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Vehicle Design Versus Aggressivity

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FINAL REPORT

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16. Abstract

The objective was to determine how certain characteristics of cars, sport utility vehicles, vans, and pickup trucks influence the fatality risk for occupants of cars with which they collide - the aggressivity of the striking vehicle.

Fatality risks were estimated by combining data on fatalities from FARS with data on collision involvements from NASS GES. To make them compatible, certain states had to be excluded.

A model including the ratio of the weights of the colliding vehicles, and the speed environments was developed to control for their strong influence on the fatality risk in a collision.

In collisions with pickup trucks or vans, car drivers are exposed to a much higher fatality risk than in collisions with cars. In collisions with sport utility vehicles, the risk for car drivers was even higher. This holds even after control for the confounding factors.

The controlled fatality risk for the car driver tended to increase with the weight of the striking vehicle, its height of the center of force, and its frontal static stiffness, as measured in crash tests.

However, only for sport utility vehicles were the relations with these factors clear, though they could not be completely separated with the available data. In addition to these apparent

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

Executive Summary

OBJECTIVE
Quantify the aggressivity of LTVs - sport utility vehicles, vans, and pickup trucks - in collisions with cars. Determine the effect of selected characteristics of LTVs (and as baseline also those of cars) in collisions with cars on the car driver's fatality risk. Studied were vehicle weight, the height of the center of force, and static and dynamic front stiffness, as measured in crash tests.

DATA
To calculate fatality risks, fatality counts from FARS, and involvement estimates from NASS GES for the years 1991-97 were combined. Because some vehicle information is systematically missing in NASS GES, the data bases had to be made statistically compatible.

CONFOUNDING FACTORS
Several factors have a strong influence on the fatality risk in collisions. Their effects have to be separated from those of vehicle parameters. A model was developed to do this to some extent. It included the ratio of the colliding vehicles' weights, and the speed limit as a rough indicator of impact speed.

TYPES OF COLLISIONS
Studied were all collisions involving a car and one of the LTV types, and separately also front-front, front-left, and front-right collisions, where the vehicle struck in the side was a car.

COMPARISON OF VEHICLE TYPES
After controlling for the two confounding factors, a car driver's fatality risk in collisions with a sport sport utility vehicle was 3.4 times as high as in collisions with a car of equal weight, in collisions with a van 2.3 times, and in collisions with a pickup truck 1.9 times as high. In front-front collisions, the corresponding factors were 6.4, 4.2, and 3.6.

EFFECTS OF VEHICLE PARAMETERS
If one does not distinguish striking vehicles by class, the car driver's fatality risk increases with each of the vehicle characteristics studied. Distinguishing vehicle classes reveals that this is primarily an effect of differences between the LTV classes. Within the LTV classes, no strong effects of vehicle characteristics were apparent. For sport utility vehicles and pickup trucks, weight , the height of the center of force, static stiffness, and dynamic stiffness showed all positive relations with aggressivity. For sport utility vehicles, the effect of weight appeared strongest, for pickup trucks that of static stiffness. Within the class of vans, no clear effect appeared; some relations had a negative slope.

COMPARING VEHICLE MAKE/MODELS

Each vehicle make/model has practically the same parameters, but make/models can differ in important features other than the parameters used. This can confound the effects of the studied parameters. Therefore, for make/models with sufficient case numbers, the driver fatality risks in the cars they collided with were calculated. These risks were analyzed in relation to the vehicle parameters.

For sport utility vehicles, a model for aggressivity containing vehicle weight and the height of the center of force was developed fitted the data well. Stiffness alone also gave a good fit, however, with the Isuzu Trooper as a far outlier. Reviewing the correlations between the vehicle parameters showed that the effects of all parameters could not be separated with the available data.

For pickup trucks, only a relation with weight appeared. Up to about 3000 lbs of weight, the aggressivity increased, at higher weights it increased only little, if at all.

For the van models with sufficient case numbers, differences in aggressivity were too small to allow an analysis.

