in the frequency of truck occupant or other deaths as a consequence of a changing automobile population.

†Estimated on the basis of information presented in References 18 and 19.

the market shares of compacts and intermediates will decline somewhat, that of standard cars will increase, and that of luxury cars will nearly double. In Scenarios B and C the market shares of standard and luxury cars will increase slightly more than in A, in B beginning with 1980, in C with 1974. In Scenario C, the market share of subcompacts will increase to 40 percent, that of compacts to 25%, whereas that of standard and luxury cars will decrease to a combined 10 percent, all by 1980.

TABLE 5-1

TSC estimated percentages of car purchases by size class for various Scenarios (A, B, C, D). Note: the car classes differ from those used in this study; see Appendix B).

Year	Subcompact	Compact	Intermediate	Standard	Luxury[a]
1972 A, B, C, D	19	13	21	35	12
1974 A, B, C, D	22	17	24	29	8
1975 A, B	21	16	22	31	10
C	19	10	19	35	17
D	40	25	25	6	4
1985 A	20	10	20	33	17
B, C	19	9	18	35	19
D	40	25	25	6	4

(a)The luxury car class includes a sizable number of larger and more expensive "standard" vehicles, e.g., some Mercurys, Dodges, Buicks, Oldsmobiles and Pontiacs.

The automobile classes used by TSC in these projections differ from those used in our analysis in the preceding section. Appendix B describes how we translated the market share of the TSC car classes into those for the CEM car classes. Figure 5-1 shows the resulting projections of market shares for the four scenarios using the CEM automobile classes.

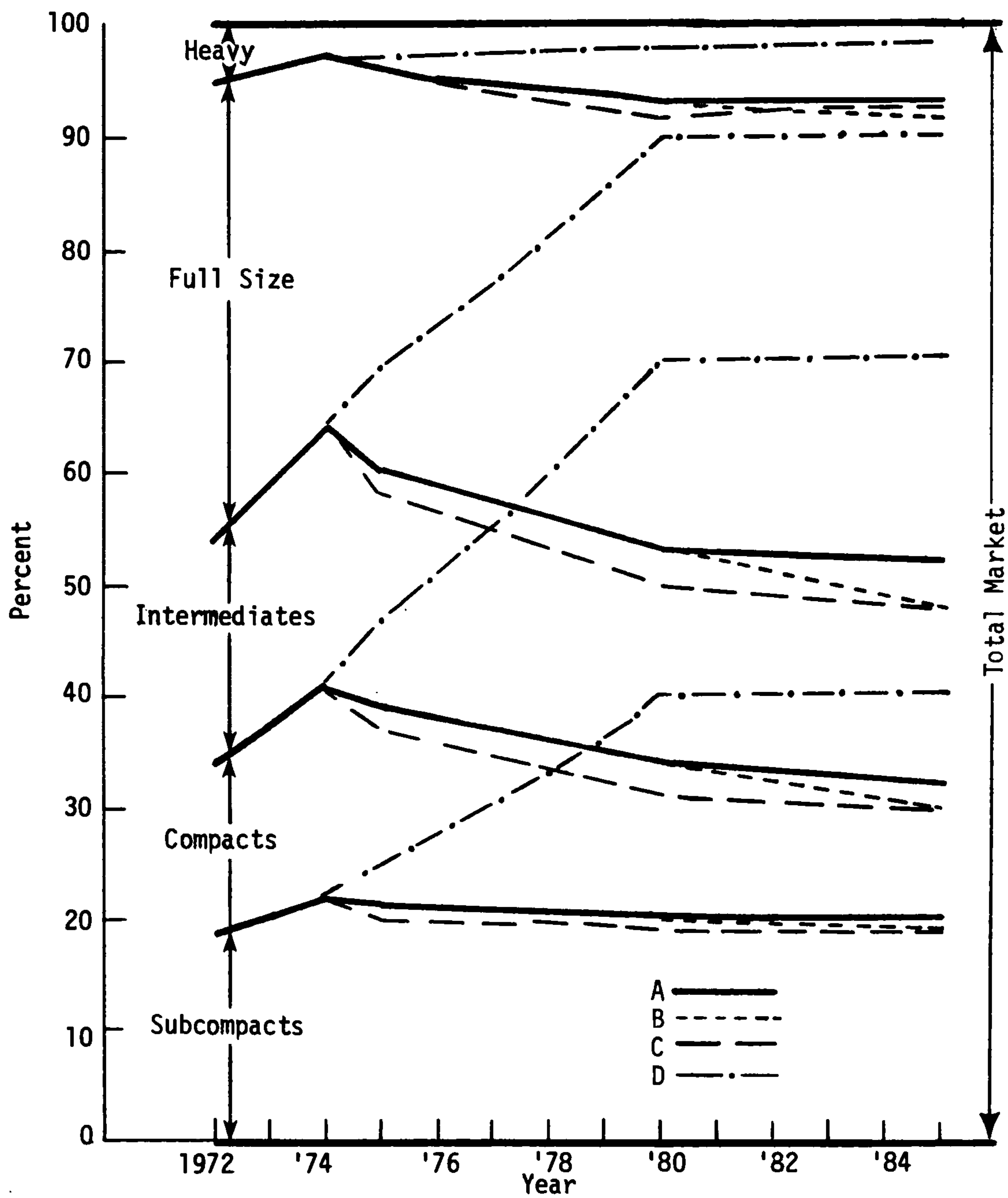

Figure 5-1. Market shares of the CEM automobile classes corresponding to the TSC Scenarios A,B,C,D. The lines separate the total market (represented by the heavy lines at 0 and 100 percent) into the market shares of the classes indicated.

5.1.2 Projections of Changes in Car Occupant Fatality Risk

The "average" car occupant fatality risk measured by the ratio of car occupants killed to car occupants involved in crashes* depends on many factors. Those related to the car population are:

- The model year (vehicle age)/car class composition of the car population;
- The Federal Motor Vehicle Safety Standards and other model year related differences in automobile crash-worthiness;
- Vehicle age related accident involvement;
- Vehicle age related seatbelt use; and
- Relative frequencies of single-car, car-car, and car-truck crashes.

CEM has developed a model [17] which quantifies, on an empirical basis, the influence of these factors and calculates the injury (fatality) risks for single-car crashes, car-car crashes, car-truck crashes and an "average" crash relative to a base year. A description of the model and of the computer program for its application is given in Appendices E and F.

The model calculated risks relative to a base year rather than absolute risks, because absolute risks depend strongly on the degree of reporting of minor crashes, as discussed in Appendix A, and cannot, therefore, be defined on a national basis with the information currently available.

Using the specific assumptions and input data described in Appendix E, and changing only the composition of future automobile sales in terms of size, according to Scenarios A through D, the CEM model projects the relative risks shown in Figure 5-2.

The continuous decline of the average risk in single-car crashes for Scenarios A, B and C is due to the phasing-out of older cars which do not satisfy the FMVSS. This compensates for the increase in risk due to the phasing-in of smaller cars into the automobile population.

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*Which we assume to be equal to the ratio of drivers killed to cars in crashes, as discussed above.

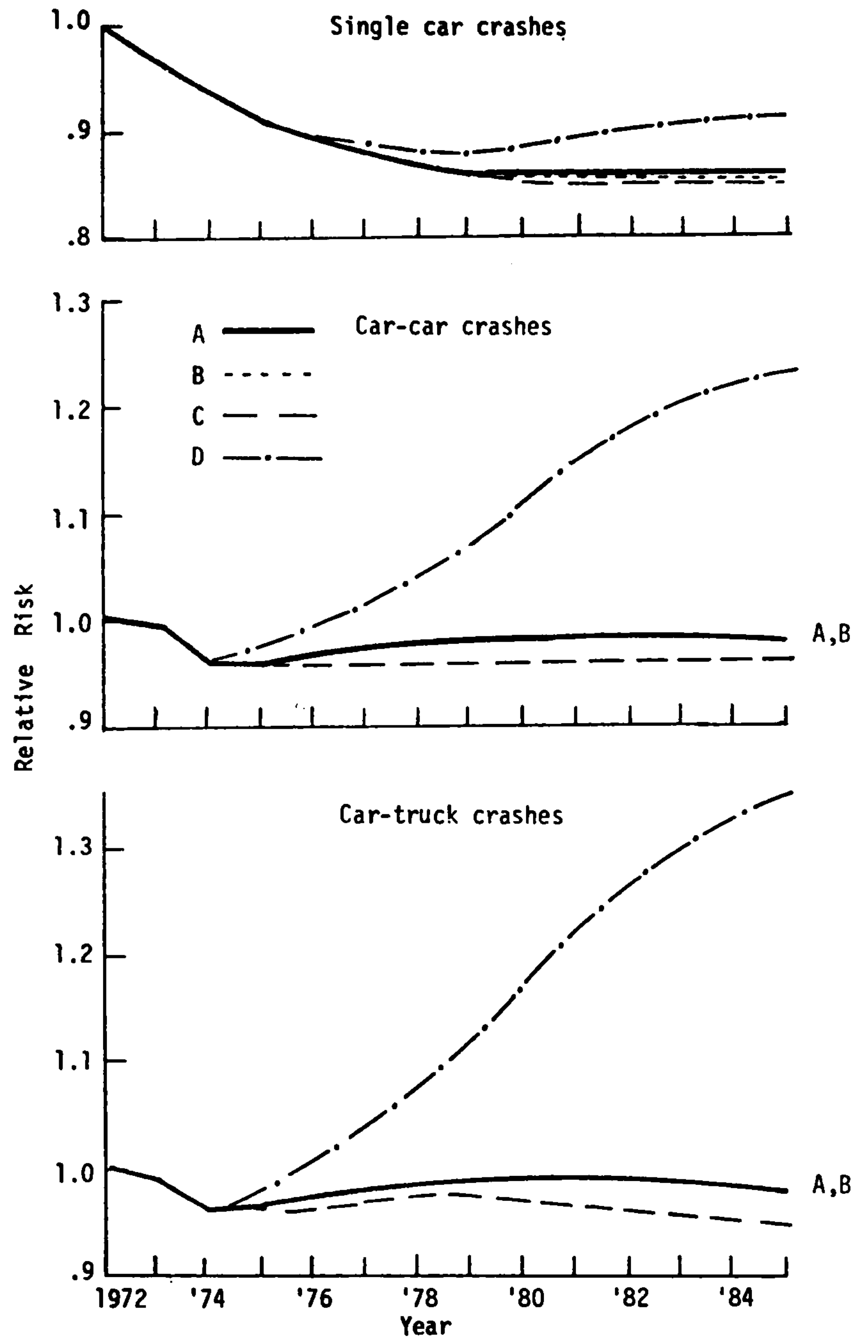


Figure 5-2. Risk of fatal injury for an automobile driver (assumed to hold also for occupants), relative to 1972 (=1) resulting from the CEM injury risk model using automobile market Scenarios A, B, C, and D. For car-car and car-truck crashes, the results for Scenarios A and B are indistinguishable within the accuracy of the drawing.

In the case of car-car and car-truck crashes, the risk declines only up to 1974. After that, there is a slight increase, because the phasing-out of the pre-FMVSS cars is not sufficient to compensate for the increase in risk due to the new, small cars facing older, heavier cars. This is especially obvious for Scenario D, where a large increase in the market share of small cars is assumed. In this case, for car-truck collisions accounting for about one-sixth of car occupant deaths, the risk increases by more than 30 percent; in the case of car-car collisions accounting for one-third of all car occupant deaths, the risk increases by about 25 percent. The difference is due to the fact that the phasing-in of lighter cars decreases the "average aggressiveness" of the car population and thereby somewhat reduces the increase in risk due to smaller cars.

The CEM injury risk model combines the injury risks in single-car, car-car and multi-car crashes to an overall risk. The result of treating multi-vehicle crashes as car-car crashes, as discussed in Paragraph 4.4.3, is shown in Figure 5-3.

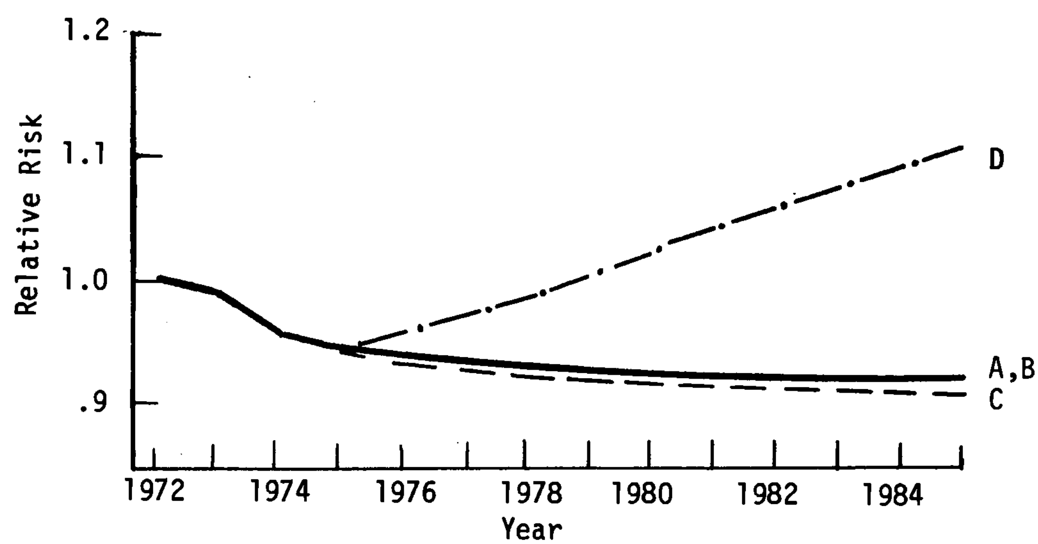


Figure 5-3. Risk of fatal injury for an automobile driver (assumed to hold also for occupants), relative to 1972 (=1), resulting from combining the risks shown in Figure 5-2 with the relative frequencies of single-car, car-car and car-truck crashes using automobile market Scenarios A, B, C, and D. Scenarios A and B are indistinguishable within the accuracy of the drawing.

5.1.3 Sensitivity Analysis

As discussed in Paragraph 4.4.5, the differences in the frequencies of fatal and serious driver injuries between automobile classes--and consequently our estimates of the differences in the frequencies of fatal injuries--are subject to considerable uncertainties. Therefore, the following sensitivity analyses were performed, varying the numerical values of certain estimates.

In Paragraph 4.3.1 we found that for single-car crashes, injury risk in small cars 50 percent higher than in large cars appeared reasonably certain, but the pattern of change of injury risk between these extremes was highly uncertain. Therefore, we varied the relation between injury risk and vehicle size from a pattern corresponding to "u" in Figure 5-4a (as assumed in the calculations of Paragraph 5.1.2) to the patterns "v" and "w". u, v, and w cover roughly the range of possibilities compatible with the relations shown in Figure 4-4. The resulting estimates of the relative fatality risk are shown in Figure 5-4b. For 1975, the range of predictions for Scenario C is from -14 percent to -18 percent, relative to 1972, and for Scenario D from -6 percent to -9 percent. Looked at in a different way: in 1985, the fatality risk under Scenario D is between 6 percent and 12 percent higher than under Scenario C. These estimates do not consider any uncertainty in the total range of fatality risk between large and small cars.

For car-car crashes, the formula in Table 4-8 used for the calculations in Section 5.1.2 was varied from

$$0.93^{w} \times 1.02^{w'} \qquad (5\text{-}1)$$

to

$$0.92^{w} \times 1.02^{w'} \quad \text{(X, corresponding to the New York State experience),} \qquad (5\text{-}2)$$

$$0.94^{w} \times 1.02^{w'} \quad \text{(Y, corresponding to the Washington State experience),} \qquad (5\text{-}3)$$

and

$$0.96^{w} \times 1.01^{w'} \quad \text{(Z, corresponding to the Texas experience).} \qquad (5\text{-}4)$$

Similarly, for car-truck crashes, we used the first factor (b^{w}) of these formulas. The resulting relative fatality risks are shown in Figure 5-5. For car-car crashes, the fatality risk estimates in 1985 range

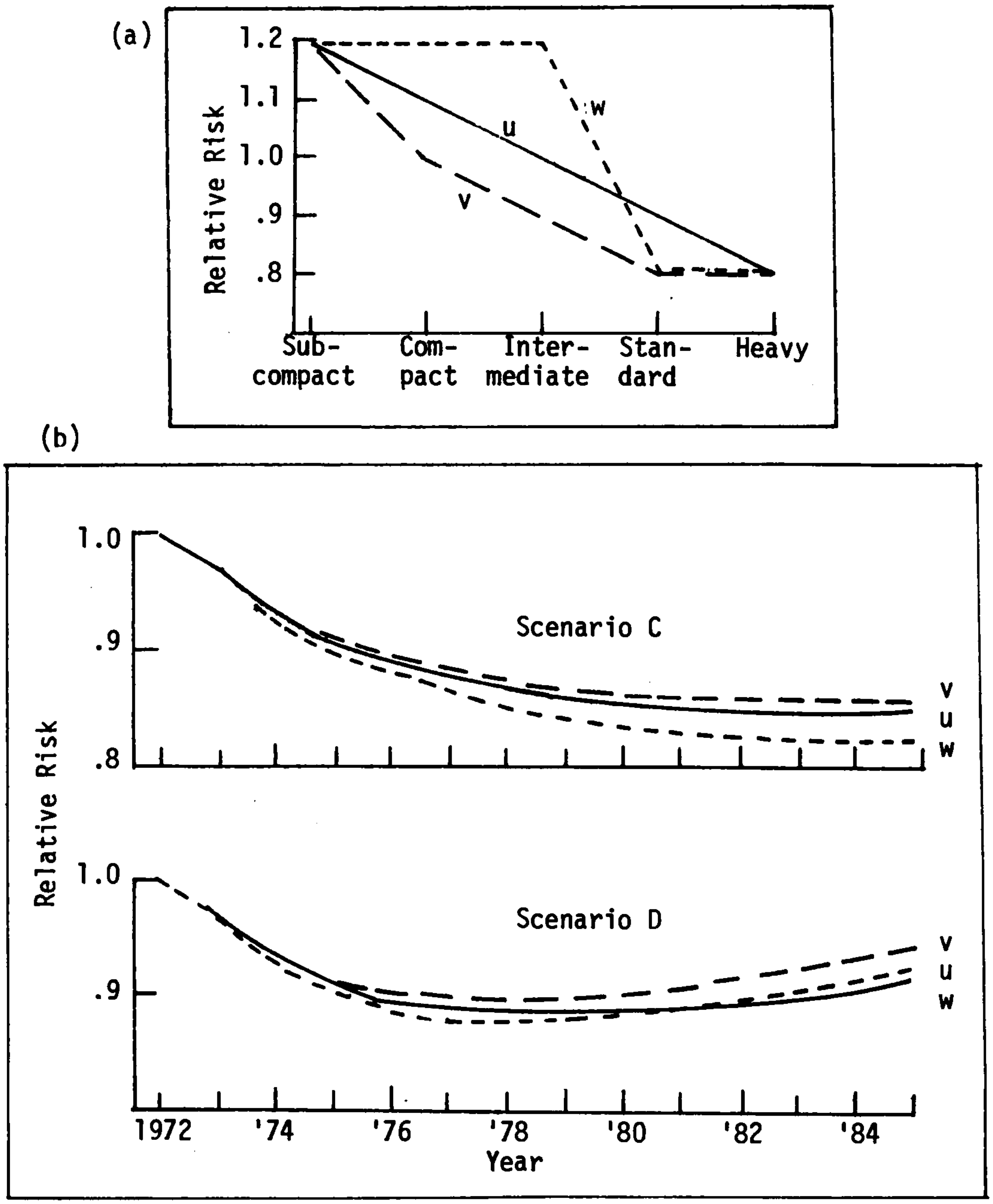


Figure 5-4. Sensitivity of the relative fatal (and fatal or serious) injury risk to car drivers in single-car crashes (b) to three assumptions (u, v, w) on the relation between fatality risk and car size (a), for Scenarios C and D giving the extremes in Figure 5-3.

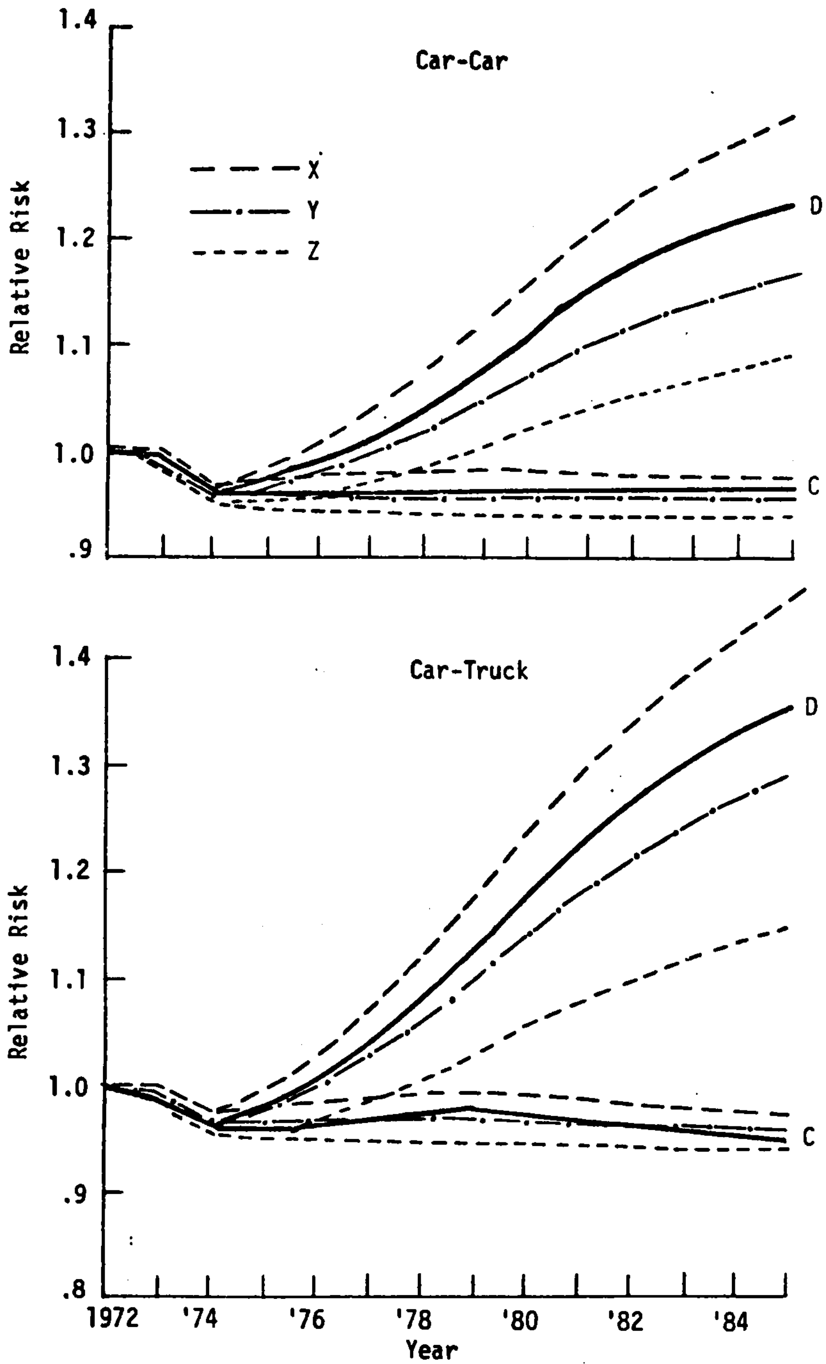


Figure 5-5. Sensitivity of the relative fatality risk to car drivers in car-car and car-truck crashes to changes of formula (5-1) [X assumes formula (5-2), Y: (5-3), and Z: (5-4)].

from -2 percent to -6 percent for Scenario C, from +9 percent to +31 percent for Scenario D. However, if we do not consider the Texas accidents (Z) because of the exclusion of subcompacts, the ranges are reduced to -2 percent to -4 percent, and +17 percent to +31 percent. For car-truck crashes these ranges are -3 percent to -6 percent for Scenario C (-3 percent to -5 percent without Z) and +15 percent to +45 percent for Scenario D (but only +29 percent to +45 percent without Z). Considering only the situation in 1985, in car-car crashes the fatality risk under Scenario D would be higher than that under Scenario C by between 16 percent and 35 percent; in car-truck crashes by between 22 percent and 50 percent.