CONCLUSIONS

Strong differences in aggressivity were found between cars, and vans or pickup trucks - but little between these two classes. The aggressivity of sport utility vehicles was higher than that of the other two LTV types. The vehicle parameters used in this study did not suffice to explain the differences between the vehicle types though they appeared to have effects in sport utility vehicles. More vehicle parameters, or modifications of those used, need to be studied to explain the largest part of the aggressivity of LTVs.

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Abbreviations

AOPVIN	A computer program which determines the type of occupant restraint system by decoding the VIN, and other vehicle information
FARS	Fatality Analysis Reporting System (previously the Fatal Accident Reporting System)
NASS GES	General Estimates System
LTV	Light Truck and Van, includes (sport) utility vehicles
NASS	National Automotive Sampling System
NCAP	New Car Assessment Program
NHTSA	National Highway Traffic Safety Administration
PSU	Primary Sampling Unit
SUV	Sport Utility Vehicle, the same as utility vehicles in FARS and NASS GES, body style codes 14-19
VIN	Vehicle Identification Number

1. Introduction

The fatality - and injury - risk to a vehicle occupant in a collision with another vehicle depends on characteristics of both vehicles. Those of his or her vehicle determine its "crashworthiness," those of the other vehicle determine that vehicle's, "aggressivity". Usually, aggressivity refers to a comparison of risks, for instance, the risk to a car occupant in a collision with a car, and that in a collision with a light truck.

Some analyses distinguish only broad classes of vehicles, such as cars, sport sport utility vehicles, vans, and pickup trucks. That is only a gross qualitative distinction. Of greater interest are analyses which determine relations between the risk and specific vehicle parameters. In this study, the vehicle weight, the height of the center of force, as measured in barrier tests, and the static and dynamic-stiffness, also measured in such tests, were used.

This study was restricted to drivers, because information on other occupants is probably not complete. Fatality risks to car drivers are estimated by the ratio of drivers killed to drivers involved in collisions. Information on driver fatalities was obtained from FARS, the Fatality Analysis Reporting System, information on drivers involved in collisions from NASS-NASS GES, the National Automotive Sampling System General Estimates System. The basic data files for these analyses were developed by the Volpe National Transportation System Center for NHTSA. Several technical problems have to be addressed when combining data from these separate sources. Some of them were solved successfully, others could be dealt with only incompletely.

Fatality risks are influenced by many factors beyond the characteristics of the vehicles involved. The differences of these confounding factors between collisions at least increase the random variability of estimates. If such factors differ systematically, e.g. between collisions of two cars, and collisions of a car and a sport sport utility vehicle, then they can bias a comparison. To reduce these consequences, some control for confounding factors is necessary. To control for all known confounding factors proved to be beyond the scope of this study, but a limited model was developed. Collisions between two cars served as baseline, and collisions between a car and a vehicle of another class were compared with them, using the model to control for confounding factors. The resulting, adjusted risk differences between car-car collisions and collisions with another vehicle were used in the final analyses.

The analyses were performed at three levels. At the first, only classes of vehicles were distinguished: sport utility vehicles, vans, and pickup trucks. At the second level, vehicles were further distinguished by their weight, height of the center of force, and static, and dynamic stiffness. At the third level, vehicles were aggregated by make/model. At this level it was studied to what extent differences among make/models could be explained by the parameters mentioned above.

2. Overview of the work

This section presents an overview of the work as it was done. There were some deviations from the original plan when it became apparent that the planned approaches could not be completed within the scope of the work.

2.1 Combining FARS and NASS GES

FARS is a census of all fatal motor vehicle traffic crashes in the U.S.. Detailed information is collected from the police crash reports and other sources, and it is put into a standard format by specially trained FARS analysts located in the states. There are extensive quality checks. NASS GES is a data base containing information on about 50,000 crashes per year. The crashes are selected from all police reported crashes in the U.S. according to a complex multilevel sampling plan. Information from the police crash reports are coded in a standard format, which is to a large extent identical or at least similar to that used by FARS. However, no collateral sources are used, and the controls are not as strict as in FARS. Each NASS GES case has a "weight" which essentially describes how many of all cases in the given year in the entire U.S. it represents.

Thus, FARS and the weighted NASS GES cases are a conceptually validly matching representation of all fatal, and of all crashes in the U.S. Therefore, one can calculate - or more precisely, estimate - fatality rates for drivers, for right front seat occupants, etc, for all vehicles together, for certain vehicle classes, for certain crash conditions, etc., by selecting corresponding cases from all data sets.

While this is conceptually possible, there are some practical differences because not all data elements in FARS and NASS GES correspond exactly to each other, and in NASS GES sometimes data are missing which are available in FARS.

For this study, to exactly identify vehicles at the make/model level was critical. The only way to achieve this is to decode the Vehicle Identification Number (VIN). In FARS for nearly all vehicles, VINs are given. For vehicles in NASS GES, it is often missing. Simply ignoring these cases would at least result in overestimating fatality risks. More important is that systematically missing VINs can give biased estimates.

There is indeed a pattern: in the Southern NASS GES region (the same as the Census region), VINs are nearly always given, in the North-East, they are nearly always missing. These patterns, and those for the other regions were studied. As result, the NASS GES cases from the regions South, Central, and West excluding California were used, and the FARS cases from the corresponding states. This again resulted in a statistically valid match.

To distinguish collision configurations such as front-front, front-left, etc., impact locations on the vehicles are needed. FARS and NASS GES use codes which do not correspond exactly to each other. Therefore, combinations of codes had to be studied to find the best practical match.

2.2 Errors

Several kinds of errors have to be distinguished. Some are errors in the literal sense of the word, such as misreading a character in a VIN, coding the body style of a sport sport utility vehicle as a truck, and similar errors. Some of them are caught by the consistency checks of the quality control process. The remaining ones have to be ignored. They may increase the estimates of the other types of errors which are obtained by statistical analyses. These gross errors are ignored in the following discussion.

FARS is a census, therefore counts of crashes, of deaths, etc. of certain types are exact, without an error. However, if in one year 10 deaths of a certain kind were counted, in the next year 11, and in the third year 12, the question arises whether this increase is "real". To even ask this question requires that one considers crashes random events. Consequently crash counts are treated as random numbers. This allows an analysis to determine whether the trend 10, 11, 12 is unlikely to be a mere chance fluctuation. With NASS GES, the primary error is due to the sampling of cases. The sampling plan consists of a first level of stratified cluster sampling, a second level of simple cluster sampling, and a third level of stratified systematic sampling. The error of counts resulting from such a plan can be rigorously estimated, but the process is tedious. Therefore, NHTSA has developed approximate error estimates for broad classes of estimated counts.

These error estimates, however, deal with the error of the NASS GES estimates relative to the actual nationwide numbers of crashes. As in the case of FARS, these actual numbers have to be treated as random variables. The combination of the random "error", and the sampling error is much more complex than the NASS GES sampling error.

The combined errors of ratios of FARS counts to NASS GES estimates are even more complex. A thorough study of this problem turned out to be far beyond the scope of this project. Therefore, only heuristic estimates were attempted. They were based on the approximate error estimates published by NHTSA, and additional assumptions.

2.3. Confounding factors

The fatality risk in a collision is influenced by many factors. The collision configuration is an important one: the driver fatality risk is much larger if his vehicle is struck in the left side, than if it is struck in the front at the same speed. Speed plays an important role, primarily because both vehicles' speeds determine, together with the ratio of their weights, the velocity change which is a good predictor of fatality and injury risks. In a crash of a given physical severity, an older person is much more likely to die than a younger person, and a person under the influence of alcohol is more likely to die than a sober one (this effect is independent of the effect of alcohol on the collision risk, and on the physical severity of the collision).

One effect of such factors is to increase the random errors of estimates. For instance, the car with which pickup trucks of model A collide, their occupants, and collision conditions, will differ from those in collisions involving pickup truck model B. Any observed differences in fatality risks will be influenced by the effects of the confounding factors, and by any differences in aggressivity. Differences in aggressivity can be better recognized if one can control for confounding factors, or if one can obtain large numbers of collisions where the effects of confounding factors tend to be reduced.

The latter, however, works only if there is no correlation between the types of vehicles which collide. If, e.g. pickup truck A has a high percentage of young drivers, then because of use patterns, it is also more likely to collide with cars driven by young drivers: it will appear less aggressive than a pickup truck B colliding more often with cars driven by older drivers. In such a situation, only a mathematical model controlling for such factors can eliminate their influence.