To combine these estimates of uncertainty for 1985, we consider that about 50 percent of all car occupant deaths occur in single-car crashes, 50 percent in multi-vehicle crashes, of which about two-thirds are in car-car and multi-car crashes and one-third in car-truck crashes. Assuming that the variations u, v, 2, and x, y, and z are independent, we find that the fatality risk under Scenario C will be between 9 percent and 12 percent lower than in 1972, under Scenario D it will be between 1 percent and 14 percent higher than in 1972.

Comparing the baseline (solid line) projections in Figure 5-5 with those for alternatives X and Y, we can easily make an estimate of how much the risk for fatal or severe injury would differ between Scenarios C and D in 1985, because the curves suggest that for car-car crashes and to some extent for car-truck crashes, one can approximately linearily extrapolate from

$$0.92^{w} \times 1.02^{w'} , \tag{5-5}$$

$$0.93^{w} \times 1.02^{w'} , \tag{5-6}$$

and

$$0.94^{w} \times 1.02^{w'} \tag{5-7}$$

to

$$0.95^{w} \times 1.02^{w'} \tag{5-8}$$

which represents our estimate for the dependence on the frequency of fatal or serious injury upon the weights of the two cars. A rough estimate is that for car-car as well as for car-truck crashes, the difference between Scenarios C and D in terms of fatal or serious injuries is 60 percent of that for fatal injuries.

5.2 AUTOMOBILE CRASHWORTHINESS IMPROVEMENTS

5.2.1 Potential Crashworthiness Improvements

To estimate the impact of potential crashworthiness improvements of cars of current design (excluding safety vehicles of considerably different design), we contacted the National Highway Traffic Safety Administration (NHTSA) and Naval Research Laboratory (NRL) staff and reviewed the literature listed in Appendix G. It was found that there exists a considerable body of engineering knowledge on how to modify automobiles of current design by using current manufacturing processes in order to improve occupant deceleration patterns in crashes and strengthen the occupant compartment. However, rarely were the effects of these improvements estimated in terms of reduction of injury and fatality frequency. Carter [20] shows the effects of various modifications of automobile structures. His figures show that with such changes and air bags car occupant fatalities in frontal impacts would be reduced by 70 percent. Since about 50 percent of all occupant fatalities occur in frontal impacts*[9, 19, 21], overall occupant fatalities would be reduced by 35 percent. Air bags and structural design could add 300 lb to the weight of a 4000 lb car.

Alexander, Conrad and Neale [22] analyze the effects of various structural improvements and improved seatbelts, but no air bag by computer simulation. They use two highly speculative approaches to estimate the resulting reductions in occupant fatalities. The reductions in frontal impacts are shown in Table 5-2. These estimates are conservative: the actual improvements made were for frontal and side impacts

TABLE 5-2

Fatality reduction (%) in frontal impacts resulting from certain automobile improvements adding 2.5% and 5% to the vehicle weight, estimated by Alexander, et al.

Added weight of improvements (%)	Automobile Weight			
	2000	3000	4000	5000 lbs
2.5	4	0(?)	14	4
5.0	7	0(?)		16

*Estimated from data in References 9, 19, and 21.

and for rollover accidents, adding 5 percent or 10 percent to the vehicle weight. However, fatalities saved due to improvements for side impacts and rollovers could not be estimated. It was estimated that 50 percent of the weight increase was for improvements for frontal impacts; therefore, we assumed the weight increases corresponding to the estimated savings of 2.5 percent and 5 percent. These improvements for frontal impacts do, however, also improve protection in side impacts and rollovers somewhat (personal communication with Mr. Neale). Thus, the estimates shown in Table 5-2 are conservative.

In a joint report [19], NHTSA and TSC estimate that the air bag could reduce occupant facilities by 41 percent, injuries by 35 percent, assuming 60 percent lapbelt usage. These estimates were made when the seatbelt-ignition-interlock was still a requirement of the FMVSS's. Since this requirement has been rescinded in the meantime, 60 percent seatbelt usage appears unrealistically high. Therefore, we modified NHTSA/TSC's estimates, assuming only 20 percent lapbelt usage, which corresponds approximately to current usage. This reduces fatality savings of the air bag system to 35 percent. The air bag system adds about 75 lbs to the weight of a car [20]. The effects of this weight increase are well within the limits of other undertainties of our estimates and will therefore not be considered.

There is a question whether the air bag has different effects in small and in large cars. We assume that there is no difference, for the following reason. The functions of air bags are very similar to that of lap-shoulder belt combinations, and somewhat similar to that of lapbelts. Results obtained by the Highway Safety Research Center of the University of North Carolina [23] show that seatbelts in 1970-1972 model cars reduced severe and fatal driver injury in single-car crashes by 46 percent in subcompact cars, by 45 percent in compact cars, and in car-to-car crashes by 37 percent for both subcompact and full-size cars: the effects of the seatbelts are the same in small and large cars.

5.2.2 Projection of the Potential Effects of the Air Bag System

Of the improvements discussed in the preceding section, the air bag has the largest effect--as large as the earlier NHTSA estimate of the effects of air bag and structural improvements. Therefore, we will consider no other vehicle improvements.

The effects of optional air bag use we estimate to be negligible: in the 1974 model year, General Motors sold 5,500 air bags as optional equipment; that is for 0.5 percent of the cars for which this option was offered. In the 1975 model year, so far 2,000 have been sold. General Motors estimates that in the model years 1976 and 1977, 30,000 air-bag equipped cars may be sold. Also, overall effects of air bags on the fatality risk are only slightly higher than those of the lap-shoulder belt combination. Therefore, a safety conscious and presumably well-informed buyer will have relatively little incentive to buy an air bag as an option, because he can obtain nearly the same effect by just using the lap-shoulder belt combination which is installed in each car.

Therefore, we made projections of the overall air bag effects only for the case of mandatory installation. Though current FMVSS's require a passive restraint system for cars of the 1977 and later model year, NHTSA considers the 1978 model year as the earliest realistic date for the general introduction of air bags. We used the CEM injury risk model and replaced for cars of the model years 1978 and later, the effects of voluntary seatbelt use by the effects of the air bag: a reduction of fatalities by 41 percent for the 60 percent lapbelt use and by 35 percent for the 20 percent lapbelt use assumption. The resulting relative risks for Scenarios C and D (those for A and B are very close to that for C) are shown in Figure 5-6. The figure shows that introduction of the air bag would more than compensate the increase of the fatality risk due to the increased use of small cars assumed in Scenario D.

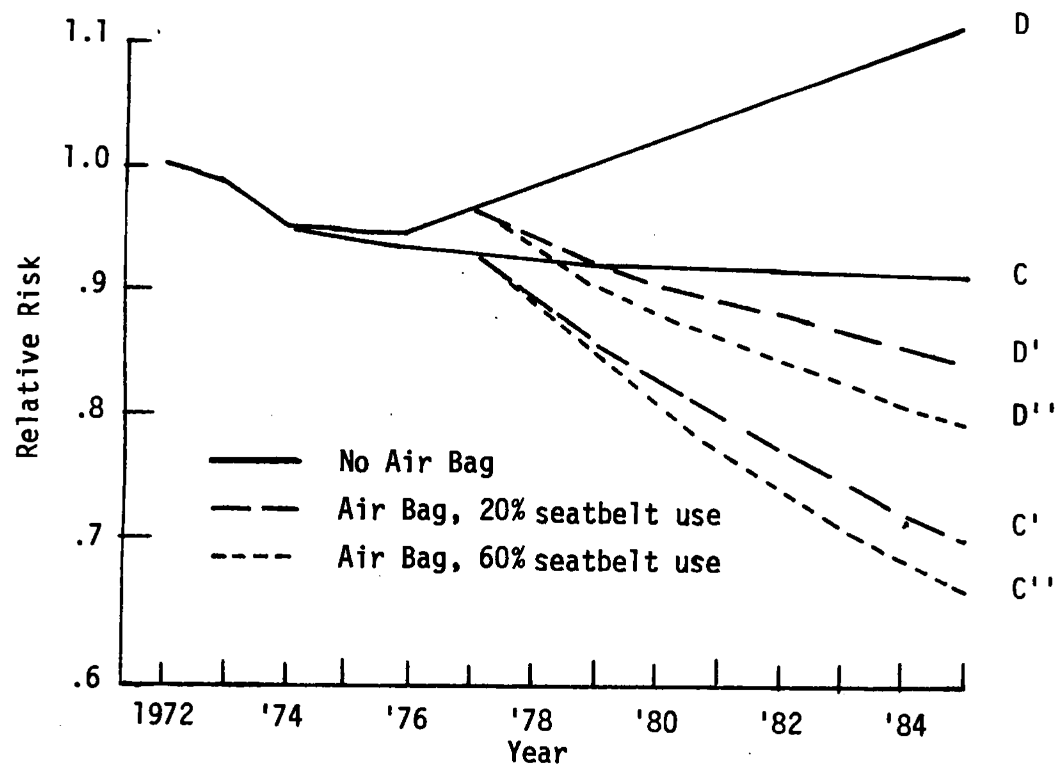


Figure 5-6. Relative risk of fatal automobile driver injury for scenarios C and D assuming no air bag and air bag with 20 percent seatbelt use, and with 60 percent seatbelt use, for cars from the 1978 model year on.

5.3 ILLUSTRATIVE PROJECTIONS OR CAR OCCUPANT DEATH NUMBERS

All previous analyses dealt with changes of the risk of injury or death once a crash had occurred. The changes in the numbers of deaths or injuries also depend on the number of crashes occurring. This number is neither well defined, nor known on a national basis. However, if we could project which numbers of deaths or injuries would occur if there were no change in the vehicle population, then we could apply the risk change and estimate how the numbers of deaths and injuries would change. This is what the CEM Accident Trend Model, described in Appendix E, does. Basis for the projections are projections of the numbers of new car sales, up to 1985, provided by TSC. They are shown in Table 5-3.

TABLE 5-3

Projections of new car sales
(in millions) provided by TSC

Year	1974	1975	1976	1977	1978	1979	1980	1985
Passenger cars	9.4	9.8	10.2	11.5	12.1	12.6	12.7	13.6

The results of applying the model to the car population resulting from these projections, and of applying the risk changes corresponding to Figure 5-6, are shown in Figure 5-7. It shows, for Scenario D, a strong increase in the number of deaths, beginning about 1978, which would, however, be essentially levelled by introduction of the air bag. Under Scenario C, there is also an increase in the number of deaths, beginning about 1978, but of lesser magnitude. Introduction of the

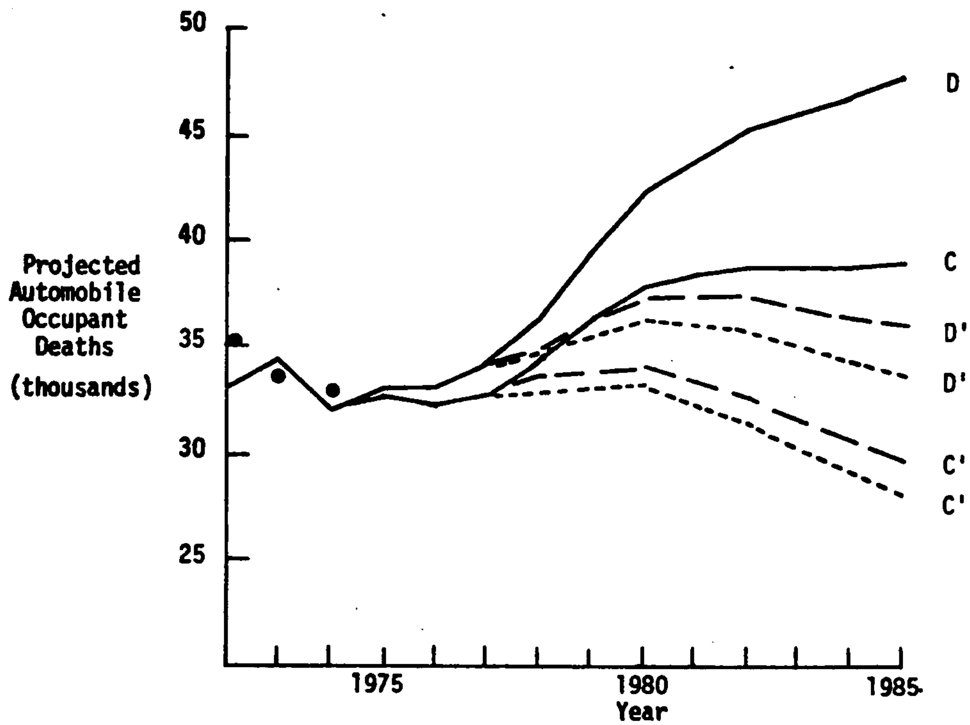


Figure 5-7. Illustrative projections of the number of automobile occupant deaths under Scenarios C and D, and the two assumptions on air bag effectiveness. Caution: the projections are based on the overall trend in travel patterns up to 1973. The recent changes in travel speed and annual VMT might change the future trend drastically. Therefore, the projections can be considered illustrative only.

air bag would not only level this increase immediately, it would even reduce the absolute number of deaths beginning about 1980.

These projections have to be interpreted with great caution, because the trend model is based on the accident trend up to 1973, during a period when the influence of many factors affecting the trend could not be separated. Since these correlations have been interrupted by the reduction of travel speeds and VMT in 1974, the projections of the model may become quantitatively unreliable, although the overall tendency of the trend may still be correct.

5.4 SUMMARY

The effects of changes in future automobile sales according to Scenarios A and B are practically indistinguishable. They are also very close to those of Scenario C. Only Scenario D gives considerably different results. Under Scenario C, the car occupant fatality risk in 1985 would be between 9 percent and 12 percent less than in 1972, primarily due to the phasing out of older cars not satisfying the FMVSS. Under Scenario D, the risk would be between 12 percent and 26 percent higher than under Scenario C.

Introduction of the air bag with the 1978 model year would have reduced in 1985 the overall fatality risk by between 24 percent and 29 percent.* This would be more than sufficient to reduce the risk under Scenario D to less than under Scenario C without the air bag.

*The full benefits of the air bag, a 35 percent to 41 percent reduction, would be achieved about 1990.

6. VEHICLE USE FACTORS AND ACCIDENTS

Vehicle miles of travel (VMT) is an obvious quantitative measure for motor vehicle use; travel speed is an important, if not the most important, qualitative (though quantifiable) aspect of vehicle use. Changes in VMT and changes in travel speed will affect the number of motor vehicle accidents and the number of injuries and deaths. In this section, we review what is known about such relations in order to obtain a basis for making estimates of the impact of changes in vehicle use upon traffic deaths.

6.1 THE RELATION BETWEEN VMT AND FATAL ACCIDENTS

CEM has explored this relation in a previous study [17].* From various sources relating accident or death rates to average daily traffic (ADT), which is proportional to VMT for any given highway segment, we conclude that the number of deaths or fatal accidents on a highway segment or system, depends on the number of VMT. This is not surprising since a change in VMT changes traffic density, and consequently speed and the types of accidents occurring. We found no justification for the frequent practices of multiplying the fatality rate with the change in the number of VMT in order to estimate the consequent change in traffic deaths.

We performed additional analyses which are described in Appendix D. The results, which have to be considered as illustrative and not as definitive, are shown in Figures 6-1 and 6-2. Figure 6-1 shows, on the aggregate of rural highways of Connecticut, Florida, and Ohio, both overall and separately by type of highway, how the number of fatal accidents would change if VMT would change. Figure 6-1a assumes the same percentage change of VMT over all segments; Figure 6-1b assumes that the entire change occurs on the segments with lowest traffic density; and Figure 6-1c assumes that the change occurs on the segments with highest traffic density. The overall change for case (a) is practically proportional to the change in VMT. However, the

*See Section 2.8 of Reference 17.

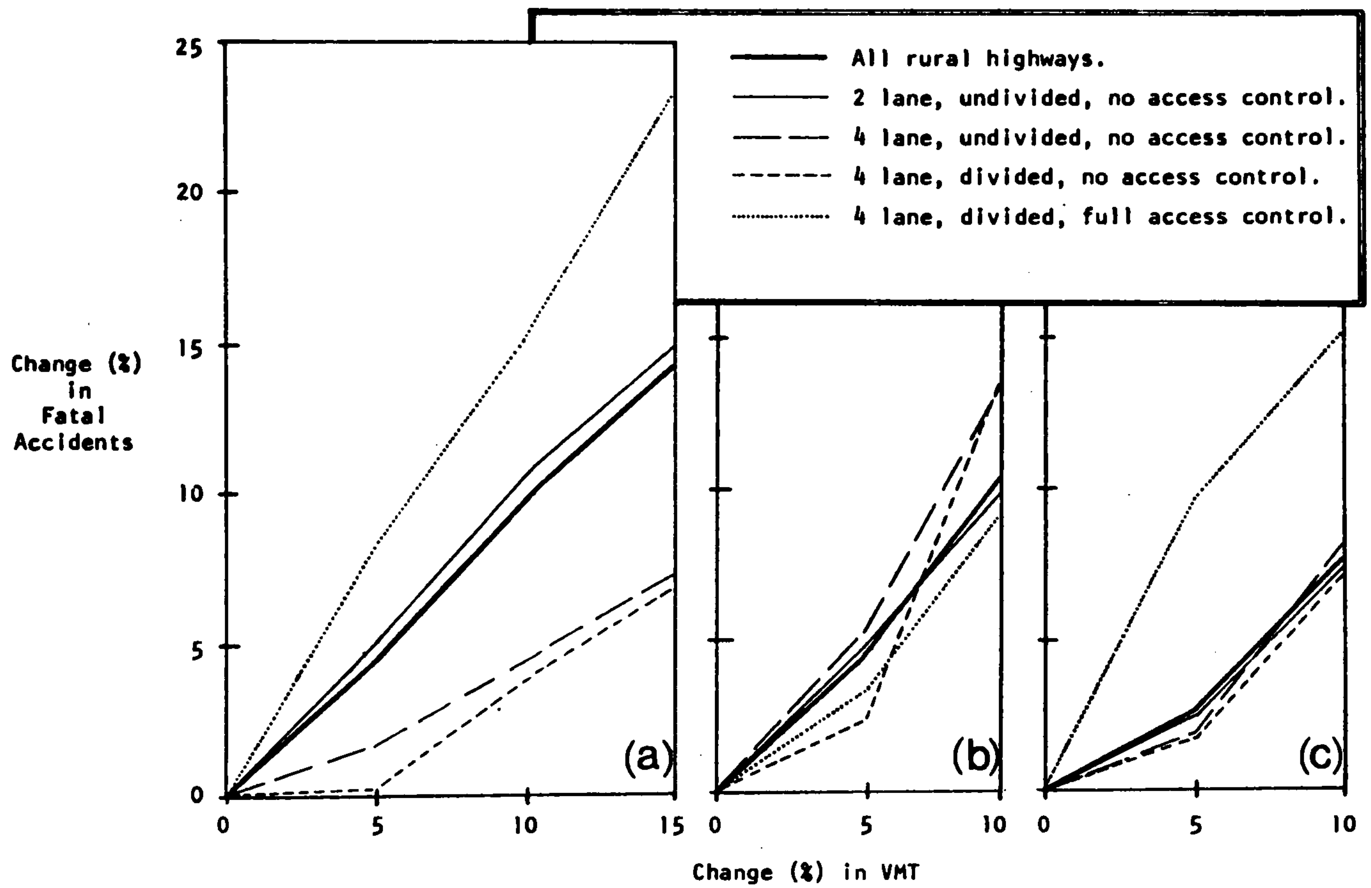


Figure 6-1. Change in fatal accidents on rural highways in Connecticut, Florida, and Ohio, resulting from a change (reduction) in vehicle miles of travel (VMT), by type of highway. In (a), the change occurs uniformly on all highway segments; in (b), only on the segments with lowest traffic densities; and in (c), only on segments with the highest traffic densities.

changes on four-lane highways with full access controls are much greater than proportional to VMT. In case (b), the overall change is again practically proportional to the change in VMT, and the differences between highway types are not large. This is not surprising because on highways with low traffic density, traffic density will still remain low after a change, and speeds will be little affected. In case (c), the change in fatal accidents is much less than proportional to the change in VMT; the only exception is four-lane divided highways with full access control, possibly because even at the highest traffic densities traffic is not yet congested.

Figure 6-2 shows estimates of the change in traffic deaths resulting from a change in VMT based on a cross-sectional analysis of the states. Not only does it show that the change in the number of deaths is less than proportional to the change in VMT, it also shows a surprisingly large difference in the changes for 1969 and 1972.

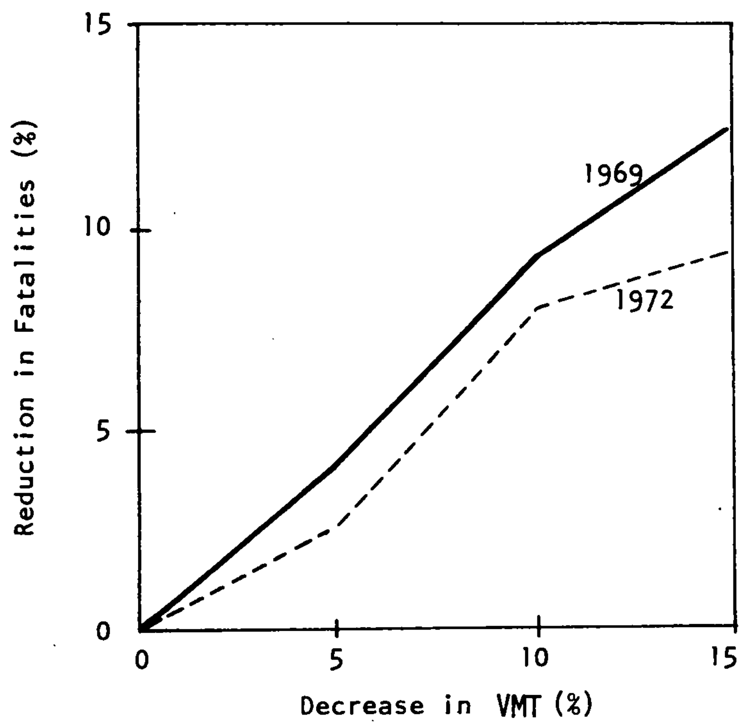


Figure 6-2. Nationwide change in traffic deaths resulting from a uniform change in VMT in all states for 1969 and 1972, estimated on the basis of the relation shown in Figure D-5.

A strict comparison of the relation shown in Figures 6-1 and 6-2 is not comparable, because the first applies to rural highways, the second to all highways nationwide. Therefore, one can only conclude that on rural highways fatal accidents may change, on the average, proportionally to VMT (the relation depending strongly on highway type and traffic density), but that on all highways it is likely to change much less than proportional to VMT.