We considered a number of confounding factors: age, sex, and blood alcohol of the driver whose fatality risk was to be estimated, vehicle weight, and crashworthiness characteristics as determined by compliance and NCAP tests, air bag availability (but not belt use, because information on it in FARS, and even more in NASS GES is considered unreliable), speed limit as a very rough proxy for travel speed at the collision site, and weight of the other vehicle. Since many of the studied factors had highly non-linear relation with the fatality risk, and interactions of the factors also seemed to have strong effects, developing a realistic comprehensive model was beyond the scope of this study. Only a fairly simple model, using in effect a non-linear function of the speed limit, and interactions of this function with the ratio of the weight of the two vehicles was developed.

Such models were developed for car-car collisions: for all collisions configuration combined, for front-front collisions, front-left collisions, and front-right collisions.

2.4 Vehicle characteristics considered

Vehicle characteristics expected to contribute to the aggressivity in a collision are the stiffness of the front structure of a vehicle, because stiff elements can intrude into the other vehicle, and the height of the stiffest structural elements, because differences in these heights for the two vehicles can result in override in a collision.

Rather than assuming certain design features to be the critical factors in aggressivity, and to quantify them from direct measurements or engineering specifications, measurements from actual crash tests - compliance, and NCAP tests - were used.

Static and dynamic stiffness were used, and the height of the center of force as an indicator of the height of the stiffest vehicle parts. This is a simplification, because one would expect that the aggressivities of vehicles with the same height of the center of force differ, if in one it is concentrated, in the other spread out over a larger area.

Though the effect of vehicle weight on the velocity change was already included in the modeling of the confounding factor, vehicle weight was retained as a factor possibly related to aggressivity by a different mechanism

2.5 Studying the relations between aggressivity and vehicle characteristics

There are several approaches to study the relations between aggressivity and vehicle parameters. After comparing the advantages and disadvantages of the several approaches, the following was chosen.

As baseline, collisions between two cars were used. A collision between one of the light truck types and a car was compared with a "similar" collision between two cars. The difference between the car driver fatality risks in the two situations, the "risk increase" was used as a dependent variable in the subsequent analyses. Actually, collisions were not directly compared, but rather through a more complex analysis.

The empirical risk in a single car-LTV collision is either 0 or 1. It was compared with the risk in a collision between a car, and a car of the same weight as the LTV, in the same speed environment as the actual collision. This risk was calculated by the model described in section 2.3. The difference will be called "risk increase".

The risk increases thus calculated were studied in relation to the selected parameters, including some low powers, and interactions of them. Standard regression techniques were used. In some analyses each collision was used as one data point, in others each make/model of the striking vehicle was considered a data point, the value of the dependent variable being the average over all cases involving that make/model. The advantage of the latter approach is that one can more easily identify make/models which are outliers. This might help to find design characteristics whose effects are not captured by the parameters included in the analyses.

3. Data

3.1 Data Bases

Objects of this study were collisions between two vehicles, involving two passengers cars, or one passenger car and a sport sport utility vehicle, a van, or a pickup truck. Data for the years 1991 through 1997 were used. The Volpe National Transportation System Center provided data files for such collisions derived from the FARS and the NASS GES files. In addition to the data contained in the files, vehicle weights derived from the VIN, and vehicle weights obtained by Dr. C. Kahane of NHTSA were included. Also, detailed make/model codes developed by Kahane were added. These codes were used to identify classes of physically similar vehicles, and also to add to the file vehicle parameters derived from NHTSA's crash tests. Collisions involving two vehicles with body style codes less than 40 were selected. This includes passenger cars, passenger car derivatives (which were later excluded from the analyses), sport utility vehicles, vans, and pickup trucks. The information for the crash, each of the two vehicles, and the front-outboard seat occupants of the two vehicles was combined into one record. Such a record constituted one "observation" for the analyses.

Detailed results of compliance tests and of NCAP tests including data on stiffness and height of center of force were provided by NHTSA. The information on height of the center of force and stiffness was combined with the crash data.