The relations shown in Figures 6-1 and 6-2 are between annual traffic deaths (or fatal accidents) and annual VMT. They represent averages over a wide range of traffic densities, varying daily, weekly, and seasonally. To estimate an effect of a change in VMT occurring at certain hours, or certain days of the week only, one would need a relation between hourly traffic deaths and hourly VMT, and comparable highways (studies of one highway are not sufficient, because traffic density and time of day are related, and a separation of their effects is usually not possible). There are only few and isolated studies [24]* of this question made and the results are not sufficient to draw any conclusions.

Our overall conclusion is that the state-of-the-art is not sufficient to allow responsible estimates of the effects of a change in VMT--both overall changes and changes at certain times or highways--on motor vehicle deaths.

6.2 THE RELATION BETWEEN ACCIDENTS AND SPEED

The relation between accidents and speed has two aspects:

- how the frequency of accidents depends upon speed, and
- how injury frequency and severity depend upon speed once an accident has occurred.

In the first case, "speed" means travel speed before the accident; in the second case, impact speed is the factor influencing frequency and severity of injury, which may be lower than travel speed before the accident. In controlled crash tests, the impact speed is known,

*They are reviewed in Reference 24.

in actual crashes the impact speed may be estimated, to a certain extent, from the vehicle deformation. Usually, however, accident reports give an estimate of travel speed before the accident. How reliable this information is is not known.

Actual measurements of travel speed on level, straight sections of main travel highways, in free flowing traffic, are performed by many state highway departments and summarized by the Federal Highway Administration. These measurements cover only part of the highway system--parts where accidents appear less likely than in curves and on grades--and only part of the traffic condidions. However, that they are related to travel speed in general is suggested by Figure 6-3, which shows the relation between the measured average speed of free flowing traffic on straight, level main rural road sections, and the average indicated travel speed before fatal accidents on all rural roads over several years in Virginia. For each mph increase of the average travel speed, the speed before fatal accidents increases by about one-half mph. For the relation between travel speed and the probability of getting involved in an accident, Solomon [18] found a "U-shaped" relation: this probability is lowest for speeds around

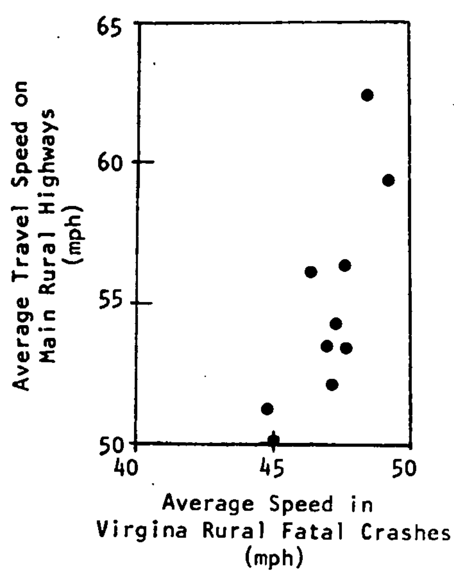


Figure 6-3. Relation between average travel speed on level straight sections of main rural highways, and average travel speed before fatal accident involvements in Virginia, 1961-1970.

the average travel speed on that section of highway and increases for lower as well as for greater speeds. Later studies have accepted this structure of the relations and made only new quantitative estimates. We took a closer look at detailed accident and speed data collected in Indiana [25] and found no suggestion of a U-shaped curve for single-car accidents; rather the probability of getting into an accident appeared to increase monotonically with travel speed. Considering this result, which also agrees with intuitive expectations, we have to conclude that the U-shaped curve is a descriptive, not a functional relation, and that the effects of speed on single-car and other accidents must be different. Since we do not know what the effects of speed are on single-car accidents and other accidents, we cannot make meaningful estimates of the effects of a speed change upon the frequency of accidents.

It is well-known that the frequency and severity of injury increases with speed. Recent data have been summarized by Joksch [25]. Based on his results, Figure 6-4 shows the smoothed empirical relation between the frequency (relative to 1 for the 40-50 mph range) of a fatal accident involvement and travel speed before the accident.

A conceptual problem is that the speed of each vehicle is considered separately: if a vehicle traveling at low speed is involved in a fatal colision with a vehicle traveling at high speed, it appears as one fatal involvement at low speed and one fatal involvement at high speed. A gross analysis of a sample of Texas and Virginia accidents, however, shows no systematic differences between the corresponding curves for single- and two-car crashes. Considering this, and the good agreement between the sources on which the relation is based, we are quite confident that Figure 6-4 realistically describes the general relation between travel speed and the frequency of fatal injury in an accident, though the numerical values are subject to some uncertainty.

In addition to the relation between speed and the frequency of an accident being fatal, one needs to know the distribution of fatal accidents by speed. Figure 6-5 shows these distributions for those states

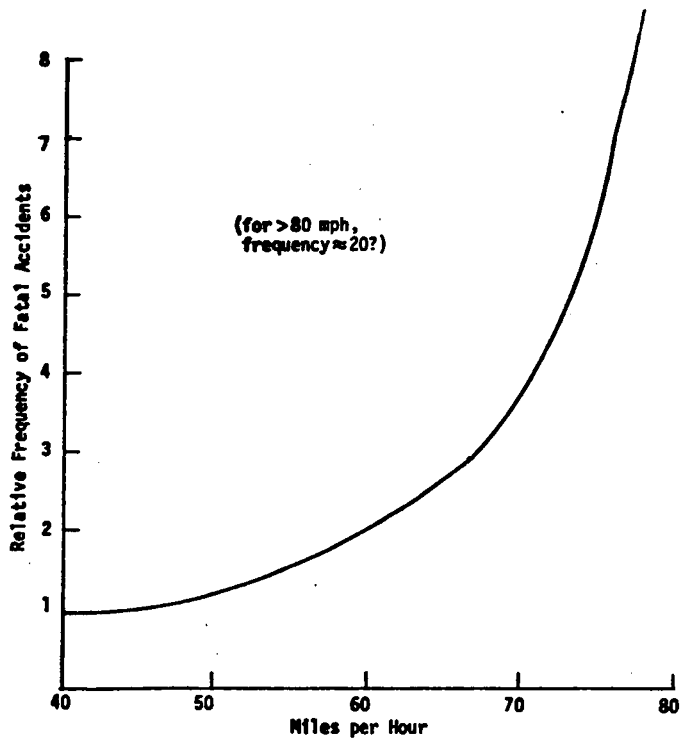


Figure 6-4. Idealized relation between the relative (to that in the 40-50 mph range) frequency of fatal accident involvement and travel speed before the accident.

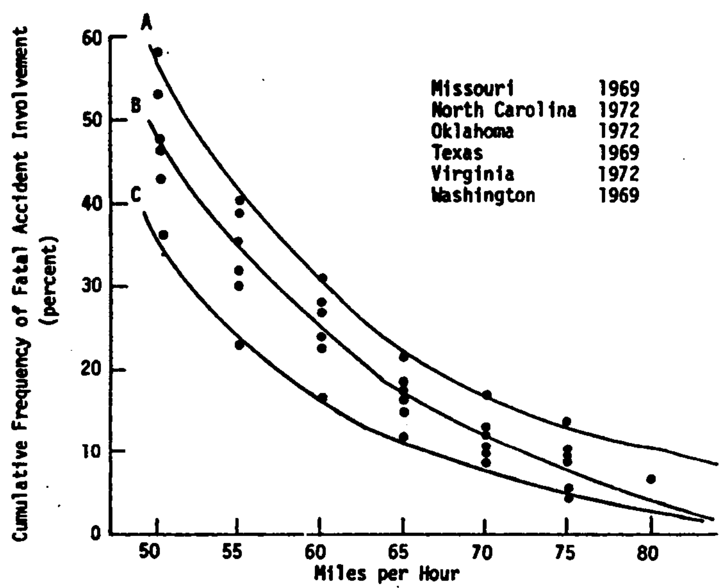


Figure 6-5. Cumulative frequency distribution of fatal accident involvements for six states. The curves A, B, C are hand-fitted to represent a "high," "best," and "low" estimate of the speed distribution.

for which recent data were available (many states did not collect or summarize this information beyond 1969; however, to combine 1969 and 1972 data appears defensible since the national average travel speed on main rural highways was essentially the same in 1972 as in 1969). To derive a nationally representative distribution from these considerably differing data is necessarily speculative; therefore we denote a "best" (B), a "high" (A), and a "low" (C) curve for the cumulative frequency distributions. The resulting distributions of fatal accident involvements by speed in travel are shown in Table 6-1 and Figure 6-5.

TABLE 6-1

Frequency of fatal accident involvements by speed intervals, resulting from curves A, B, C shown on Fig. 6-5.

Cumulative distribution	Speed (mph)							
	50	55	60	65	70	75	80	
A	43	16	10	8	6	4	3	10
B	52	13	10	8	5	4	3	5
C	64	13	7	4	3	3	3	3

The results of this section have to be interpreted with some caution. The summary statistics utilized count fatal accident involvement. It was found [17] that on the average, 1.1 persons are killed in a fatal accident involving only one motor vehicle, and 1.3 in a fatal accident involving more than one motor vehicle. Therefore, per fatal involvement of a single vehicle, 1.1 persons are killed, whereas for each of the vehicles involved in a fatal collision of several vehicles at most 0.65 persons are killed. If the relative frequencies of single- and multi-vehicle crashes depend on speed, the frequency distribution of persons killed by travel speed will differ from that of vehicles involved in a fatal accident. This, however could be tested only by extensive processing of original accident data.

6.3 SUMMARY

The current state-of-the-art is insufficient to estimate the effect of a change in total vehicle miles of travel on traffic deaths, much less that of a change occurring at specific times.

The relation between travel speed and accident frequency is too complicated and not sufficiently understood to allow an estimate of how the number of accidents would change with a change in travel speed.

However, the relation between travel speed and accident severity--in terms of fatal or injury involvements per involvement--is fairly well established, as represented in Figure 6-4.

7. THE EFFECTS OF CHANGING VEHICLE USE

7.1 THE FIFTY-FIVE MPH SPEED LIMIT

There are basically two* approaches to estimate the effects of the 55 mph speed limit upon accidents: (1) to analyze records of accidents having occurred "before" and "after"†, and (2) to analyze changes in travel speed and estimate their impact upon accidents. The first approach could not be used, because 1974 accident records were not yet available. Also, only few states have speed estimates in their accident records; thus, this approach alone might give nonrepresentative results. Therefore, we had to use the second approach, basing it on a special study by the Federal Highway Administration and National Highway Traffic Safety Administration of travel speeds in 1973 and 1974 [27].

The changes in travel speed in free-flowing traffic, on straight, level highway sections are shown in Figures 7-1 through 7-3. The shifts of the cumulative distributions to the left indicate a reduction to the travel speeds. An exception are urban primary roads; on them, speeds above 55 mph were reduced, but below 55 mph, more drivers increased their speeds.

Even though many states increased speed enforcement, as found in the FHWA/NHTSA study, still 47 percent of all vehicles on main rural roads and 36 percent on Urban Interstate Highways exceeded the 55 mph limit. If there had been literal compliance with the 55 mph speed limits, all vehicles traveling in 1973 above 55 mph would have reduced their speed to 55 mph in 1974, those traveling below 55 mph would not have changed their speeds (possibly even increased them, as in the case of urban primary roads, following a long-term trend). Literal compliance

*A third obvious approach would be to compare the overall accident experience of the first ten months of 1973 with that of the corresponding months of 1974. However, in addition to speed, other factors changed: VMT, the seatbelt interlock was introduced with the 1974 model and its requirement rescinded later in 1975, the type of cars sold in 1973 and 1974 changed (more small cars), and the economic recession which began late in 1973.

†We will ignore the fact that the reduced speed limit was initially 50 mph, and that the states introduced and changed the speed limit at different times.

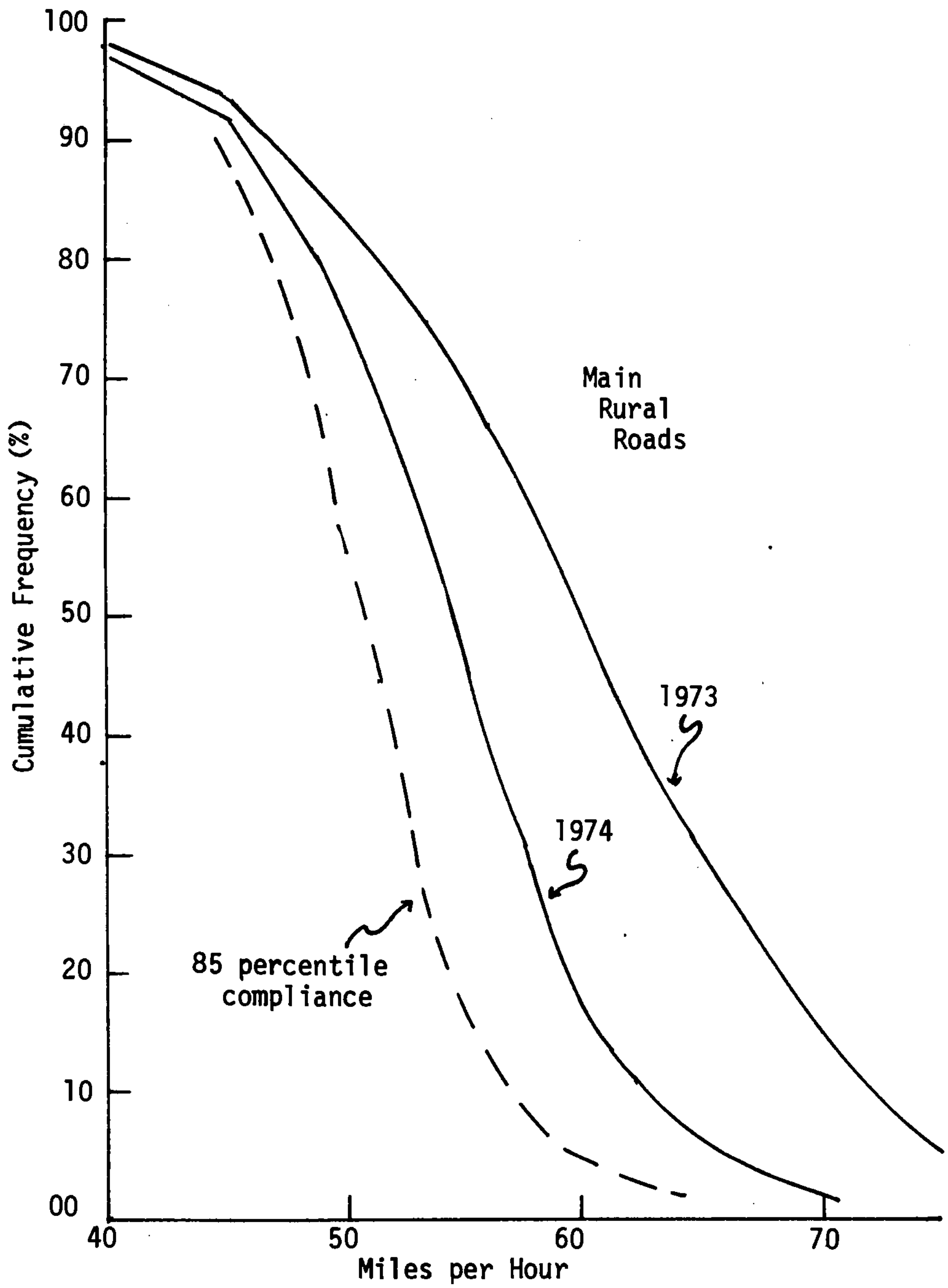


Figure 7-1. Cumulative distribution of travel speeds in free-flowing traffic on straight level sections of main rural roads, 1973 and 1974. The broken curve represents CEM's estimate of the speed distribution if 85 percent of all drivers would travel at 55 mph or less.

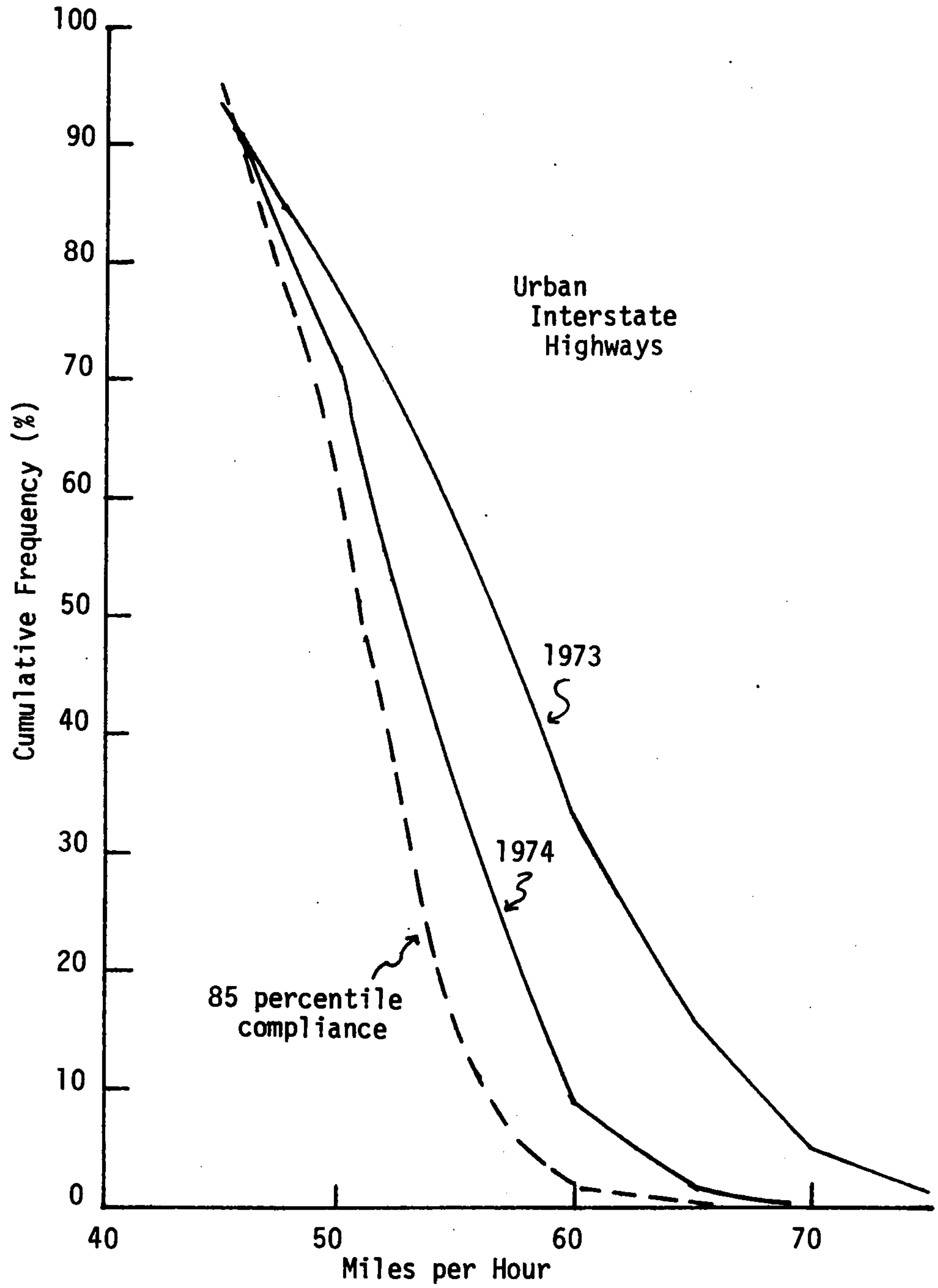


Figure 7-2. Cumulative distribution of travel speed on urban Interstate Highways, 1973 and 1974. The broken curve represents CEM's estimate of the speed distribution if 85 percent of all drivers would travel at 55 mph or less.

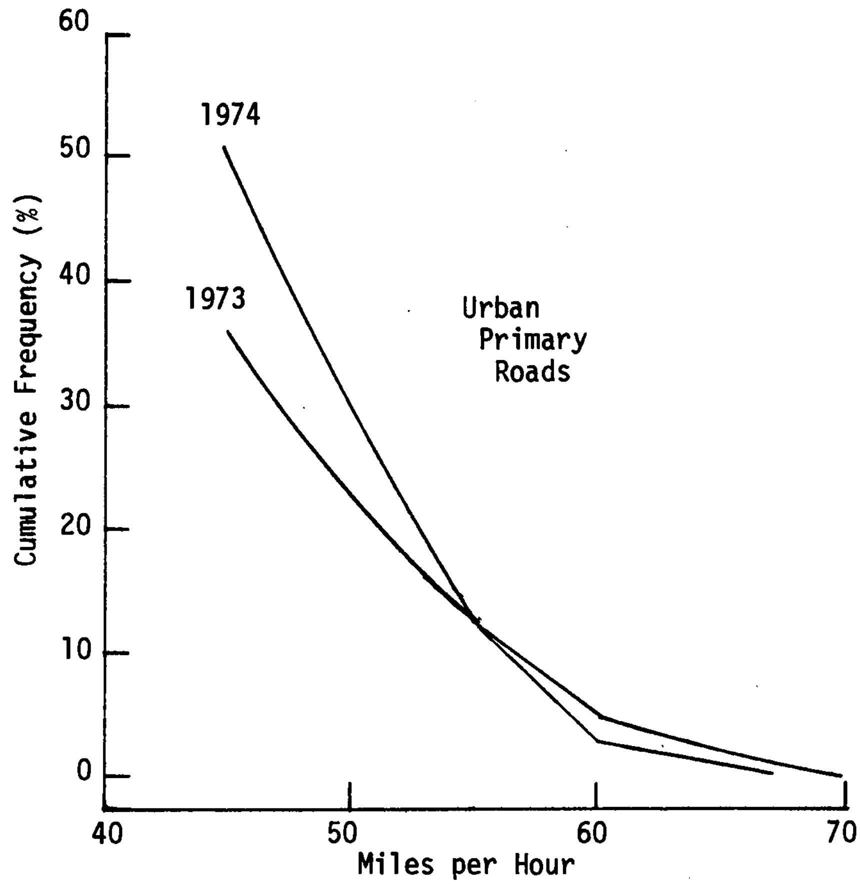


Figure 7-3. Cumulative distribution of travel speeds on urban primary roads, 1973 and 1974.