Restraint type, specifically air bag availability, was derived from the VIN using a computer program AOPVIN, developed by M. Walz of NHTSA.

3.2 The Combining of FARS and NASS GES

FARS data are a census of all fatal motor vehicle traffic crashes in the U.S.. NASS GES data are a nationally representative sample of police reported motor vehicle crashes obtained by a complex sampling plan. NASS GES data expanded by the proper sampling weights are a statistically valid match of the FARS data. To a large extent, the data elements in FARS and NASS GES are the same. Therefore, it is possible to combine FARS and NASS GES data for selected classes of crashes, vehicles, or persons, and then calculate fatality rates (fatality risk estimates) for them. While the calculation of rates is straightforward, difficulties arise if one wants to estimate their errors, and perform statistical analyses. These questions are addressed in Appendix 2.

In this work, critical variables were linked via the VIN. In FARS, the VIN is nearly always available. In NASS GES it is often missing. A closer inspection shows a pattern: in some PSUs, VINs are nearly always missing, in others they are nearly always (90% or more often) given. Therefore, a combination of all FARS cases with all NASS GES cases where the VIN is available could result in biased estimates. In the Northeast region of NASS, VINs are missing in all but one of the PSUs. Table 3.2-1 shows the availability of VINs by Primary Sampling Unit (PSUs). In the Southern NASS region, VINs are available in all but one PSU. In the Central Region, VINs are available in 12 out of 16 PSUs. In the West, VINs are missing in all of the California PSUs, they are available in all PSUs for the other states.

Table 3.2-1 Availability of Vehicle Identification Numbers by Region and type of Primary Sampling Units. The Northeast region is omitted because VINs are usually missing.

	Type of PSU					
	Large Central City		Large Suburban area		Other	
Region	VIN	No VIN	VIN	No VIN	VIN	No VIN
South	4	0	7	1	6	0
Central	3	1	6	2	3	1
West California	0	1	0	3	0	0
Other States	1	0	5	0	2	0

The availability of VINs in these three regions is sufficient to expand at least approximately from the NASS GES cases with VINs to all police reported crashes in these three regions. This data can be combined with FARS data for the states in these regions to calculate fatality rates. With nearly complete VINs in fatal and other cases, the likelihood of biases due to missing VINs is greatly reduced.

Considering that the PSUs in each of the 9 strata shown in Table 3.2-1 are randomly selected, one can obtain an unbiased estimate of each stratum's total from any subset of the PSUs selected for NASS GES. One can even use the original sampling weights, as long as one adjusts for the changed number of PSUs. Thus, one would estimate the total for the large suburban area of the South from the 7 PSUs with VINs by using the NASS GES weights multiplied with 8/7. Similarly, in the Central region, one would use factor 4/3 for all three land use strata[1]

This holds true as long as there are no systematic differences between PSUs with VINs, and without VINs, with regard to crash types and crash characteristics. That appears plausible in the South and Central regions. It appears questionable in the West where all missing VINs are in California and all PSUs with VINs are outside of

[1]This holds strictly only if samples were drawn with replacement. Otherwise, the situation becomes more complicated, and the adjustments shown above are only approximations.

California. California may well be sufficiently different from the rest of the West to make an expansion from the PSUs with VINs invalid. Therefore, a new region was defined: the West, excluding California. We call it briefly the "truncated West". The PSUs in the other states are a valid sample from this truncated West. To make estimates for the truncated West, the NASS GES weights were adjusted by the ratios of the crashes in the truncated West to crashes in the entire West, separately for the three land use strata. NHTSA provided the necessary data. However, for some initial analyses only rough estimates of the crash numbers could be used.

3.3 Validating the combination of FARS and selected NASS GES regions.

3.3.1 Some estimates for the entire country

In this section, some nationwide estimates based on the combination of FARS and NASS GES data are shown. They serve as basis for a comparison with estimates based on a combination of data from FARS states selected to match the selected regions of NASS GES.