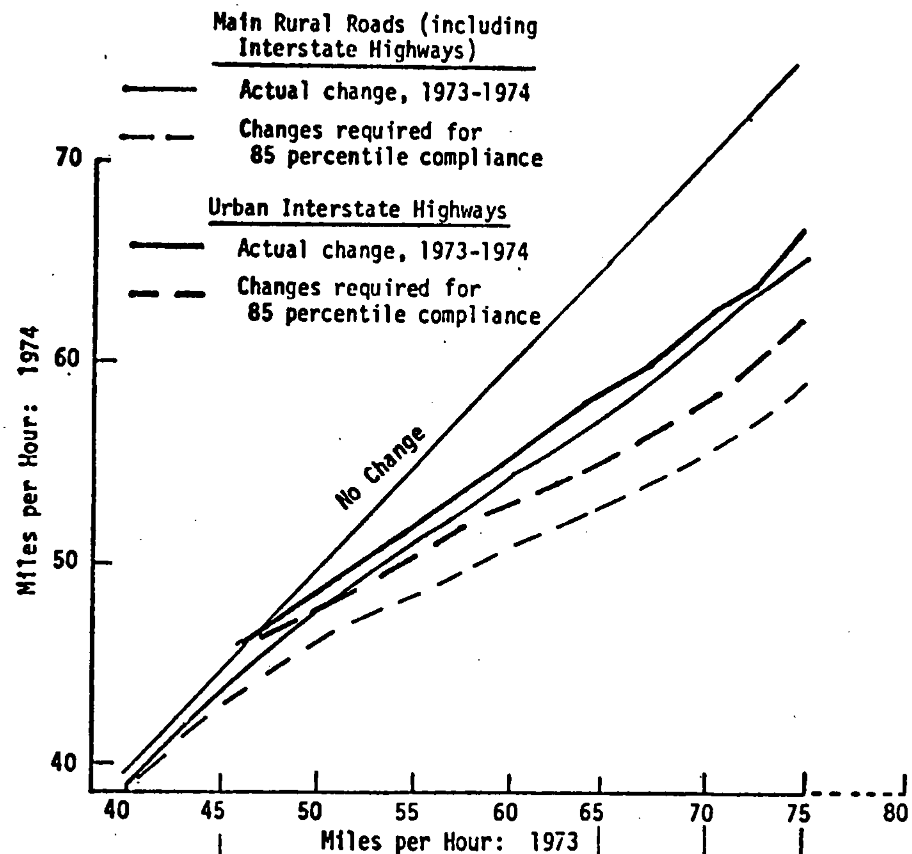
with speed limit, however, appears to be impossible to enforce. Therefore, we had to estimate which speed distribution one could reasonably expect under "strict" enforcement in practical terms. A clue is given by the traffic engineering rule [28] to set the speed limit at the 85th percentile of the distribution of free-flowing travel speeds. Since this allows 15 percent of all vehicles to exceed the speed limit, we assumed, arbitrarily, that strict enforcement of a speed limit would also still allow 15 percent of the vehicles to exceed it. We extrapolated from the speed distributions in 1973 and 1974 others which had the 85th percentile at 55 mph; they are shown as broken lines in Figures 7-1 and 7-2.

The relation between 1973 and 1974 travel speeds which result in the actually observed change in the speed distributions are shown in Figure 7-4.* The relations for main rural roads and Urban Interstate Highways are essentially the same (never differing by more than 1.5 mph). Also shown are the speed changes which would have been necessary to achieve 85 percent compliance. Travel speeds on main rural roads would have to be reduced more than on Urban Interstate Highways because they were initially higher. The changes of fatal accident risk resulting from applying the speed reduction in each speed interval to the relation shown in Figure 6-4, are shown in the table below the graph. Also shown are the risk changes which would result under "literal" compliance with the 55 mph speed limit: all vehicles traveling above 55 mph in 1973 would travel at 55 mph in 1974, all vehicles traveling below 55 mph in 1973 would travel at the same speed in 1974.

The speed changes discussed apply to vehicles traveling in free-flowing traffic on straight, level sections of main rural roads (or Urban Interstate Highways). We do not know what happened to travel speed in congested traffic on sections where travel speed would usually be reduced--curves, grades, intersections, construction sites, etc.--nor in cases where drivers had been traveling at high speed on other than main rural roads, perhaps speeding. The assumption that all travel speeds were changed as shown in Figure 7-4 appears optimistic, and will result in a high estimate of the reduction in fatal accidents.

A low estimate has been obtained by Council and Waller [29]. They used North Carolina accident data, combining travel speed estimates with information on posted speed. They assumed that drivers would exceed the 55 mph speed limit by the same amounts by which they had been exceeding the posted speed limits and arrived at a 3 percent reduction of vehicles involved in fatal accidents. Though the basic approach is plausible and probably realistic, the numerical estimate cannot be generalized, because the distributions of posted speeds in North Carolina

*This does not imply that each driver traveling at 70 mph in 1973 reduced his speed by 9 mph, etc.; it shows which speed changes could have resulted in the actually observed change.



	Change of Fatal Accident Risk due to Speed Reduction (relative to 1.0)							
Actual Speed Change	1.0	1.0	.9	.8	.7	.6	.5	(.4)
85 Percent Compliance	1.0	1.0	.8	.7	.6	.5	.4	(.25)
Literal Compliance	1.0	1.0	1.0	.9	.7	.5	.3	(.2)

Figure 7-4. Changes in travel speed 1973 to 1974 corresponding to the changes of speed distributions shown in Figures 7-1 and 7-2. The table below the graph shows the change in fatality risk, resulting from the relation in Figure 6-4, due to the change in speed on main rural roads in the speed range above. "Literal" compliance assumes that all speeds above 55 mph would be reduced to 55 mph, speeds below not changed. The values, in parentheses, for speeds in the 75-80 mph range are extrapolated.

may not be nationally representative, and the percentage of speeders may be neither, depending on how "reasonable" speed limits are set and how strictly they are enforced. However, the important result is that the impact of the 55 mph speed limit upon fatal accidents may be quite small.

To make our optimistic estimate, we use the distributions (A, B, C) of fatal accidents by speed shown in Figure 6-5, assuming that they apply to 1973 (which is not too strong an assumption considering the uncertainty of the distributions). To the percentage of fatal accidents in each speed interval, we apply the factor (from Figure 7-4) changing the risk of a fatal accident resulting from the corresponding speed reduction. For the fatal accidents above 80 mph, we make two alternative assumptions: (1) that speeds are reduced as in the 75-80 mph range, (2) that speeds are not reduced. The first appears a very optimistic assumption because most vehicles traveling at more than 80 mph are in gross violation of speed laws and little likely to be influenced by the 55 mph speed limit. The results are summarized in Table 7-1.

TABLE 7-1

Reduction (%) of the number of fatal accident involvements resulting from the speed changes shown in Fig. 7-4. The first number assumes no reduction in the speed range exceeding 80 mph (excessive speeding which might not be influenced by the 55 mph limit), the second, in parentheses, assumes for the range above 80 mph the same reduction as for the 75-80 mph range.

Speed Changes		Distribution of Fatal Accidents (Fig. 6-5) A	B	C
Actual, 1973-1974		12-(18)	12-(14)	7-(9)
85% Compliance	55 mph	17-(24)	16-(20)	12-(14)
Literal Compliance	55 mph	12-(20)	11-(15)	8-(10)

It is surprising that under the assumption of "literal" compliance the number of fatal accidents would be reduced by less than in the case of 85 percent compliance. This is so because in the latter case, also travel speeds below 55 mph would be reduced somewhat and speeds between 55 and 60 mph would be reduced below 55 mph. Though the risk of a fatal accident is not changed much by the small speed reduction, there are many fatal accidents in these speed ranges. The greater risk reduction achieved by literal compliance in the highest speed ranges applies to only a few accidents and can, therefore, not compensate the effect in the lower speed ranges.

Our conclusion from Table 7-1 is that the reduction in fatal accident involvements due to the 55 mph speed limit may have been "up to" 7-12 percent, at the very most 18 percent. It was most likely less, perhaps as low as 3 percent. The change in the number of deaths could be different, if the number of deaths in fatal crashes would depend upon speed, as discussed in Subsection 6.2.

On the other hand, the estimates of the change in fatal accident involvements assuming stricter enforcement, are not upper bounds but best estimates, because we assume a reduction of speeds to 85 percent compliance everywhere. Table 7-1 suggests that a reduction of 10-12 percent, possibly as high as 24 percent, could be achieved. Again, the number of deaths might be changed by different amounts.

Since frequency of accident involvement injury changes less with speed than that of fatal accidents (Figure 1b, Appendix E), the impact of the 55 mph speed limit upon the number of injuries will be considerably less than that for fatalities. Considering the uncertainty of the estimate for fatalities, no attempt was made to estimate this change beyond the obvious statement that it will be much less than 10 percent.

These estimates apply to the change from 1973 to 1974. The future impact cannot be unambiguously defined, much less estimated. If we assume that without the 55 mph speed limit the long term trend of increasing speeds--though interrupted 1969 to 1973--would have continued, and that the 55 mph limit would keep speeds at current levels, then the effect the speed limit would increase from year to year. If we assume that current speeds would not be maintained in the future but would increase at the same rate as before, but at a level reduced as in 1974, then the effect would still increase from year to year, but at a much lower rate as in the first case. A basically different assumption would be that the leveling of the speed trend 1969 to 1972 was not a temporary interruption, but a permanent phenomenon. In this case, the reduction of speeds to 1974 levels, if maintained, would result in a constant annual reduction for all future years. The most pessimistic assumption is that despite the 55 mph speed limit, actual speeds will over the next years reach the levels they would have had without the limit. In this case, the estimated effects of the speed limit would be transient only.

7.2 REDUCTION OF COMMUTER TRAVEL

One scenario asked for estimating the effects of a 10 percent, 20 percent, and 30 percent reduction in commuter travel. Table 7-2 presents some information on home-to-work travel in relation to total annual VMT [30].* It shows that typical "commuter" travel--home-to-work, Monday through Friday, during the hours 6-9, 15-18--account for only 14% of all vehicle miles of travel, compared with 23 percent for all home-to-work trips. However, it appears unlikely that an appreciable reduction in home-to-work travel on weekends and during weeknights is possible, except by drastically changing work patterns. Measures to reduce home-to-work trips by improving public transportation and increasing car pooling are most likely to be applied during the 6-9 and 15-18 hour periods, Mondays through Fridays. Therefore, we interpret a reduction in commuter travel to apply only to the 14 percent of all VMT. Thus, a 10 percent, 20 percent or 30 percent would result in a 1.4

TABLE 7-2

Home-to-work travel in relation to total annual vehicle miles of travel (1969-70)

All home-to-work travel	23%
Home-to-work travel, Monday-Friday	21%
Home-to-work travel, Monday-Friday, 6-18 hours	17%
Home-to-work travel, Monday-Friday, 6-9, 15-18 hours	14%

*Derived from information in Reference 30.

percent, 2.8 percent and 4.2 percent reduction of total VMT. Considering that fatalities per VMT are less during the day than at night, and that commuter travel often occurs on congested roads at lower speeds than at other times of the day, one can expect much lower changes in the number of traffic deaths.

In Figure 7-5 the distribution of VMT and of fatal accidents over the hours 6-18, Mondays through Fridays, are shown. They are not strictly comparable, because the fatal accidents are statewide figures, whereas the VMT's are based mainly on samples from metropolitan areas; only very little information on hourly traffic volumes in rural areas is published.* The general pattern, however, was similar for the metropolitan and the other areas in the sample.

The obvious difference between the distribution of VMT and fatal accidents is that the peaks of VMT in the morning and afternoon, corresponding to commuter traffic, are approximately equal, whereas hourly fatal accidents during the afternoon commuting hours are about twice as high as during the morning commuter hours.

To explore the relation between VMT and fatal accidents during the day, in Figure 7-6 fatal accidents per hour--in percent of the daily total--are plotted versus VMT per hour--also in percent of the daily total corresponds to a change in fatal accidents of 2/3 percent of the daily total. One, however, has to be careful to interpret this as a relation between fatal accidents and VMT only: for the points on the line, the hour of the day is correlated with VMT and may also influence the frequency of fatal accidents.

The obvious deviation from this pattern are the hours 7-8 and 8-9: they have nearly as many VMT as the afternoon hours, but only half as many fatal accidents. This corresponds to the comparison between Figure 7-5a and b made above. Comparing only the morning hours 6-9, one would conclude that a change in VMT has essentially no influence on the number of fatal accidents.

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*The Federal Highway Administration has hourly traffic-volume information collected by several states in the form of data tapes. No summaries, however, exist.

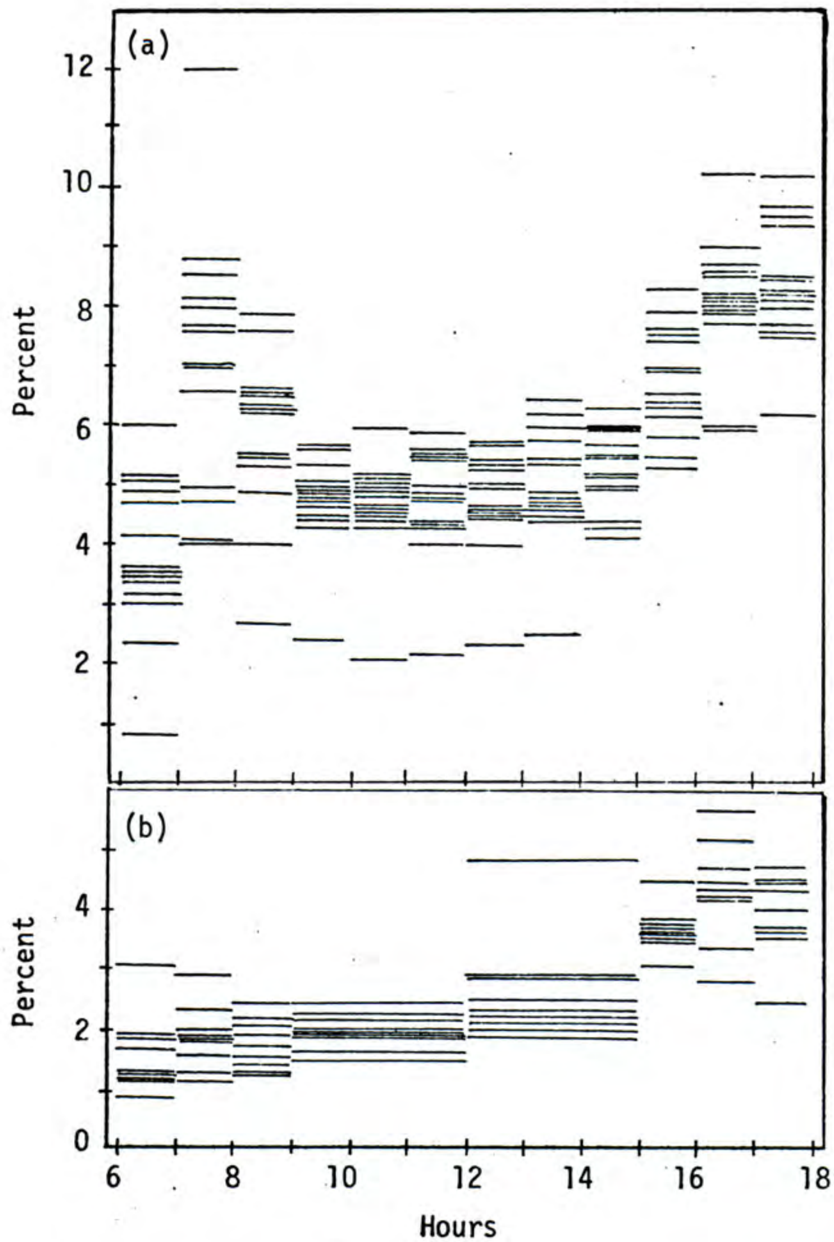

Figure 7-5. Daily pattern of travel and fatal accidents (Monday through Friday). Each line indicates the hourly percentage of the daily total from one source.
(a) Distribution of vehicle miles of travel (14 locations).
(b) Distribution of fatal accidents (9 states).
Sources for (a) are listed in Appendix G. Sources for (b) are accident summaries for the states of California, Illinois, Missouri, New York, Pennsylvania, Texas, Virginia, Washington, Wyoming.

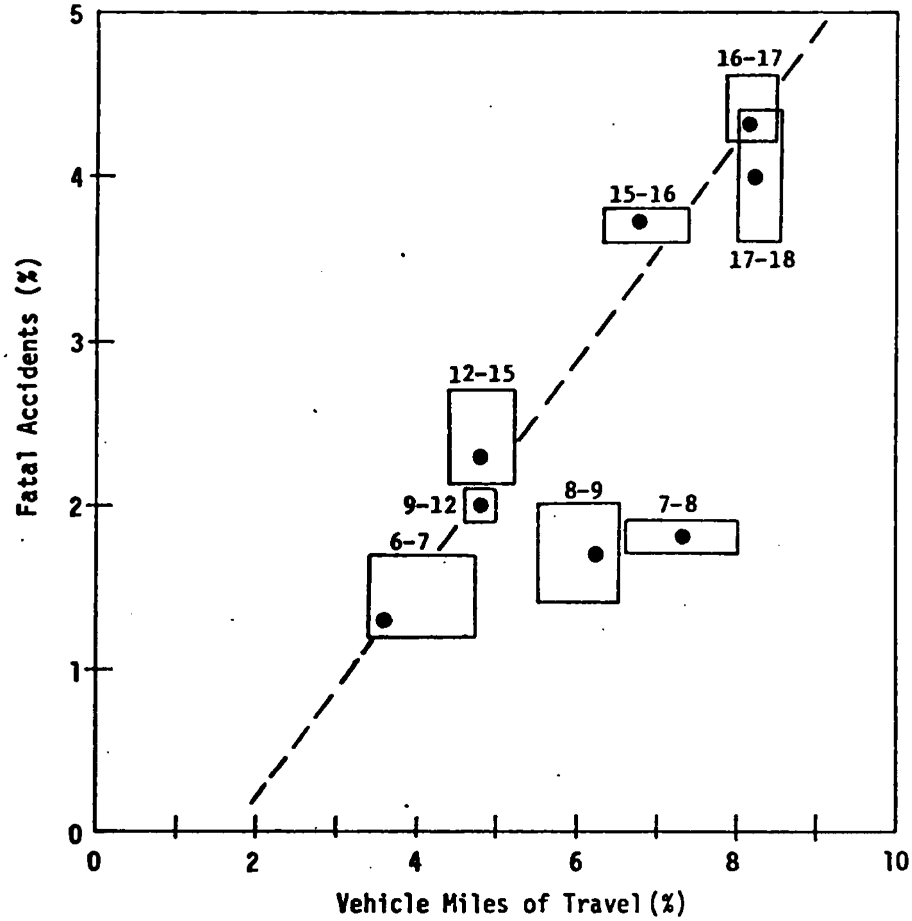

Figure 7-6. Hourly fatal accidents versus hourly VMT, both as percent of the daily total, Monday through Friday, based on Figure 7-5 (a) and (b). The dots are the median values, the "boxes" represent approximately the middle tertile of the values in Figure 7-5 (a) and (b). The broken line is hand-drawn to fit the points except those for 7-8 and 8-9 hours.

Figure 7-6 suggests the following argument: a change in commuter travel during the afternoon hours will reduce fatal accidents by 2/3 percent for each 1 percent of daily VMT eliminated, but the corresponding change during the morning hours will have no influence on fatal traffic accidents. Table 7-3 shows commuter VMT as percent of all hourly VMT [30, 31].* Combining this with the assumed reductions of commuter travel by 10 percent, 20 percent and 30 percent we obtain the estimates for reductions of fatal accidents shown in Table 7-4.

The estimated reductions in fatal accidents are very small, much smaller than the corresponding reductions in VMT, which is not surprising, as discussed above. Even if we would assume a reduction in fatal accidents during the morning rush hours too, contrary to the suggestion of Figure 7-6, the reduction in fatal accidents achieved by a reduction in commuter travel as drastic as 30 percent would be less than 2 percent.

TABLE 7-3

Commuter VMT as percent of total hourly VMT

Hour	6		7		8		9		12		15		16		17		18
% Commuter Travel		67		63		37		12		15		14		35		40	

TABLE 7-4

Reduction (%) of VMT and estimated reduction (%) in fatal accidents resulting from a reduction in commuter travel

	Reduction in Commuter Travel		
	10%	20%	30%
Reduction VMT	1.4	2.8	4.2
Reduction of Fatal Accidents	0.3	0.6	0.9

*Derived from References 30 and 31.

These results have to be used with great caution, because of the great diversity and possible incomparability of the data sources, and the speculative interpretation of Figure 7-6 as a function VMT-fatal accident relation. However, the overall conclusion that the effects of even drastic reduction of computer travel upon fatal accidents are very small, if not negligible, appears defensible.

7.3 ELIMINATION OF SUNDAY TRAVEL

One of the scenarios considered the elimination of all Sunday travel. A critical question is what is meant by "elimination." If there were no travel on Sundays and none of the trips previously made on Sundays were not made on another day, then the 21 percent of all traffic deaths which occur on Sundays or holidays (assuming that a ban on Sunday driving would also hold for holidays) would be eliminated. However, a look at the trip purposes as shown in Table 7-5 suggests that some Sunday travel, such as to and from work, could not be completely eliminated, and that many trips could, and would possibly be made on another day if they could not be made on a Sunday. The question reduces essentially to one of "demand elasticity" for certain trips. The ques-

TABLE 7-5

Data on traffic fatalities and personal travel on Sundays [32]*

Fatalities on Sundays and Holidays:	21% of Weekly Total
Personal Travel on Sunday:	14% of Weekly Total
To and from work:	7% of Sunday Total
Shopping:	4%
Other family business:	8%
Educational, civic and religious:	9%
Visiting friends and relatives:	29%
Pleasure driving:	9%
Vacations:	4%
Other societal and recreational:	26%
Other:	4%

*Derived from Reference 32.

tion of which trips would not be made, and which would be made on another day, if Sunday travel were prohibited, could be answered only, if at all, by a carefully designed household survey. But even if this were done, it is beyond the current state-of-the-art to predict what the fatal accidents would be, if the shifted VMT would be traveled at other days and times, changing the traffic density at these times, as discussed in Section 6 and Subsection 7.2.

We conclude that no reasonable estimate of the effects of a ban on Sunday travel can be made.

7.4 SUMMARY

The reduction of traffic deaths in 1975 due to the 55 mph speed limit might have been "up to" 7 to 12 percent, at the very most 18 percent. It was most likely less, possibly as low as 3 percent. If the 55 mph limit had been strictly enforced, a reduction of 10 percent to 20 percent, possibly as high as 24 percent, would have been achieved.

No predictions of future development appear possible.

A reduction of typical commuter travel by as much as 30 percent might reduce traffic deaths by about 1 percent.

No prediction can be made as to how a ban on Sunday travel would change traffic deaths.

8. INTERACTIONS

There exist potential interactions between the effects of the factors discussed in Sections 5 and 7. The most obvious ones are between:

1. speed and vehicle size;
2. speed and time of week; and
3. vehicle size and time of week.

The first interaction, suggested by the arguments in Appendix C, would be that the differences in injury and fatality risk between large and small cars would decrease with decreasing speed. Thus, the effects of an increasing number of small cars would be less under the 55 mph limit than it would be otherwise. However, the analysis in Paragraph 4.3.6 does not provide empirical evidence for the suspected interaction.

The second interaction is suggested by Figure 8-1: relatively more automobile occupants are killed on week days at speeds below 55 mph than on week nights or weekends. Therefore, the 55 mph speed limit will have less impact on weekday deaths than on weeknight and weekend deaths. Thus, any effect of a reduction in commuter travel would, to a large extent, be in addition to that due to the speed limit. On the other hand, the 55 mph speed limit and elimination of Sunday travel combined would save a smaller number of deaths than the sum of the effects of the two measures taken separately. Considering the uncertainty of the effects of both a reduction in commuter travel and an elimination of Sunday travel, it would not be meaningful to estimate the effect of the interactions.

The third interaction, between vehicle size and time of week, is suggested by Table 8-1: there are considerably more car-truck collisions on weekdays, in which small cars fare much worse than large cars, than on weeknights and weekends. However, this is not necessarily true for the hours of commuter traffic. Therefore, one cannot conclude that a reduction of commuter travel would, on the average, improve the position of small cars relative to that of large cars. On the other hand, elimination of Sunday travel with a low proportion

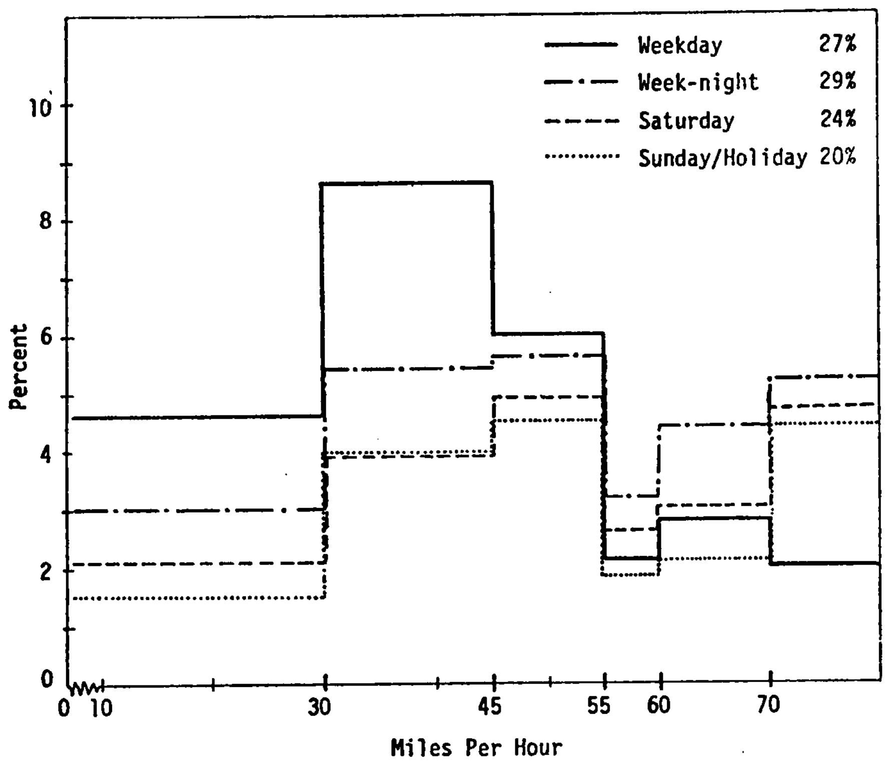

Figure 8-1. Distribution of automobile occupant deaths by time of week and travel speed before the accident. Derived from original accident data tape from Virginia, 1971 and 1972.

TABLE 8-1

Distribution (%) of persons killed in motor vehicle accidents by time of week and type of accident. Derived from original accident data tapes. The figures are for Texas, Virginia and Washington States.

Type of Accident	Weekday			Weeknight			Saturday			Sunday/Holiday		
Single car	8	10	12	13	16	15	9	12	9	12	11	10
Two-car	6	5	4	6	5	4	6	6	4	7	5	4
Multi-car	0.3	0.8	0.8	0.4	1	1	0.2	0.6	1	0.7	0.6	1
Car/truck	7	6	8	4	3	3	3	2	3	2	2	1
Other	5	6	5	5	4	5	3	3	4	3	2	2
Total	26	27	31	28	29	30	21	24	21	24	20	18

NOTE: Totals were derived from actual figures, not the rounded numbers which appear in the table.

of car-truck collisions would worsen the position of small cars relative to that of large cars. Again, considering the uncertainties, an attempt to estimate these interactions would not be meaningful.

9. CONCLUSIONS

The overall structure of the relationship between automobile occupant death or injury frequency, once a crash has occurred, and the weight(s) of the car(s) involved, by type of crash, has been well established. The relations have also been grossly quantified. There remain, however, considerable differences between the quantitative results obtained from different data bases. These differences may be partly due to differences in crash factors which were not accounted for; they are probably also to some extent due to differing definitions of what constitutes an "accident" and is recorded as such. To reconcile such differences and arrive at quantitatively more reliable, nationally representative relations would be desirable. However, it does not appear worthwhile, under practical aspects, to improve our knowledge of the relation between injury frequency and car size (or weight) very much, using only a one-dimensional classification of cars by weight or size class, which are correlated in the present automobile population. It would be more important to attempt to separate the effects of size (a protective property) and weight (a primary hostile property) on the occupant injury risk in the car considered, and another car. Such a relation would allow the study of more varied future developments, e.g., what would happen if small cars would become heavier, due to added optional equipment, or if large cars would become lighter, due to a reduction in optional equipment. Also, it would allow exploration of a wider range of policy options, considering both energy and accident consequences of changing automobile populations.

A disappointing conclusion is that, despite a wealth of engineering studies and crash tests, very little is known on how certain feasible automobile improvements would change the injury or fatality risk in a crash.

Due to these limitations on the basic knowledge, the projections of changes in fatality risk which we made, though of reasonable quantitative reliability, are fairly narrow in conceptual terms, assuming that cars remain essentially unchanged except for the possible introduction of air bags.

The relations between vehicle use factors and traffic deaths or injuries are much less well known. Only on the relation between travel speed and the frequency of an accident involvement being fatal is our knowledge fairly good. However, the answers to more specific questions, such as how a car occupant fatality risk depends on his speed (and the speed of the other vehicle, if any) are not known. Our knowledge of actual travel speeds is very limited: we do not know how accurate and reliable the speed estimates are which are given in some states' accident records, and we do not know how those travel speeds which are actually measured for the Federal Highway Administration relate to the speeds of cars in accidents.

On the relation between speed and the frequency of accident involvement, only descriptive but no functional information is available.

Therefore, an estimate of the impact of the 55 mph speed limit has to be quite uncertain (at best an upper limit could be obtained). However, a fairly reliable estimate of the impact under assumption of general compliance could be made, although its practical relevance is questionable, because it is not known to what extent compliance with a 55 mph speed limit--often far below the design speed of a highway--could be enforced in the long run. To make projections of the effect of the speed limit into future years is uncertain, not only because of the uncertainty of how actual travel speeds will develop, but also because of the uncertainty of how future speeds would have developed without the speed limit.

There are many studies of the relation between accidents and traffic density. However, how the number of accidents and deaths change with vehicle miles of travel (which are related to traffic density) is not known, much less if we ask the same question for specific hours of the day and week. There is some indication that typical commuter traffic (6-9 a.m.) is a fairly "safe" traffic, suggesting that the frequency of accidents and their severity depend upon trip purpose. Nothing, however, is known on this. Therefore, how a change in the amount of automobile travel would affect the deaths can, at best, be speculated at, even more so if changes in certain kinds of travel at certain hours are specified.

An outright prohibition of certain kinds of travel, e.g., on Sunday, is likely to result in a substitution of other kinds of travel (e.g., on other weekdays). To what extent such a substitution takes place depends on the "demand elasticity" for this kind of travel, and the "cross elasticity" against other kinds of travel (e.g., on other days, for the same purpose. Even if these substitutions were known, the problem discussed above remains: what is the effect of adding travel with a certain purpose to the traffic at other hours on other days, on accidents and their severity? Since we know nothing about these two relations, the effects of prohibiting certain kinds of travel cannot be estiamted. At best, an upper and lower limit can be given.

10. RECOMMENDATIONS FOR FURTHER RESEARCH

In order to fully answer the questions addressed in this study, and similar ones, the following should be studied:

(1) Using existing accident data bases, it should be estimated how the frequency of car occupant injury depends on both car size (protective) and car weight (hostile) and weight of the other car, if any, eliminating the effects of the present correlation between car weight and size.

(2) Using existing data bases, it should be explored whether differences in injury frequency and severity between cars of different size might be less for lower speeds. If this is so, then the effects of the 55 mph speed limit on differences in the injury frequencies of small and large cars should be estimated.

(3) The engineering literature on the effects of certain vehicle improvements resulting in better occupant deceleration patterns and better compartment integrity should be reviewed. The results should be combined with an analysis of the results of the various in-depth accident investigation programs, and of mass accident data, to make estimates of the effects of the vehicle improvements in terms of reduced injury and/or fatality risk.

(4) In order to obtain a larger data base than any one state's accidents can provide, and to avoid potential biases due to (possibly unrecognized) pecularities of any one state, the existing accident records of several states should be compared, and the reasons for differences determined. Methods to make future, and, if possible, existing records comparable should be developed so that nationally representative results can be obtained from them.

(5) The relation between vehicle miles of travel and accidents and deaths (and also how it depends on other factors) should be studied. This should be done for annual totals, as well as for hourly values, and then the annual values should be related to the hourly values. We expect that with existing data only overall relations can be established. To establish detailed relations, e.g., by hour, will probably require special data collection efforts.

(6) The current knowledge on the relation between injury and fatality risk and speed should be improved. Specifically, the relation between the number of deaths or injuries and speed should be explored and

separate relations should be established for single car crashes and multi-vehicle crashes, the latter possibly being further disaggregated. In two-car collisions, the speeds of both cars should be considered. Some useful results may be obtainable from an analysis of existing data. To obtain reliable results, however, better speed information has to be developed.

(7) An approach should be structured, and the availability of data determined to study the functional relationship (as distinct from the descriptive "U-shaped" curve) between travel speed, separating types of crashes, highway types, etc., as necessary.

(8) An approach should be developed and the availability of data determined to study the relationship between actual travel speeds, speed limit, highway and environmental characteristics, enforcement and speed in accidents. Of specific interest is how speed in accidents (by severity) relates to "normal" travel speed at the same times and places.

(9) A plan should be developed for a collection of actual travel speed measurements which are more representative of the overall travel speed distributions than the speed measurements currently collected by the Federal Highway Administration.

(10) The feasibility of studying the relations between trip purpose and accidents and their severity should be determined. If considered feasible, a plan for such a study should be developed.

A P P E N D I X

A

DATA BASES

The bases for the New York State and North Carolina accident tabulations have been described in the original publication [5, 13, 10]. Washington and Texas accident data were obtained from original accident data tapes provided by the States of Washington (1972) and Texas (1971 and 1972). The Washington State tapes contained information on 150,000 accident-involved cars and 30,000 trucks, the Texas tapes on 500,000 accident-involved cars and 100,000 trucks per year. Due to the format of the data, processing of the original tapes was extremely time consuming and expensive, therefore, "compressed" tapes, containing only selected information in a format easier to process, were generated. For the analysis of the distribution of crash types and speeds by time of week, we also used Virginia data for 1971 and 1972 (which contain speed estimates, but use only very few car classifications by make, but not model) containing 450,000 accident-involved cars and 100,000 trucks.

From the compressed tapes, aggregate tables were generated as needed for the various aspects of the study. Since all deal with the relation of certain accident consequences to car size, a classification of cars by size was always used. As discussed in Subsection 4.1, "size" and weight have to be distinguished in their functions, even though they are correlated in current cars. For this study, only a gross classification into "subcompact," "compact," "intermediate," "full size" and "heavy" cars was used. Which cars were assigned to these classes is described in Appendix B. To keep processing time within acceptable limits, car model information could be checked only against a limited list of models. Therefore, about 35 percent of all cars could not be identified by class and were excluded for most analyses.

There are some obvious differences between the various data bases and results derived from them. For instance, in North Carolina, the frequency of unbelted driver fatal or serious injury is 3 percent in a collision between two full-size cars. In New York State data, it is 6 percent. For all drivers (without regard to seatbelt use) in New York accidents it is 4 percent. For all drivers in Washington and Texas they are 1.3 percent and 1 percent, respectively. These discrepancies may be due to regional differences in classifying injuries as "serious;" they might also be due to differences in the reporting of minor property damage accidents.

In all states, accidents have to be reported if a person is injured, or if property damage exceeds a certain threshold. This threshold is:

New York	\$200
North Carolina	\$100 (\$200 for more recent cases)
Texas	\$25
Virginia	\$100
Washington State	\$100

Thus, not only are number of accidents between states not comparable, but also accident numbers of the same state are not comparable between years if the cost of repairing the same damage increased.* That the reporting and classification of injuries differs between states is suggested by a comparison of the ratio of injured persons to killed persons between the states (data obtained from the annual accident summaries of the states).

TABLE A-1

Ratio of Persons Injured to Persons Killed
(except pedestrian and bicyclist)

State	Serious Injury	Any Injury
New York	16:1	78:1
N. Carolina	8:1	130:1
Texas	7:1	39:1
Virginia	30:1	47:1
Washington	8:1	82:1

*An unpublished estimate by CEM is that an increase in repair cost by 1 percent would result in an increase of the number of reportable accidents by 1/2 percent under a \$100 reporting threshold.

Part of these differences might be due to differences in accident types, but most of them are due to differences in the interpretation of definitions of severity and actual reporting. Such differences make comparison between results from different data bases difficult; to make them comparable would require very extensive analyses. The differences also show that it is not sufficient to rely on any single data base if one wants to obtain nationally applicable results.

Differences in what constitutes an injury or serious injury are so large that it appears meaningless to attempt estimating national injury figures on the basis of such data. The only consistent and nationally valid data on traffic accident injuries are those obtained by the Health Interview Survey. The data, however, give no other information on the accident, therefore, their value for further analysis is limited.

A P P E N D I X

B

AUTOMOBILE CLASSIFICATION

In Washington State and Texas accident data, cars are described by a make-model code.* In addition, Washington State recently started to use the Vehicle Identification Number (VIN). However, since for only relatively few cars in our data base the VIN was given, we did not use it despite its greater precision in identifying cars and their characteristics.

Cars were classified into "subcompact" (representative† weight 2,000 lb), "compact" (3,000 lb), "intermediates" (3,400 lb), "full size" (3,900 lb), and "heavy" (4,700 lb) according to the lists given in Tables B-1 and B-2. This assignment to the classes was primarily made on the basis of the weight, but considering also size or popular perception of a car as a compact, etc. Sometimes an assignment could not be made unambiguously; sometimes a misclassification (such as Chrysler Imperial as a "full size," not "heavy" car) was accepted, if it simplified data processing.

The car identification code in the accident records was checked against the makes and models in the tables, in approximate order of decreasing frequency of the models. To limit data processing time, the number of makes and models included in the tables had to be limited. Those models not included and those without make-model identification were coded as "others." About 35 percent of all cars were classified as "others" and not used in most analyses.

A special problem with the Texas data was that "Volkswagen" could not be unambiguously disaggregated by model and, therefore, had to be omitted. This severely reduced the number of subcompacts in the Texas accident data used.

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*In the New York State and North Carolina data, no problem of car classification arose, because cars were already grouped or identified by weight.

†These weights are representative for cars of the late 1960's, on which most of the analysis is based. Current models are usually heavier.

TABLE B-1

Classification of Car Models in
The Washington State Accident File

Make	Model
Subcompact	
Chevrolet	Vega
Ford	Pinto
American	Gremlin
Volkswagen	113
Volkswagen	120
Volkswagen	130
Volkswagen	150
Datsun	
Opel	KAD
Toyota	Corolla
Toyota	Corona
Compact	
Chevrolet	Nova
Plymouth	Valiant
Chevrolet	Chevy 2
Pontiac	Tempest
Dodge	Dart
Dodge	Swinger
Ford	Maverick
Ford	Falcon
Ford	Mustang
American	Hornet
Chevrolet	Camaro
Pontiac	Ventura
Mercury	Comet
American	Javelin
American	Marlin
American	AMX
Pontiac	Firebird
Intermediate	
Oldsmobile	Cutlass
Oldsmobile	F85
Ford	Torino
Ford	Fairlane
Chevrolet	Chevelle
Chevrolet	Malibu
Chevrolet	MOC
Pontiac	LeMans
Pontiac	GTO
Dodge	Coronet
Mercury	Montego
Plymouth	Satellite
Plymouth	SAV
Mercury	Cougar
American	Matador
American	Rebel
Dodge	CHL
Full-Size	
Chevrolet	Impala
Chevrolet	BelAir
Chevrolet	BIS
Chevrolet	CAP
Ford	Galaxie
Ford	LTD
Ford	XL
Buick	Electra
Buick	LeSabre
Buick	INV
Oldsmobile	88
Oldsmobile	DLT
Oldsmobile	DLM
Oldsmobile	Dynamic
Oldsmobile	98
Pontiac	BON
Pontiac	Grand Prix
Pontiac	CAT
Buick	Skylark
Buick	CEN
Plymouth	Fury
Plymouth	BEL
Dodge	Polara
Dodge	Monaco
Chrysler	300
Chrysler	Imp
Chrysler	NEW
Chrysler	TOW
Pontiac	GRA
Mercury	Montclair
Mercury	Monterey
Mercury	Marquis
American	Ambassador
Heavy	
Cadillac	CAL
Cadillac	DEV
Cadillac	ELD
Cadillac	FLE
Lincoln	CON
Lincoln	CUS
Lincoln	MK3
Lincoln	MK5
Ford	Thunderbird
Oldsmobile	TOR

TABLE B-2

Classification of Car Models in
The Texas State Accident File

Make	Model
Subcompact	
Datsun	
Opel	Kadette
Toyota	Corona
Compact	
Chevrolet	Nova
Plymouth	Valiant
Chevrolet	Chevy-II
Chevrolet	Camaro
Dodge	Dart
Ford	Maverick
Ford	Falcon
Ford	Mustang
Plymouth	Duster
Mercury	Comet
Rambler	AMX
Rambler	Javelin
Intermediate	
Oldsmobile	F-85
Oldsmobile	Cutlass
Ford	Torino
Ford	Fairlane
Chevrolet	Chevelle
Buick	Skylark
Pontiac	LeMans
Pontiac	GTO
Pontiac	Tempest
Dodge	Coronet
Mercury	Montego
Pontiac	Firebird
Mercury	Cougar
Dodge	Charger
Full-Size	
Chevrolet	Impala
Chevrolet	BelAir
Chevrolet	Biscayne
Chevrolet	Caprice
Ford	Galaxie
Ford	LTD
Buick	Electra
Buick	LeSabre
Oldsmobile	Delta 88
Oldsmobile	Delmont 88
Pldsmobile	98
Pontiac	Bonneville
Pontiac	Catalina
Pontiac	Executive
Plymouth	Fury
Plymouth	Belvedere
Dodge	Polara
Dodge	Monaco
Chrysler	Imperial
Chrysler	Newport
Chrysler	New Yorker
Chrysler	Saratoga
Chrysler	400
Chrysler	Windsor
Pontiac	Grand Prix
Mercury	Marquis
Mercury	Montclair
Mercury	Monterey
Mercury	Parklane
Rambler	Ambassador
Heavy	
Buick	Riviera
Cadillac	Calais
Cadillac	DeVille
Cadillac	Fleetwood
Lincoln	Continental
Ford	Thunderbird
Oldsmobile	Toronado

The scenarios given by TSC used a classification into "subcompact, and compact," "intermediate," "standard," and luxury." These classes are described in Table B-3. Since this classification considers not only size and weight, but also price, we could not use it for the injury risk model which uses car weight explicitly. Table B-4 shows how we translated market shares of the TSC car classes into those of CEM car classes, based on a detailed analysis of market shares model by model.

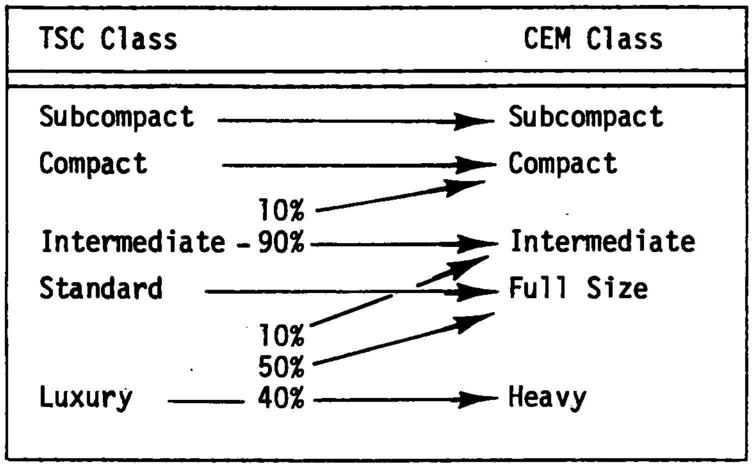
TABLE B-3

Auto Size-Price Classification Used by TSC

Compact and Subcompact				
Austin	Datsun	Maverick	Renault	Vega
Colt	Fiat	Nova	Simca	Ventura
Comet	Gremlin	NSU Prince	Subaru	Volkswagen
Cricket	Honda	Opel	Toyota	
Dart	Hornet	Pinto	Valiant	
Intermediate				
Barracuda	Chevelle	Javelin	Montego	Skylark
Camaro	Coronet	LeMans	Mustang	Torino
Capri	Cougar	Matador	Opel	Truimph
Challenger	Cutlass	Mazda	Saab	
Charger	Firebird	MG	Satellite	
Full-Size				
Ambassador	Catalina	Fury III	Monte Carlo	Newport Royal
Audi	Delta 88	Galaxie 500	Monterey	Polara
Bel Air	Ford Custom 500	Impala	Monterey Custom	Rover
Biscayne		LeSabre		Sport Fury
Bonneville	Fury I	LTD	Newport Custom	Tempest
Caprice	Fury II	Monaco		Volvo
High Price Full-Size Speciality				
				Peugeot
BMW	Electra 225	Grand Prix	New Yorker	Porsche
Centurion	GrandVille	Marquis	Olds 98	Rover
Luxury				
Alpha Romeo	Corvette	Imperial LeBaron	Mark IV	Riviera
Aston Martin	DeVille		Mercedes	Rolls Royce
Bentley	ElDorado	Jaguar	Panterra	Thunderbird
Calais	Ferrari	Jensen	New Yorker Brougham	Toronado
Citroen	Fleetwood	Lotus		

TABLE B-4

Translating Market Shares of TSC Automobile Classes Into Those of CEM Automobile Classes



APPENDIX

C

THE DIFFERENCE BETWEEN OCCUPANT INJURY RISK IN LARGE AND SMALL CARS IN RELATION TO SPEED

Assume two cars of masses m_1 and m_2 moving with velocities v_1 and v_2* and colliding. Assuming an inelastic collision--which appears to be an acceptable first approximation--they will move together after the collision with a velocity v, where

$$v = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2} \quad . \tag{C-1}$$

The changes in velocity $\Delta_1 = v_1 - v$ and $\Delta_2 = v_2 - v$ determine the deceleration suffered by the occupants of the cars. From (C-1) one obtains

$$\Delta_1 = \frac{(v_1 - v_2)\, m_2}{m_1 + m_2} \tag{C-2}$$

and

$$\Delta_2 = \frac{(v_2 - v_1)\, m_1}{m_1 + m_2} \quad . \tag{C-3}$$

If the collision would occur at speeds lower by a factor f, this would be equivalent for occupants of car 1 to colliding with a car of mass $m_2' < m_2$ at the original speeds. Similarly, for occupants of car 2, it is equivalent to colliding with a car of mass $m_1' < m_1$ at the original speeds. m_1' and m_2' can be obtained from

$$\frac{f\, m_i}{(m_1 + m_2)} = \frac{m_j'}{(m_j + m_i)} \ , \tag{C-4}$$

giving

$$m_i' = m_i \Bigg/ \left(1 + \frac{1 - f}{f} \cdot \frac{m_1 + m_2}{m_j}\right) . \tag{C-5}$$

If a change of speed by a factor f is for occupants of car i, equivalent to changing the mass m_j of the other car to m_j' at unchanged speeds, then according to the formula in Table 4-8 the fatality risk will be changed by the speed change by a factor of $1.02^{m_j' - m_j}$. The ratio of the fatality risks for occupants of car 1 and for occupants of car 2 will

*Including the sign indicating the direction.

be changed by

$$1.02^{m_1'-m_1-m_2'+m_2} \quad . \tag{C-6}$$

Table C-1 illustrates this for a few numerical examples.

TABLE C-1

Change of the Ratio of Fatality Risks for Occupants of 3000 and 4000 lb. cars, and of occupants of 2000 and 4000 lb. cars due to speed reduction

Cars (lb)	Speed Reduction			
	0%	5%	10%	20%
2000 versus 4000	1	.93	.88	.81
3000 versus 4000	1	.96	.94	.90

They show that the difference in fatality risk for cars of different size decreases with decreasing speed. This conclusion should, of course, be used only with great caution, because the model used is, at best, a very crude approximation of reality.

A P P E N D I X

D

TRAFFIC DEATHS IN RELATION TO VEHICLE MILES OF TRAVEL

D.1 THE RELATION BETWEEN FATAL ACCIDENTS AND VEHICLE MILES OF TRAVEL ON RURAL HIGHWAYS

In a previous study [17] CEM has shown that the number of fatal accidents changes with vehicle miles of travel in a more complicated manner than proportional. We studied this relation between fatal accidents and VMT in greater depth, using data on accidents, highway characteristics and average daily traffic volume on rural highways in Connecticut, Florida and Ohio, collected by Kihlberg and Tharp [33].

Figures D-1 through D-3 show how the annual number of fatal accidents on 0.3 mile segments of rural highways depends on average daily traffic volume (ADT). Since all segments have the same length, ADT is proportional to vehicle miles of travel (VMT) on each segment. The figures also show the percentage of VMT traveled on segments of different traffic densities by highway type.

These figures suggest strongly that the number of fatal accidents depends upon the number of vehicle miles of travel differently for different types of highways. Therefore, how a certain change in the total VMT affects the number of fatal accidents, depends critically upon which highway segment (both in terms of highway type and traffic density) such a change occurs.

Calculations under three alternative assumptions were made to study this further:

- a percentage change in VMT will occur on all highway segments uniformly;
- a percentage change in VMT will affect only the highway segments with lowest traffic density (separately for each highway category);
- a percentage change in VMT will affect only the highway segments with highest traffic density (separately for each highway category).

For each highway type and state, a smooth curve was drawn to represent the relation between fatal accidents and ADT. These curves are sometimes quite uncertain because of the great scatter of certain data points.

An "across-the-board" change in VMT reduces the ADT on each segment, thereby shifting it on the curves and changing the distribution

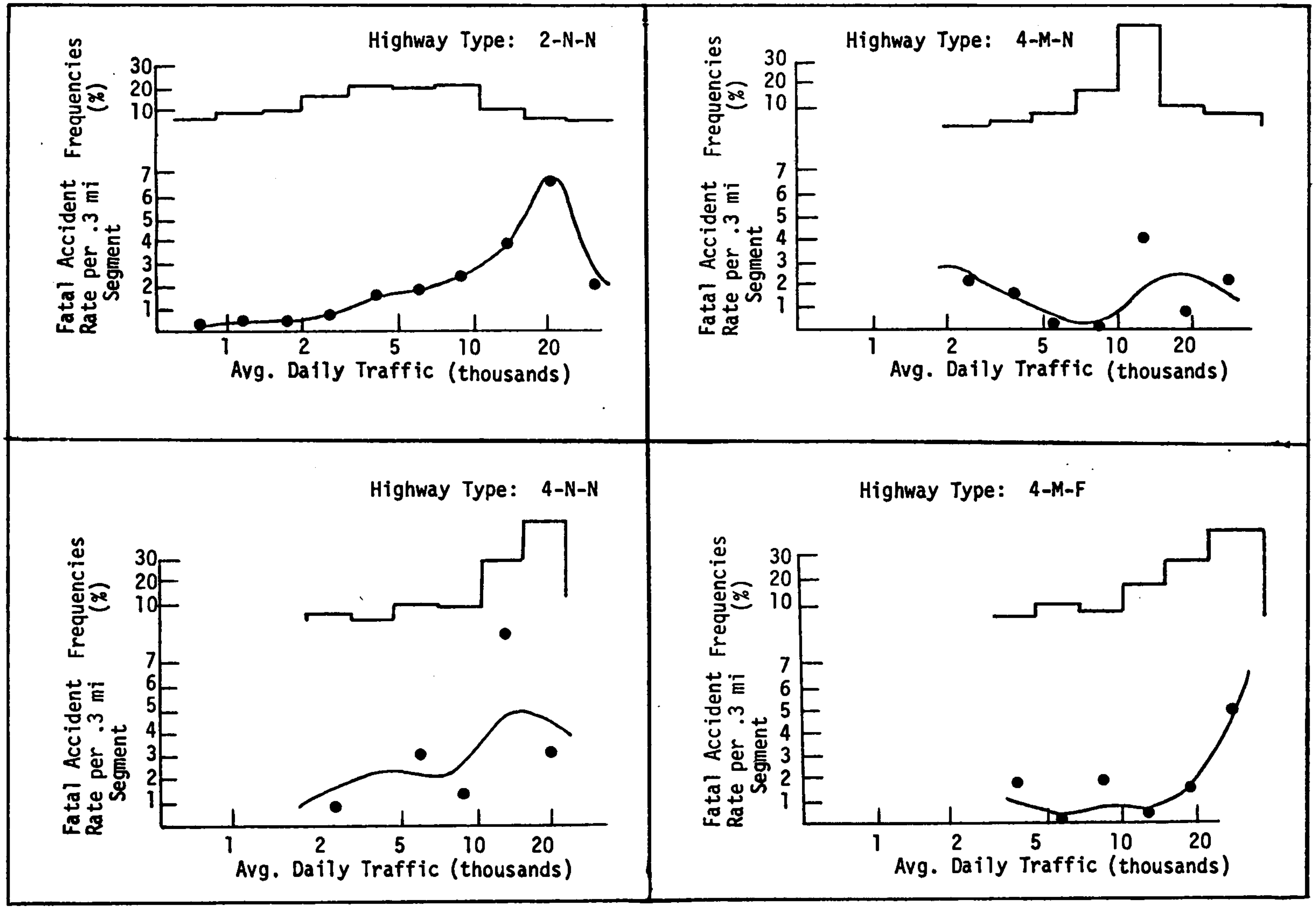


Figure D-1. Fatal accident rate and distribution of vehicle miles traveled by average daily traffic segments of highway type: Connecticut rural highways.

2-N-N = 2-lane, no median divider, no access control
4-N-N = 4-lane, no median divider, no access control.
4-M-N = 4-lane, median divider, no access control.
4-M-F = 4-lane, median divider, full access control.

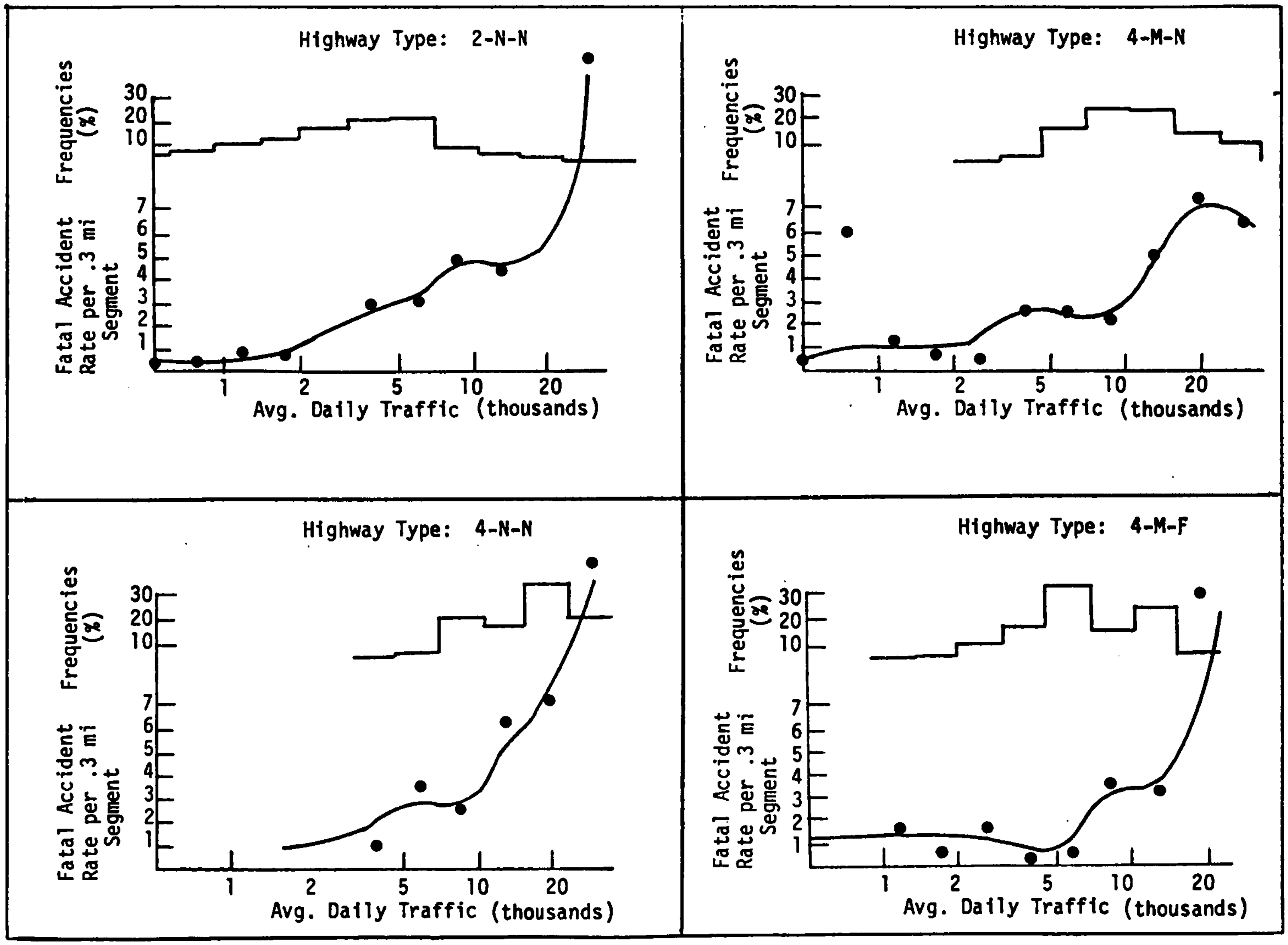


Figure D-2. Fatal accident rate and distribution of vehicle miles traveled by average daily traffic segments by highway type: Florida rural highways.

2-N-N = 2-lane, no median divider, no access control.
4-N-N = 4-lane, no median divider, no access control.
4-M-N = 4-lane, median divider, no access control.
4-M-F = 4-lane, median divider, full access control.

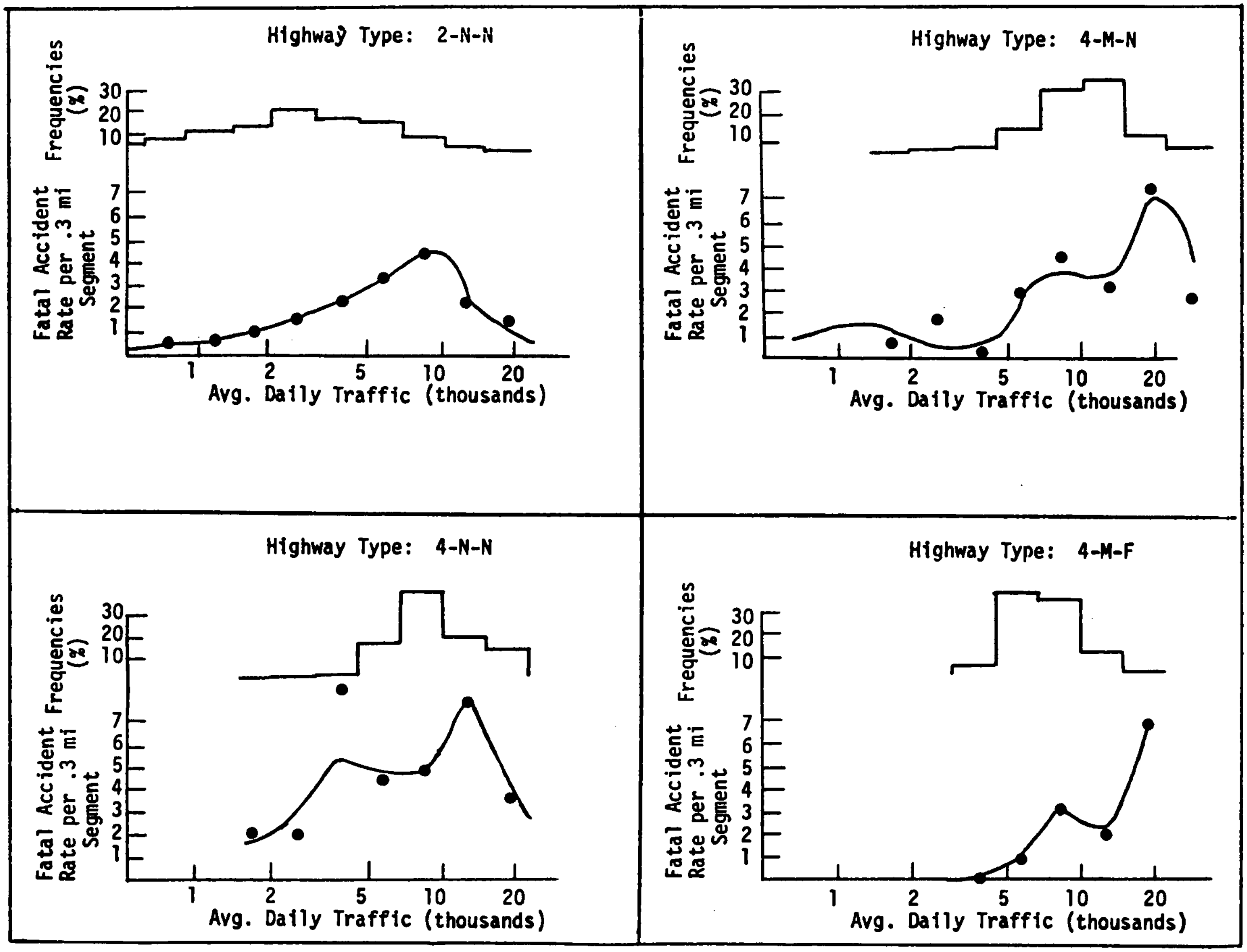


Figure D-3. Fatal accident rate and distribution of vehicle miles traveled by average daily traffic segments by highway type: Ohio rural highways.

2-N-N = 2-lane, no median divider, no access control.
4-N-N = 4-lane, no median divider, no access control.
4-M-N = 4-lane, median divider, no access control.
4-M-F = 4-lane, median divider, full access control.

of VMT. Using this distribution of VMT over the segments, the resulting number of fatal accidents was calculated. In the case of changes only at the lower or upper end of the ADT range, the procedure was slightly different: completely eliminating the highest and lowest, 5 percent or 10 percent of VMT, and calculating the remaining fatal accidents.

The results are shown in Figure D-4. They show that the change of fatal accidents with VMT depends strongly on the highway type, and the traffic density on the segments when the change occurs.* Aggregating over highway types (and/or states) tends to reduce the variation and bring the changes closer to proportionality. From this, however, one should not conclude that in reality an aggregation over the entire U.S. would even closely approximate proportionality. Some systematic differences between the states suggest that there are other factors which have to be explored before the results can be generalized. We also suspect that our results are influenced by the simple approximation of the data points by hand-drawn curves.

D.2 A CROSS-SECTIONAL ANALYSIS OF THE RELATION BETWEEN TRAFFIC DEATHS AND VMT

The objective of this analysis was to establish a relation between traffic deaths and vehicle miles of travel (VMT) by a cross-sectional analysis of the states of the U.S.

To eliminate the influence of the different sizes of states, death rates per highway mile were used as dependent variables. Death rates per highway mile, as distinct from those per VMT, have the advantage that they are a pure scaling factor: all other factors--vehicle mix, traffic density, speed, etc.--being equal, the number of deaths will be the same on each mile of highway. Since traffic density is known as an important variable influencing traffic accidents, we use VMT per highway mile (HM) which measures average traffic density in a state as an independent variable. The common denominator of highway miles in

*There are also considerable differences among the changes for the three states.

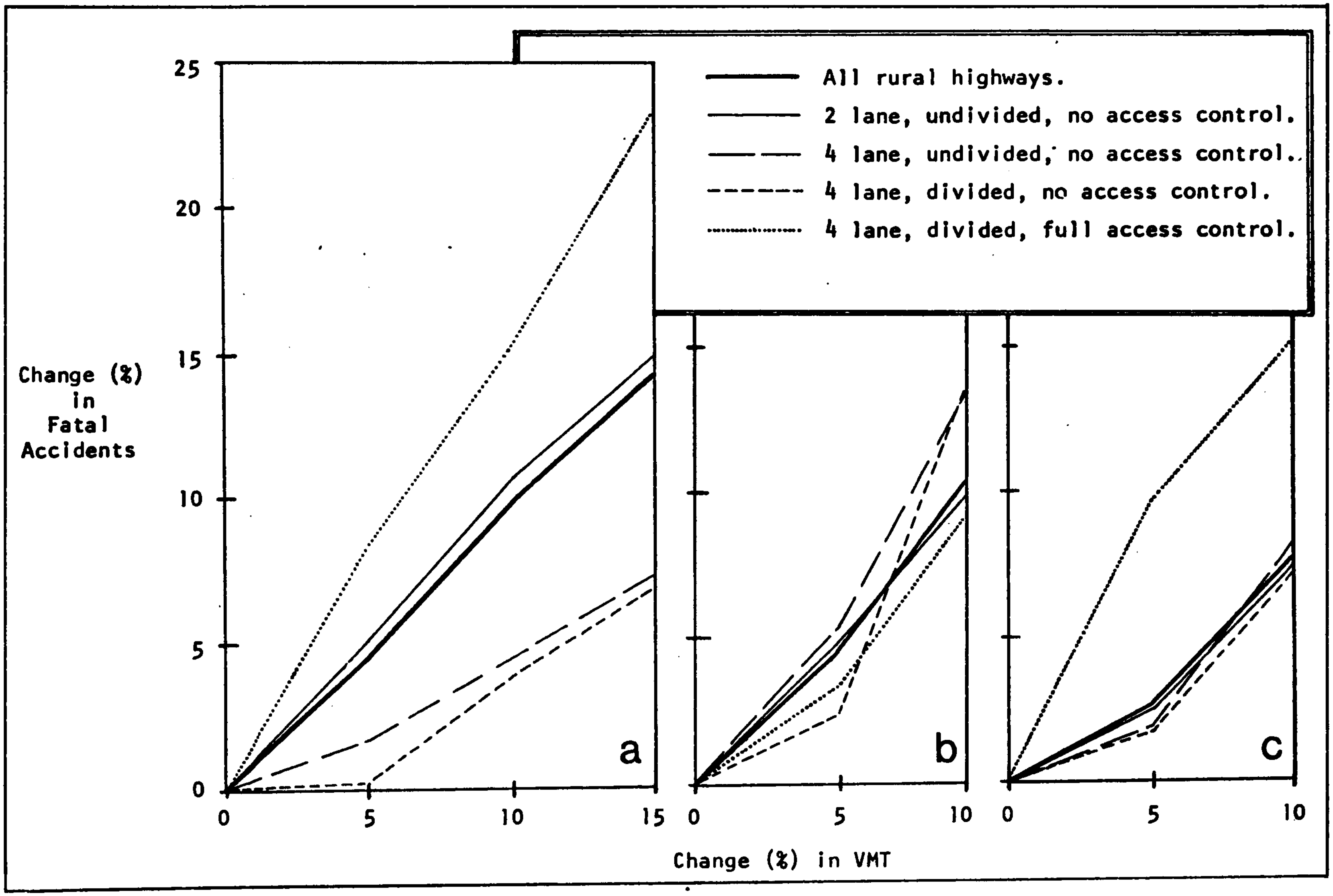


Figure D-4. Change in fatal accidents on rural highways in Connecticut, Florida, and Ohio, resulting from a change (reduction) in vehicle miles of travel (VMT), by type of highway. In (a), the change occurs uniformly on all highway segments; in (b), only on the segments with lowest traffic densities; and in (c), only on segments with the highest traffic densities.

both the dependent and the independent variable could cause a spurious relation, or distort a real one. In this case, however, since both ratios are physically meaningful, this is unlikely. Also, the results do not suggest that the relation may be spurious.

In Figure D-5, deaths/HM are plotted versus VMT/HM for the states (for 1972). The points suggest a generally close, definitely nonlinear, relationship. It is represented by the solid curve which is hand-drawn through the points. The corresponding curve for the 1969 data is shown as a broken line. The difference between the 1969 and 1972 curves is due to the influence of factors other than VMT, such as vehicle improvements, highway improvements, and possibly others (speed which could be a major factor, changed only insignificantly from 1969 to 1972).

To explore the consequences of the relations expressed by these curves, the following calculations were made. For each state the number of deaths expected on the basis of these curves was calculated from the actual VMT. Then, changes in VMT of 5 percent, 10 percent and 15 percent were assumed and the corresponding number of deaths calculated. In Figure D-6, the resulting changes of total deaths are plotted versus the changes in VMT. It shows that a change in deaths is less than proportional to the change in VMT, and that the changes differ considerably between 1969 and 1972.

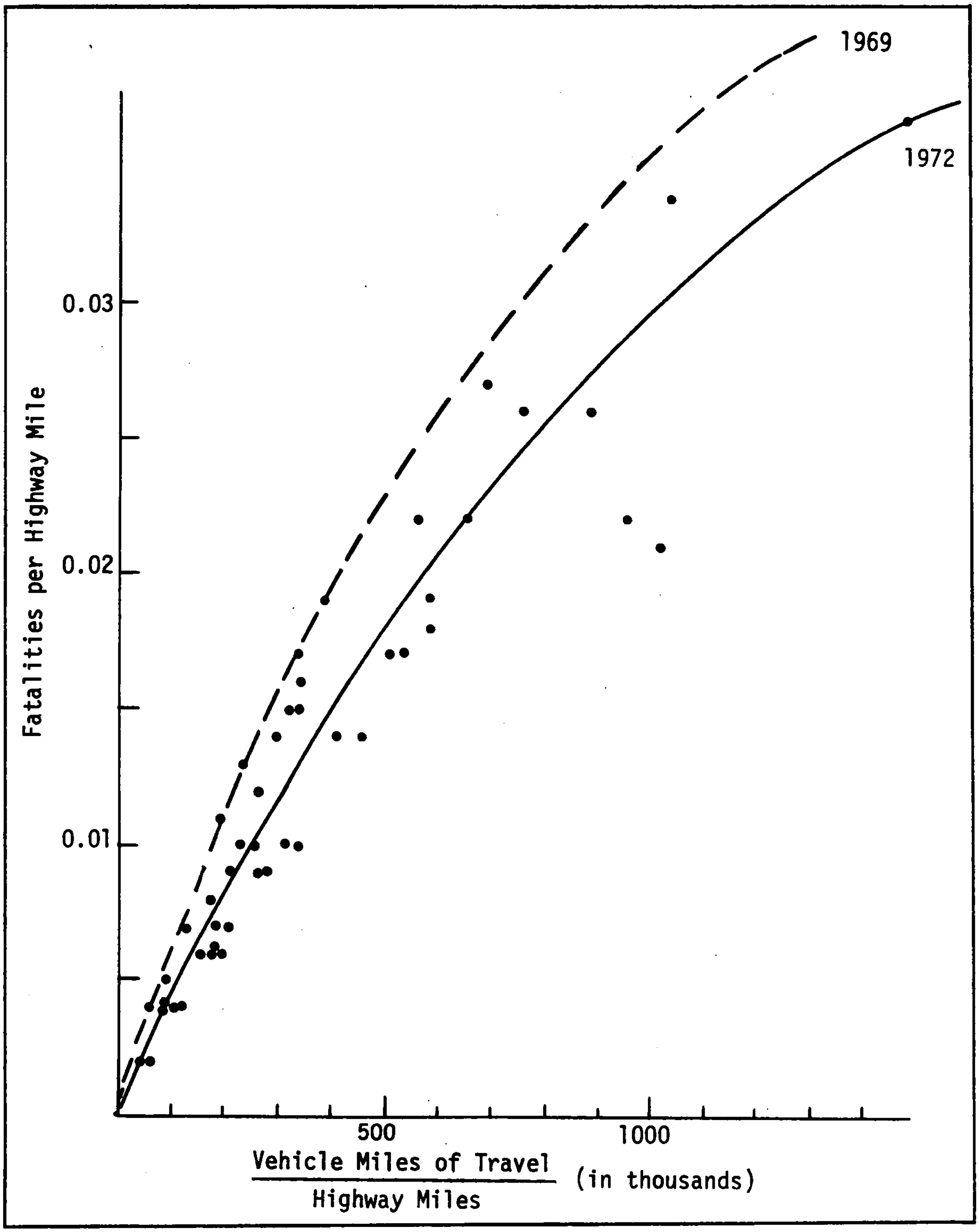


Figure D-5. Fatalities per highway mile in relation to VMT per highway mile, by state, 1972. The solid line is hand-drawn through the points. The broken line is from a similar graph for 1969 data.

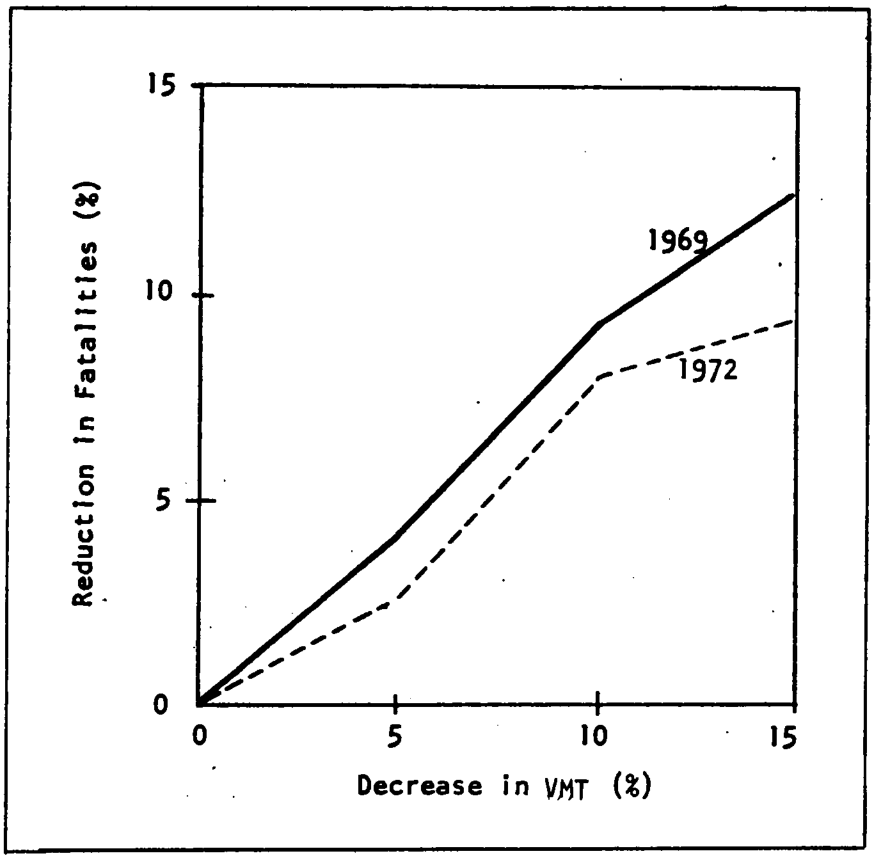


Figure D-6. Nationwide change in traffic deaths resulting from a uniform change in VMT in all states, estimated on the basis of the relation shown in Fig. D-6, for 1969 and 1972.

A P P E N D I X

E

THE CEM ACCIDENT MODEL

The following is a summary description of an accident model developed by CEM [17]. It has two major components:

1) an accident severity model describing how the frequency of automobile occupant injury or death change with certain changes in the automobile population; and
2) an accident trend model describing how the number of automobile occupant deaths would have changed over time had there been no changes in the automobile population.

Both can be combined to calculate changes in automobile occupant deaths resulting from changes in the automobile population and the trend.

E.1 THE ACCIDENT SEVERITY MODEL

E.1.1 Single-Car Crashes

The model uses the following parameters:

- r_{ij} the number of cars of model year j registered in calendar year i.
- W_{jk} the fraction of cars of model year j in weight class k. It is assumed that cars of different weight classes "survive" over time in the same manner.
- a'_{i-j} the relative (to cars of the current model year) frequency of occupant injury in single-car crashes per registered automobile per year, for cars of age i-j. Empirical values are given in Table E-1.

TABLE E-1

Relative (to cars of current model year) frequency of automobile occupant death or serious injury in single-car crashes per registered car per year.

	Car age (years)						
	0	1	2	3	4	5-10	over 10
Frequency of death or serious injury	1.00	0.79	0.68	0.66	0.65	0.75	0.70

- w'_k the relative (to an arbitrary basis) frequency of injury for occupants of cars of weight class k. It is assumed that these relative frequencies are model year independent.

- ρ'_j a factor describing the frequency of occupant injury in cars of model year j relative to that for a base year. It is assumed that this frequency is the same for all car weight classes for any given model year. Values derived from empirical data are given in Table E-2.

TABLE E-2

Fatality risk for car occupants in single-car crashes by car model year relative to that for 1957-1966 model year cars.

	Model year				
	1957-1966	1967	1968-1973	1974	1975 and later
Relative risk	1.00	0.95	0.75	0.54	0.75

For the scenarios assuming introduction of air bags with the 1978 model year, we used $\rho' = 0.49$ and 0.45, assuming that the air bag reduced fatal injuries by 35 percent or 41 percent, and that the effect of the air bags are in addition to those of other safety standards.

- s_{ij} the effect of seatbelt use. We assume that seatbelt use in cars of earlier than the 1964 model year is negligible, and that seatbelt use declines with vehicle age, i-j, resulting in the factor shown in Table E-3.

TABLE E-3

Overall reduction of fatal or serious injury frequency resulting from seatbelt use or actually declining with vehicle age.

	Car age (years)							
	0	1	2	3	4	5	6-9	Over 10
Risk reduction factor	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99

For the scenario assuming introduction of the air bags, $s_{ij} = 1$ for the model years equipped with air bags.

Combining the effects of all factors,

$$R_i^1 = \frac{\sum_k \left(\sum_j r_{ij} W_{jk} a'_{kj} \rho'_j s_{ij} \right) w'_k}{\sum_k \left(\sum_j r_{ij} W_{j_o k} a'_{kj} \rho^o_j s^o_{ij} \right) w'_k}, \tag{F-1}$$

in the overall injury risk for car occupants in single-car crashes in calendar year i, relative to that for a car population of the same age composition, but with the W_{jk}, ρ_j and s_{ij} for a base year 0. Thus, R_i^j expresses changes in the fatality risk due to changes in the mix of cars of different size, car improvements by model year, and the availability and use of seatbelts.

E.1.2 Car-Car Crashes

r_{ij}, W_{jk}, a''_{i-j}, ρ''_j, and s_{ij} are defined as for single car crashes, except for the numerical values of a''_{i-j} and ρ''_j which are given in Tables E-4 and E-5.

TABLE E-4

Relative (to cars of current model year) frequency of automobile occupant death or serious injury in car-car crashes per registered car per year.

	Car age (years)							
	0	1	2	3	4	5	6-9	Over 10
Frequency of death or serious injury	1.0	0.70	0.63	0.58	0.56	0.54	0.50	0.40

TABLE E-5

Fatality risk for car occupants in car-car crashes by car model year relative to that for 1957-1966 model year cars.

	Model year				
	1957-1966	1967	1968-1973	1974	1975 and later
Relative risk	1.00	0.92	0.84	0.60	0.84

For the scenarios assuming introduction of the air bag, the ρ''_j given in Table E-5 will be replaced by $\rho''_j = 0.55$ or 0.50, depending on the assumed fatality reduction of 35 percent or 41 percent, for the affected model years. Also, s_{ij} will be set to 1 for the affected model years.

- w_k is the representative weight for cars of size class k, in 100 lb.

Assuming the fatality risk for an occupant of a car of class k colliding with one of class h to be proportional to

$$0.93^{W_k} \times 1.02^{W_h} \quad , \tag{E-2}$$

one obtains

$$R_i^2 = \frac{(0.93^{\bar{w}})\ (1.02^{\bar{w}})(1+0.002\tilde{\sigma}^2)\ (1+0.0002\bar{\sigma}^2)\ \sum_j r_{ij} a''_{ij} \rho''_j s_{ij}}{(0.93^{\bar{w}_o})\ (1.02^{\bar{w}_o})\ (1+0.002\tilde{\sigma}_o^2)\ (1+0.002\bar{\sigma}_o^2)\ \sum_j r_{ij} a''_{kj} \rho''^o_j s^o_{ij}} \tag{E-3}$$

for the change in overall frequency of car occupant injury per crash involvement due to changes in W_{jk}, ρ_j, and s_{ij}. $\bar{w}_i$, $\tilde{w}_i$, $\bar{\sigma}_i$, and $\tilde{\sigma}_i$ are defined as

$$\bar{w}_i = \frac{\sum_k (\sum_j x_{ijk} a''_{ij})\ w_k}{\sum_{j,k} x_{ujk} a''_{ij}} \quad , \tag{E-4}$$

$$\tilde{w}_i = \frac{\sum_k (\sum_j x_{ijk} a''_{ij} \rho''_j s_{ij})\ w_k}{\sum_{j,k} x_{ijk} a''_{ij} \rho''_j s_{ij}} \tag{E-5}$$

$$\bar{\sigma}_i^2 = \frac{\sum_k (\sum_j x_{ijk} a''_{ij})\ w_k - \bar{w})^2}{\sum_{j,k} x_{ijk} a''_{ij}} \tag{E-6}$$

$$\tilde{\sigma}_i^2 = \frac{\sum_k (\sum x_{ijk} a''_{ij} \rho''_j s_{ij})\ (w_k - \tilde{w})^2}{\sum_{j,k} x_{ijk} a''_{ij} \rho''_j s_{ij}} \tag{E-7}$$

where

$$x_{ijk} = r_{ij}\ W_{jk} \quad . \tag{E-8}$$

If (E-2) is replaced by the more general formula

$$(1 - u)^{w_k}\ (1 + v)^{w_h} \tag{E-9}$$

where u and v have to be small compared with 1, then the terms

$$(0.93^{\tilde{w}})\ (1.02^{\bar{w}})\ (1 + 0.002\tilde{\sigma}^2)\ (1 + 0.0002\bar{\sigma}^2) \tag{E-10}$$

in (E-3) have to be replaced by

$$(1 - u)^{\tilde{w}}\ (1 + v)^{\bar{w}}\ (1 + \frac{u^2}{2}\ \tilde{\sigma}^2)\ (1 + \frac{v^2}{2}\ \bar{\sigma}^2) \quad . \tag{E-11}$$

E.1.3 Car-Truck Crashes

In our original model, two alternative options for the analysis of car-truck crashes were considered. The results of Paragraph 4.3.4 of this report rule one of these options out. Comparing the formulas in Table 4-8 for car-car crashes and car-truck crashes, and applying formulas (E-9) and (E-11) for $v = 0$, one can show that the relative risk in car-truck crashes is described by formula (E-3), if one uses $\bar{w} = \bar{w}_o$ and $\bar{\sigma} = \bar{\sigma}_o$.

E.1.4 The Combination of all Types of Crashes

Assuming that all crashes where car occupants can be injured are single car, car-car, or car-truck crashes (treating multi-vehicle crashes as car-car crashes), and that fractions of car occupants killed in these three types of crashes are P_{1i}, P_{2i} and P_{Ti}, assuming car characteristics for a base year, then

$$R_i = \frac{R_i^1}{R_{i_o}^1} P_{1i} + \frac{R_i^2}{R_{i_o}^2} P_{2i} + \frac{R_i^T}{R_{i_o}^T} P_{Ti} \quad , \tag{E-12}$$

is the change of overall occupant injury risk due to changes in the vehicle population, relative to a base year for which $R_{i_o}^1$, $R_{i_o}^2$, and $R_{i_o}^T$ are calculated, which may be different from the base year used in the calculation of the R_i^1, R_i^2, and R_i^T.

We have derived empirical formulas for the relative frequency of car occupants killed in single and multi-vehicle crashes, and estimated that 30 percent of car occupants killed in multi-vehicle crashes are killed in car-truck crashes. This results in the formula

$$R_i = \frac{R_i^1}{R_{i_o}^1} \left(0.43 + \frac{1360}{1.25Z_i}\right) + \left(0.7 \frac{R_i^2}{R_{i_o}^2} + 0.3 \frac{R_i^T}{R_{i_o}^T}\right)\left(0.57 - \frac{1360}{1.25Z_i}\right) \tag{E-13}$$

where Z_i is the "adjusted" number of car occupants killed: the number which would have been killed had there been no changes in the automobile population (except increase in the number).

We also consider that about 1000 car occupants are annually killed in car-train collisions, the number being fairly stable over a long time. Since these are usually crashes where the car is very severely damaged, we assumed that neither car size nor vehicle improvements would affect the fatality risk in these crashes. Thus, if Z_i is the number of occupant deaths which would have occurred without changes in the car population, then

$$y_i = 1000 + R_i\,(Z_i - 1000) \tag{E-14}$$

is the number of deaths to be expected considering the influence of changes in the automobile population.

$$R_i^* = \frac{y_i}{Z_i} = R_i + \frac{1000}{Z_i}\,(1 - R_i) \tag{E-15}$$

is the overall change in car occupant fatality risk.

E.2 THE ACCIDENT TREND MODEL

The CEM accident trend model is a purely descriptive (not functional) empirical model representing the trend in automobile occupant deaths, adjusted for the changes in the automobile population, as described in Section E.1. Its expression for the number of "adjusted" car occupant deaths in year i, Z_i, is:

$$Z_i = 8174 + 2.15x_{1i} + 0.80x_{2i} \times 0.14x_{3i} \tag{E-16}$$

where

x_{1i} = the number of cars of current model year registered in year i,

x_{2i} = the number of cars one through three years old in year i,

x_{3i} = the number of cars four years old or older in year i,

all x_{ji} in thousands.

This formula, derived for the period 1950 through 1960, describes a major change in the trend from 1961 on very well up to 1967. From 1968 the representation of the annual values becomes less good, but the overall trend is still reflected by the formula. These deviations might possibly be due to errors in estimating the effects of the Federal

Motor Vehicle Safety Standards, which have been introduced from 1968 on.

This model does not explicitly consider many factors which have a causal impact on the number of car occupant deaths, such as VMT or travel speed. In the past, they might have been sufficiently closely correlated with one or several of the variables x_1, x_2 and x_3 which thereby also represented the influence of these factors. However, if such a correlation is broken, as currently by the 55 mph speed limit, one cannot expect (E-16) to realistically predict future automobile occupant deaths, adjusted only for vehicle population changes. Therefore, any projection of absolute number of deaths based on (E-16) is at best illustrative of the future trend in a very general sense, but not in quantitative terms.

E.3 DATA BASE FOR THE ACCIDENT MODEL

In addition to the data given in Section E.1, the data in Tables E-6 and E-7 are needed for the application of the accident model.

Table E-6 is based on Table 2.2.24-2 in our report on the Accident Trend Model, but adjustments are made for differences in the definitions of the car classes. Table E-7 is based on Table E-1 of the same report, which in turn is based on earlier work done by CEM [34]. However, for new automobile registrations from 1975 on, projections provided by TSC were used and the tables accordingly corrected.

TABLE E-6

Breakdown (%) of New Automobile Registrations Into Weight Classes by Model Year

Car Class	Subcompact	Compact	Intermediate	Full Size	Heavy
Representative Weight (lbs)	2000	2900	3300	3900	4700
Model Year					
1971	20	16	20	40	4
1970	17	20	22	37	4
1969	13	15	28	39	5
1968	10	18	28	39	5
1967	9	17	29	41	4
1966	8	20	27	38	7
1965	6	29	26	35	4
1964	5	31	25	35	4
1963	5	31	29	31	4
1962	5	32	35	29	4
1961	5	29	40	26	5
1960	6	29	44	25	5
1959	12	9	51	24	4
1958	10	0	60	25	5
1957	4	0	66	25	5
1956	2	0	68	25	5
1955 & earlier	0	0	70	25	5
		Estimates Uncertain			

TABLE E-7

Projection of United States Passenger Car Registrations
By Model Year
(in millions as of July 1)

Model Year	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
1985														9.3
1984													9.3	13.4
1983												9.2	13.2	13.2
1982											9.2	13.0	1.30	13.0
1981										9.0	12.9	12.9	12.8	12.6
1980									8.9	12.7	12.7	12.6	12.4	12.1
1979								8.8	12.6	12.6	12.5	12.3	12.1	11.7
1978							8.4	12.1	12.1	12.0	11.9	11.6	11.2	10.5
1977						8.1	11.5	11.5	11.4	11.3	11.0	10.7	10.0	8.9
1976					7.1	10.2	10.2	10.1	10.0	9.8	9.5	8.8	7.9	6.5
1975				6.9	9.8	9.8	9.7	9.6	9.4	9.1	8.5	7.5	6.3	4.9
1974			6.5	9.4	9.4	9.3	9.2	9.0	8.8	8.2	7.2	6.0	4.7	3.5
1973		8.0	11.3	11.3	11.2	11.1	10.9	10.5	9.9	8.7	7.3	5.7	4.1	3.0
1972	7.2	10.2	10.2	10.1	10.9	9.8	9.5	8.8	7.9	6.5	5.0	3.8	2.7	1.9
1971	8.9	8.7	8.6	8.6	8.3	8.1	8.4	6.6	5.5	4.3	3.2	2.3	1.6	1.1
1970	8.9	8.6	8.5	8.4	8.1	7.5	6.7	5.6	4.3	3.2	2.4	1.7	2.2	0.7
1969	9.1	8.9	8.7	8.4	7.9	7.1	5.8	4.5	3.3	2.5	1.8	1.2	0.8	2.6*
1969	8.6	8.3	8.1	7.5	6.7	5.5	4.3	3.2	2.3	1.6	1.1	0.7	2.6*	
1967	7.5	7.1	6.7	5.9	4.9	3.8	2.9	2.1	1.4	0.9	0.7	2.5*		
1966	7.9	7.3	6.5	5.3	4.2	3.1	2.3	1.6	1.0	0.7	2.5*			
1965	7.6	6.7	5.5	4.4	3.2	2.3	1.7	1.2	0.7	2.4*				
1964	5.9	5.0	3.9	2,9	2.1	1.5	1.0	0.6	2.3*					
1963	4.7	3.7	2.7	1.9	1.4	0.9	0.6	2.3*						
1962	3.3	2.5	1.8	1.3	0.8	0.5	2.2*							
1961	1.8	1.3	1.0	0.7	0.4	2.1*								
1960	1.4	1.0	0.7	0.5	2.0*									
1959	0.8	0.5	0.4	1.9*										
1958	0.4	0.3	1.9*											
1957	0.5	1.8*												
1956	1.8*													

* This figure also includes cars of earlier model years.

APPENDIX

F

COMPUTATION OF PROJECTED PASSENGER CAR OCCUPANT DEATHS

Abstract

The number of projected passenger car occupant deaths is calculated as a function of the number of adjusted passenger car occupant deaths and as a function of the relative risk factors for single-car crashes, two-car crashes and car-truck crashes.

1. INTRODUCTION

Two separate computer programs [17] for the calculation of the relative risk factor for single-car crashes and for two-car crashes have been merged into a single program designed to determine projected passenger car occupant deaths. The risk factor for car-truck crashes, also required for the calculations, is computed by means of a variation of the formula for two-car crashes. The program makes use of this fact to avoid repetition of a number of statements. The adjusted passenger car occupant deaths is represented as a linear combination of vehicle registrations grouped into three categories: (i) current model-year cars; (ii) one to three year-old cars; and (iii) cars four years old and older. The projected passenger car occupant deaths are computed from the risk factors and from the adjusted passenger car occupant deaths.

2. PROBLEM DESCRIPTION

Parameters describing seatbelt use, vehicle age, and vehicle weight are to be used to determine the relative risk for single-car crashes, two-car crashes and car-truck crashes given the number of vehicle registrations categorized according to model year and weight class. The adjusted passenger car occupant deaths have been found to obey a simple formula depending on vehicle registrations grouped into three age categories. The adjusted passenger car occupant deaths and the risk factors are to be used to calculate the projected passenger car occupant deaths.

3. METHOD OF SOLUTION

The risk R_i^1 for the calendar year i relative to the base year j_o is computed for single-vehicle accidents in accordance with the formula,

$$R_i^1 = \frac{\sum\limits_k \left(\sum\limits_j r_{ij} W_{jk} a_{ij} \rho_j s_{ij}\right) w_k}{\sum\limits_k \left(\sum\limits_j r_{ij} W_{j_o k} a_{ij} \rho_j^o s_{ij}^o\right) w_k} ,$$

where the parameters are defined as follows:

r_{ij} = vehicle registrations in calendar year i for model year j vehicles;

W_{jk} = fraction of vehicles in model year j of weight class k;

a_{ij} = usage factor, a function of age i-j;

ρ_j = model-year factor, a function of model year j;

ρ_j^o = model-year factor for model year $j_o - (i-j)$;

s_{ij} = seatbelt factor, a function of age i-j and of model year j;

s_{ij}^o = seatbelt factor for age i-j and for model year $j_o - (i-j)$;

w_k = weight factor, a function of weight class k.

The relative risk R_i^2 for calendar year i relative to base year j_o is computed for two-vehicle accidents in accordance with a formula of the type:

$$R_i^2 = \frac{(0.93^{\tilde{w}})\ (1.02^{\bar{w}})\ (1 + 0.002\tilde{\sigma}^2)\ (1 + 0.0002\bar{\sigma}^2)\ \sum\limits_{j,k} x_{ijk} a_{ij} \rho_j s_{ij}}{(0.93^{\tilde{w}_o})\ (1.02^{\bar{w}_o})\ (1 + 0.002\tilde{\sigma}_o^2)\ (1 + 0.0002\bar{\sigma}_o^2)\ \sum\limits_{j,k} x_{ijk}^o a_{ij} \rho_j^o s_{ij}^o}$$

where

$$\bar{w} = \frac{\sum\limits_k \left(\sum\limits_j x_{ijk} a_{ij}\right) w_k}{\sum\limits_{j,k} x_{ijk} a_{ij}} ,$$

$$\tilde{w} = \frac{\sum\limits_k \left(\sum\limits_j x_{ijk} a_{ij} \rho_j s_{ij}\right) w_k}{\sum\limits_{j,k} x_{ijk} a_{ij} \rho_j s_{ij}} ,$$

and $\bar{w}_o$, $\tilde{w}_o$ are computed using the above two expressions but with x_{ijk}^o replacing x_{ijk};

$$\bar{\sigma}^2 = \frac{\sum_k (\sum_j x_{ijk}a_{ij}) (w_k - \bar{w})^2}{\sum_{j,k} x_{ijk}a_{ij}} ,$$

$\bar{\sigma}_o^2$ is computed using the above formula but with x_{ijk}^o replacing x_{ijk} and $\bar{w}_o$ replacing $\bar{w}$,

$$\tilde{\sigma}^2 = \frac{\sum_k (\sum_j x_{ijk}a_{ij}\rho_j s_{ij}) (w_k - \tilde{w})^2}{\sum_{j,k} x_{ijk}a_{ij}\rho_j s_{ij}} ,$$

and $\tilde{\sigma}_o^2$ is computed using the above expression but with x_{ijk}^o replacing x_{ijk} and $\tilde{w}_o$ replacing $\tilde{w}$.

In the above formulas, we have taken

$$x_{ijk} = r_{ij} W_{jk}$$

and

$$x_{ijk}^o = r_{ij} W_{j_o k} .$$

The remaining parameters used to determine R_i^2 are defined as for the single-vehicle accident case though the numerical values for a_{ij}, ρ_j, and w_k will be different in general.

The relative risk R_i^T for calendar year i relative to base year j_o is computed for car-truck accidents in accordance with one of two formulas:

Option 1

$$R_i^T = \frac{\sum_{j,k} x_{ijk}a_{ij}\rho_j s_{ij}}{\sum_{j,k} x_{ijk}^o a_{ij}\rho_j^o s_{ij}^o} ;$$

Option 2

$$R_i^T = \frac{(0.93^{\tilde{w}}) (1 + 0.002\tilde{\sigma}^2) \sum_{j,k} x_{ijk}a_{ij}\rho_j s_{ij}}{(0.93^{\tilde{w}_o}) (1 + 0.002\tilde{\sigma}_o^2) \sum_{j,k} x_{ijk}^o a_{ij}\rho_j s_{ij}}$$

The parameters are defined as for the two-vehicle accident case though the numerical values for a_{ij}, ρ_j, and w_k again will differ in general.

The number of adjusted passenger car occupant deaths Z_i for year i is computed by means of the formula

$$Z_i = 8174 + 2.15x_{1i} + 0.80x_{2i} + 0.14x_{3i} \quad ,$$

where x_{1i} is the number of current model year cars, x_{2i} is the number of cars one to three years old, and x_{3i} is the number of cars four years old or older.

The projected number of passenger car occupant deaths y_i for year i relative to the base year i_o then is computed in accordance with the formula

$$y_i = 1000 + \left\{ \frac{R_i^1}{R_{i_o}^1} \left(0.43 + \frac{1360}{1.25Z_i}\right) + \left(0.7 \frac{R_i^2}{R_{i_o}^2} + 0.3 \frac{R_i^T}{R_{i_o}^T}\right) \left(0.57 - \frac{1360}{1.25Z_i}\right) \right\} (Z_i - 1000)$$

where the base calendar year i_o is the same as the base model year j_o defined above.

4. PROGRAM DESCRIPTION

The program is written in Basic FORTRAN and hence is compatible with the higher level FORTRAN languages. In the earlier stages of development, the program was run on the IBM 1130 until program additions called for larger core storage. In its present form, the program requires 40K bites of core storage for execution. The program requires one subroutine, called BELT, which is used to obtain the product of the model-year factor and the seatbelt factor. In this subroutine, the seatbelt factor is set equal to unity if the model year is < 1964.

5. PROGRAM USE

5.1 Input

Control Card

The input format is (12I6).

Columns	Parameter
1-6	Number consecutive calendar years for which the projected number of passenger car occupant deaths is calculated.
7-12	Earliest calendar year.
13-18	Number model years considered in each calendar year.
19-24	Earliest model year.
25-30	Total number model years considered for all calendar years.
31-36	Base year.

Option Card

The input format is (12I6).

Columns	Parameter
1-6	Model year/seatbelt factor option code: 0, if $\rho_j^o s_{ij}^o$ is desired in the denominator of the risk factors. 1, if $\rho_j s_{ij}$ is desired in the denominator of the risk factors.
7-12	Car-truck option code: 1, for $\tilde{w} = \tilde{w}_o$, $\bar{w} = \bar{w}_o$, $\tilde{\sigma} = \tilde{\sigma}_o$, and $\bar{\sigma} = \bar{\sigma}_o$ in the formula for R_i^2. 2, for $\bar{w} = \bar{w}_o$ and $\bar{\sigma} = \bar{\sigma}_o$ in the formula for R_i^2.
13-18	Punch output option code: 0, for no punch-card output. 1, for punch-card output of projected passenger car occupant deaths y_i.

Vehicle Registration Cards

These cards contain the number of vehicle registrations r_{ij} in thousands of units. The sequence is read beginning with the earliest calendar year (ICALØ) and continuing through calendar year ICALØ + ICAL-1. For each calendar year i, the registration cards have the following form:

Columns	Parameter
1-8	Registrations for model year i.
9-16	Registrations for model year i-1.
⋮	⋮
73-80	Registrations for model year i-9.

The format is (10F8.0).

Additional cards are read, if needed, until the registrations for model year i - JMOD + 1 are included, at which point the program proceeds to read the data for the next calendar year i + 1.

Weight Percentage Cards

These cards contain the fraction of vehicles W_{jk} according to weight class k for each successive model year from JMODØ through JMODØ + JTMOD - 1. The program is written to include five weight classes (some of which may contain zero vehicles). The input format is (5F6.2). For each model year, the weight percentage card has the following form.

Columns	Parameter
1-6	Fraction vehicles in 1st weight class.
7-12	Fraction vehicles in 2nd weight class.
⋮	⋮
25-30	Fraction vehicles in 5th weight class.

Seatbelt Factor Cards

The cards contain values of the seatbelt factor s_{ij} for vehicle age 0, ..., JMOD-1 years. If the corresponding model year is < 1964, the program sets s_{ij} equal to unity. The format is (12F6.2).

Columns	Parameter
1-6	Seatbelt factor for age 0 years.
7-12	Seatbelt factor for age 1 year.
⋮	⋮
67-72	Seatbelt factor for age 11 years.

Additional cards are read if more than 12 model years are considered for a given calendar year (i.e., if JMOD > 12).

Grouped Vehicle Registration Cards

Each card contains a value for each of the three parameters x_{1i} x_{2i} x_{3i} for a given calendar year i, where

x_{1i} = number of cars of model year i;

x_{2i} = Number of cars of model years i-1, i-2, i-3;

x_{3i} = number of cars of model years i-4, i-5, ...

The sequence is read beginning with the earliest calendar year ICALØ and continuing through calendar year ICALØ + ICAL-1. The format is (10F8.0). The first card in the sequence has the following form

Columns	Parameter
1-8	Number of cars of model year ICALØ.
9-16	Number of cars of model years ICALØ-1, ICALØ-2, ICALØ-3.
17-24	Number of cars of model years ICALØ-4, ICALØ-5, ...

Additional cards are read, if needed, until the values of x_{1i}, x_{2i}, x_{3i} corresponding to year ICALØ + ICAL-1 are included.

5.1.1 Single-Vehicle Input

Usage Factor Cards

The cards contain values for the usage factor $a_{ij} = a(i-j)$ corresponding to vehicle age 0, ..., JMOD-1 years for single-vehicle accidents.

Columns	Parameter
1-6	Usage factor for age 0 years.
7-12	Usage factor for age 1 years.
⋮	⋮
67-72	Usage factor for age 11 years.

The format is (12F6.2). Additional cards are read if more than 12 model years are considered for a given calendar year (i.e., if JMOD > 12).

Model-Year Factor Cards

The cards contain values of the model-year factor ρ_j corresponding to model year JMODØ, ..., JMODØ + JTMOD-1 for single-vehicle accidents. The format is (12F6.2).

Columns	Parameter
1-6	Model-year factor for model year JMODØ.
7-12	Model-year factor for model year JMODØ + 1.
⋮	⋮
67-72	Model-year factor for model year JMODØ + 11.

Additional cards are read if there are more than 12 model years considered for all calendar years (i.e., if JTMOD > 12).

Weight Factor Card

The card contains five values for the weight factor w_k for single-vehicle accidents. The input format is (12F6.2).

Columns	Parameter
1-6	Weight factor for 1st weight class.
7-12	Weight factor for 2nd weight class.
⋮	⋮
25-30	Weight factor for 5th weight class.

5.1.2 Two-Vehicle Input

Usage factor, model-year factor, and weight factor cards for two-vehicle accidents are read using the same format as for the single-vehicle case.

5.1.3 Car-Truck Input

Usage factor, model-year factor, and weight factor cards for car-truck accidents are read using the same format as for the single- and two-vehicle cases.

5.2 Output

5.2.1 Printed Output

The printed output contains the following:

1) the model year factors ρ_j for single-vehicle, two-vehicle, and car-truck crashes, and weight percentages W_{jk} as a function of model year;
2) the usage (age) factors a_{ij} for single-vehicle, two-vehicle, and car-truck crashes, and seatbelt factor s_{ij} as a function of vehicle age;
3) the weight factors w_k for single-vehicle, two-vehicle, and car-truck crashes;
4) the model-year/seatbelt option code, the car-truck option code, the index corresponding to the base model year j_o, and the index corresponding to the base calendar year i_o;
5) the grouped passenger car registrations x_{1i}, x_{2i}, x_{3i} for each calendar year i under consideration; and

6) the relative risk factors R_i^1, R_i^2, R_i^3, the adjusted passenger car occupant deaths Z_i, and the projected passenger car occupant deaths y_i as a function of calendar year.

5.2.2 Punch-card Output

If the punch-card option is set equal to 1, the program produces punched cards containing the number of projected passenger car occupant deaths y_i for each calendar year. The sequence is punched beginning with the earliest calendar year ICALØ and continuing through calendar year ICALØ + ICAL-1. The format is (10F8.0). The first card in the sequence has the form described on the following page. Additional cards are punched, if needed, until the value of y_i is included for which i = ICALØ + ICAL-1.

Columns	Parameter
1-8	Projected number passenger car occupant deaths for year ICALØ.
9-16	Projected number passenger car occupant deaths for year ICALØ + 1.
⋮	⋮
73-80	Projected number passenger car occupant deaths for year ICALØ + 9.

6. PROGRAM LISTING

```
C
C         PROJECTED PASSENGER CAR OCCUPANT DEATHS
C
      DIMENSION CARS(36,17),C(53,5),CARWT(17,5),DARSD(17,6)
      DIMENSION FAGE(17),FWT(5),FMOD(53),Y(36),Z(36)
      DIMENSION FAGE1(17),FWT1(5),FMOD1(53)
      DIMENSION FAGET(17),FWTT(5),FMODT(53)
      DIMENSION PSUM1(5),PSUM2(5),PSUM3(5),PSUM4(5)
      DIMENSION RISK1(36),RISK2(36),RISKT(36),RISK(36)
      DIMENSION X1(36),X2(36),X3(36)
         COMMON FSEAT(17),JMODO
         IR=5
         IW=6
         READ(IR,1) ICAL,ICALO,JMOD,JMODO,JTMOD,IBASE
         READ(IR,1) IRHO,ITRK,IPNCH
         JBASE=IBASE-JMODO+1
         IIBAS=IBASE-ICALO+1
      DO 100 I=1,ICAL
         READ(IR,2) (CARS(I,J),J=1,JMOD)
  100 CONTINUE
      DO 110 JJ=1,JTMOD
         READ(IR,3) (C(JJ,M),M=1,5)
```

```
  110 CONTINUE
          READ(IR,4) (FSEAT(J),J=1,JMOD)
      DO 111 I=1,ICAL
          READ(IR,2) X1(I),X2(I),X3(I)
  111 CONTINUE
C
C         SINGLE-VEHICLE INPUT
C
          READ(IR,4) (FAGE1(J),J=1,JMOD)
          READ(IR,4) (FMOD1(JJ),JJ=1,JTMOD)
          READ(IR,4) (FWT1(M),M=1,5)
C
C         TWO-VEHICLE INPUT
C
          READ(IR,4) (FAGE(J),J=1,JMOD)
          READ(IR,4) (FMOD(JJ),JJ=1,JTMOD)
          READ(IR,4) (FWT(M),M=1,5)

C
C         CAR-TRUCK INPUT
C
          READ(IR,4) (FAGET(J),J=1,JMOD)
          READ(IR,4) (FMODT(JJ),JJ=1,JTMOD)
          READ(IR,4) (FWTT(M),M=1,5)
C
          WRITE(IW,20)
      DO 112 JJ=1,JTMOD
          MOD=JMOD0+JTMOD-JJ
          JK=JTMOD-JJ+1
          WRITE(IW,21) MOD,FMOD1(JK),FMOD(JK),FMODT(JK),(C(JK,M),N=1,6)
  112 CONTINUE
          WRITE(IW,22)
      DO 116 J=1,JMOD
          JAGE=J-1
          WRITE(IW,23) JAGE,FAGE1(J),FAGE(J),FAGET(J),FSEAT(J)
  116 CONTINUE
          WRITE(IW,33) (FWT1(M),M=1,5)
          WRITE(IW,34) (FWT(M),M=1,5)
          WRITE(IW,38) (FWTT(M),M=1,5)
          WRITE(IW,25) IRHO,ITRK,JBASE,IIBAS
          WRITE(IW,42)
          WRITE(IW,43)
          WRITE(IW,40)
          WRITE(IW,41)
          WRITE(IW,50)
      DO 398 I=1,ICAL
          IYEAR=ICAL0+I-1
          WRITE(IW,51) IYEAR,X1(I),X2(I),X3(I)
  398 CONTINUE
C
C         COMPUTE ADJUSTED PASSENGER CAR OCCUPANT DEATHS
C
      DO 399 I=1,ICAL
          Z(I)=8174.+2.15*X1(I)+0.80*X2(I)-0.14*X3(I)
  399 CONTINUE
C
          IPASS=1
  400 DO 120 I=1,ICAL
          IYEAR=ICAL0+I-1
      DO 130 J=1,JMOD
          JAGE=J-1
          MODYR=IYEAR-JAGE
          JJ=MODYR-JMOD0+1
```

```
      DO 140 M=1,5
         CARWT(J,M)=CARS(I,J)*C(JJ,M)
         CARSD(J,M)=CARS(I,J)*C(JBASE,M)
140   CONTINUE
130   CONTINUE
         IF(IPASS-1) 401,401,402
401      SUM=0.0
         SUMSD=0.0
      DO 260 M=1,5
         PSUM=0.0
         PSUMS=0.0
      DO 280 J=1,JMOD
         JAGE=J-1
         CALL BELT(JAGE,IYEAR,RHO,FMOD1)
         PSUM=PSUM+CARWT(J,M)*FAGE1(J)*RHO
         IF(IRHO) 282,281,282
281      CALL BELT(JAGE,IBASE,RHO,FMOD1)
282      PSUMS=PSUMS+CARSD(J,M)*FAGE1(J)*RHO
280   CONTINUE
         PSUM=PSUM*FWT1(M)
         PSUMS=PSUMS*FWT1(M)
         SUM=SUM+PSUM
         SUMSD=SUMSD+PSUMS
260   CONTINUE
         RISK1(I)=SUM/SUMSD
402      SDNB=0.0
         SDNB0=0.0
         SDNT=0.0
         SDNT0=0.0
         SNWB=0.0
         SNWB0=0.0
         SNWT=0.0
         SNWT0=0.0
      DO 160 M=1,5
         PSUM1(M)=0.0
         PSUM2(M)=0.0
         PSUM3(M)=0.0
         PSUM4(M)=0.0
      DO 180 J=1,JMOD
         JAGE=J-1
         PSUM1(M)=PSUM1(M)+CARWT(J,M)*FAGE(J)
         PSUM2(M)=PSUM2(M)+CARSD(J,M)*FAGE(J)
         CALL BELT(JAGE,IYEAR,RHO,FMOD)
         PSUM3(M)=PSUM3(M)+CARWT(J,M)*FAGE(J)*RHO
         IF(IRHO) 182,181,182
181      CALL BELT(JAGE,IBASE,RHO,FMOD)
182      PSUM4(M)=PSUM4(M)+CARSD(J,M)*FAGE(J)*RHO
180   CONTINUE
         SDNB=SDNB+PSUM1(M)
         SDNB0=SDNB0+PSUM2(M)
         SDNT=SDNT+PSUM3(M)
         SDNT0=SDNT0+PSUM4(M)
         SNWB=SNWB+PSUM1(M)*FWT(M)
         SNWB0=SNWB0+PSUM2(M)*FWT(M)
         SNWT=SNWT+PSUM3(M)*FWT(M)
         SNWT0=SNWT0+PSUM4(M)*FWT(M)
160   CONTINUE
         WBAR=SNWB/SDNB
         WBAR0=SNWB0/SDNB0
         WTLD=SNWT/SDNT
         WTLD0=SNWT0/SDNT0
```

```
      SNSB=0.0
      SNSB0=0.0
      SNST=0.0
      SNST0=0.0
      DO 190 M=1,5
      SNSB=SNSB+PSUM1(M)*(FWT(M)-WBAR)**2
      SNSB0=SNSB0+PSUM2(M)*(FWT(M)-WBAR0)**2
      SNST=SNST+PSUM3(M)*(FWT(M)-WTLD)**2
      SNST0=SNST0+PSUM4(M)*(FWT(M)-WTLD0)**2
  190 CONTINUE
      SIGB=SNSB/SDNB
      SIGB0=SNSB0/SDNB0
      SIGT=SNST/SDNT
      SIGT0=SNST0/SDNT0
      IF(IPASS-1) 490,490,460
  460 IF(ITRK-1) 470,470,480
  470 WTLD=0.0
      WTLD0=0.0
      SIGT=0.0
      SIGT0=0.0
  480 WBAR=0.0
      WBAR0=0.0
      SIGB=0.0
      SIGB0=0.0


  490 EXP1=.96**WTLD
      EXP2=1.01**WBAR
      XNUM=EXP1*EXP2*(1.+.001*SIGT)*(1.+.0000*SIGB)*SDNT
      EXP1=.96**WTLD0
      EXP2=1.01**WBAR0
      XDEN=EXP1*EXP2*(1.+.001*SIGT0)*(1.+.0000*SIGB0)*SDNT0
      RISKT(I)=XNUM/XDEN
  120 CONTINUE
      IF(IPASS-1) 410,410,450
  410 DO 415 I=1,ICAL
      RISK2(I)=RISKT(I)
  415 CONTINUE
      DO 420 J=1,JMOD
         FAGE(J)=FAGET(J)
  420 CONTINUE
      DO 425 JJ=1,JTMOD
         FMOD(JJ)=FMODT(JJ)
  425 CONTINUE
      DO 430 M=1,5
      FWT(M)=FWTT(M)
  430 CONTINUE
      IPASS=2
      GO TO 400
  450 DO 300 I=1,ICAL
      Z125=1.25*Z(I)
      T1=(.43+1360./Z125)*RISK1(I)/RISK1(IIBAS)
      T2=0.7*RISK2(I)/RISK2(IIBAS)+0.3*RISKT(I)/RISKT(IIBAS)
      T3=.57-1360./Z125
      Y(I)=1000.+(T1+T2*T3)*(Z(I)-1000.)
      Y(I)=Y(I)+.5
      IY=Y(I)
      Y(I)=IY
      RISK(I)=Y(I)/Z(I)
  300 CONTINUE
      WRITE(IW,37) IBASE
      WRITE(IW,35)
      DO 320 I=1,ICAL
      IYEAR=ICAL0+I-1
      WRITE(IW,36) IYEAR,RISK1(I),RISK2(I),RISKT(I),RISK(I),Z(I),Y(I)
```

```
320 CONTINUE
      IF(IPNCH) 330,330,325
325   READ(IR,1) K
      PUNCH 2,(Y(I),I=1,ICAL)
330   CONTINUE
  1 FORMAT(12I6)
  2 FORMAT(10F8.0)
  3 FORMAT(5F6.2)
  4 FORMAT(12F6.2)
 20 FORMAT(1H1,//8X,'MODEL',4X,'MODEL-YEAR',2X,'MODEL-YEAR',2X,'MODEL-
   1YEAR',3X,'WT. CAT.1',3X,'WT. CAT.2',3X,'WT. CAT.3',3X,'WT. CAT.4',
   23X,'WT. CAT.5',/8X,'YEAR',6X,'FACTOR(1)',3X,'FACTOR(2)',3X,'FACTOR
   3(T)',3X,'PERCENTAGE',2X,'PERCENTAGE',2X,'PERCENTAGE',2X,'PERCENTAG
   4E',2X,'PERCENTAGE')
 21 FORMAT(6X,I6,8F12.2)
 22 FORMAT(1H1,//21X,'AGE',10X,'AGE',12X,'AGE',12X,'AGE',9X,'SEAT-BELT
   1',/32X,'FACTOR(1)',6X,'FACTOR(2)',6X,'FACTOR(T)',7X,'FACTOR')
 23 FORMAT(18X,I5,4F15.2)
 25 FORMAT(////20X,'SEAT-BELT FACTOR OPTION=',I2,5X,'TRUCK OPTION=',I2
   1,5X,'JBASE=',I2,5X,'IIBAS=',I2)
 33 FORMAT(////20X,'WEIGHT FACTORS(1)',5F10.2)
 34 FORMAT(//20X,'WEIGHT FACTORS(2)',5F10.2)
 35 FORMAT(// 9X,'CALENDAR',3X,'RELATIVE RISK',2X,'RELATIVE RISK',2X,'
   1RELATIVE RISK',2X,'RELATIVE RISK',5X,'ADJUSTED',6X,'PROJECTED',/11
   2X,'YEAR',6X,'(1-VEHICLE)',4X,'(2-VEHICLE)',4X,'(CAR-TRUCK)',4X,'(P
   3ROJ/ADJ)',8X,'DEATHS',9X,'DEATHS')
 36 FORMAT(10X,I5,4F15.4,2F15.0)
 37 FORMAT(1H1,/51X,'BASE YEAR =',I5)
 38 FORMAT(//20X,'WEIGHT FACTORS(T)',5F10.2)
 40 FORMAT(//20X,'IF TRUCK OPTION=1,     W-BAR=W-BAR0=SIGMA-BAR=SIGMA-B
   1AR0=0',/42X,'W-TILDE=W-TILDE0=SIGMA-TILDE=SIGMA-TILDE0=0')
 41 FORMAT(//20X,'IF TRUCK OPTION=2,     W-BAR=W-BAR0=SIGMA-BAR=SIGMA-B
   1AR0=0')
 42 FORMAT(//20X,'IF SEAT-BELT OPTION CODE=0,RHO0*S0 IS USED IN DENOMI
   1NATOR OF RISK FACTORS')
 43 FORMAT(//20X,'IF SEAT-BELT OPTION CODE=1,RHO*S IS USED IN DENOMINA
   1TOR OF RISK FACTORS')
 50 FORMAT(1H1,//47X,'PASSENGER CAR REGISTRATIONS',//39X,'YEAR',4X,'CU
   1RRENT',3X,'1-3YRS',4X,'4YRS+')
 51 FORMAT(39X,I4,3F10.0)
      CALL EXIT
      END
```

APPENDIX

G

LIST OF REFERENCES
AND
SUPPLEMENTARY READINGS

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APPENDIX

H

REPORT OF INVENTIONS

The purpose of this contract was to review and analyze accident data and therefore nothing patentable was developed.

After a diligent review of the work performed under this contract, no new innovation, discovery, improvement or invention was made.