FARS and NASS GES use the same codes for vehicle body style: 1-9 for cars, 14-19 for sport utility vehicles, 20-29 for vans, and 30-39 for pickup trucks. The rare car derivatives,10-13 were not used in the study. Later in the work vehicles were identified by VIN- decoded make/model. Then some miscodings of body style were found, but they were always less than, and usually much less than 2 percent of the cases.

These body style codes allow gross comparisons of the aggressivity of those four vehicle types. Table 3.3.1-1 shows the numbers of collisions by the types of vehicles colliding and the numbers of drivers killed by type of vehicle they were in, and by the types of vehicles.

Table 3.3.1-1 Numbers of collisions and drivers killed. Uppermost in each cell is the expanded number of collisions (1000) from NASS GES, below are the number of drivers killed in vehicles of type 1, and in vehicles of type 2. Data for 1991-97 from all states.

Vehicle 1	Vehicle 2			
	car	sport utility vehicle	van	pickup truck
car	26680 17189	1516.5 2999 520	2185.3 3426 565	4732.9 9967 2301
sport utility vehicle		120.5 98	128.1 118 114	289.5 347 378
van			236.2 162	420.0 391 512
pickup truck				1251.6 2018

From these numbers, the driver death rates in Table 3.3.1-2, and the ratio of the death rates - which is the same as the ratio of deaths - in Table 3.3.1-3 was calculated.

Table 3.3.1-2 Drivers killed per 1000 drivers involved by types of vehicle colliding. The upper numbers are for drivers of vehicle 1, the lower ones for those of vehicle 2 based on data in Table 3.2-1.

Vehicle 1	Vehicle 2			
	car	sport utility vehicle	van	pickup truck
car	0.64	1.98 0.34	1.57 0.26	2.11 0.49
sport utility vehicle		0.81	0.89 0.92	1.20 1.31
van			0.69	0.93 1.22
pickup truck				1.61

Table 3.3.1-3 shows that sport utility vehicles and vans have about the same gross - that is not adjusted for weight differences - aggressivity, while pickup trucks have only three quarters as much. The same ratio holds for the aggressivity of pickup trucks toward vans. However, while such gross comparison correctly reflect overall effects, they can not be meaningfully interpreted without studying the effects of vehicle weight and other factors.

Tables 3.3.1-3 Ratios of driver killed in vehicle 1 to those killed in vehicle 2 based on data in Table 3.3.1-3.

vehicle 1	vehicle 2			
	car	sport utility vehicle	van	pickup truck
car	1	5.8	6.1	4.3
sport utility vehicle		1	1.04	0.92
van			1	0.76
Pickup truck				1

In collisions between vehicles of different types, one can unambiguously define vehicle 1 and vehicle 2. In collisions between vehicles of the same type, that is not possible. Initially, when generating the data for Table 3.3.1-3, for collisions between vehicles of the same types, vehicle 1 was defined as that with the vehicle number 1 in the data file, and 2 correspondingly. Then, separate counts of drivers killed in vehicle 1 and in vehicle 2 were obtained. The resulting ratio of drivers killed in vehicle 1 to those killed in vehicle 2 was 1.27 for cars, 1.18 for sport utility vehicles, 1.10 for vans, and 1.22 for pickup
This shows a preference of police officers to first list on the crash report form the vehicle in which the driver is killed.

In Table 3.3.1-3, instead of these values, 1 is entered, because in collisions between two vehicles of the same type, both drivers face on the average the same risk. If one performs analyses where the death or survival of the driver of vehicle 1 is the dependent variable, and where vehicle 2 is the "other" vehicle, using the numbers 1 and 2 as assigned on the police report introduces a serious bias. To avoid this, we experimentally assigned number 1 and 2 randomly to the two vehicles in a collision where both vehicles were of the same type. This did not adequately remove the bias in more detailed analyses. Therefore, a different approach was used: each collision was used as two observations, once retaining the vehicle numbers 1 and 2, the other time exchanging them. This lead to the conceptually required symmetry. However, this had the effect that the data were no longer independent, which invalidates the error estimates obtained by standard statistical approaches. A heuristic correction is to halve the number of degrees of freedom obtained with the doubled data set. However, it is not clear whether this is valid when dealing with the complex sampling plan of NASS.

Table 3.3.1-2 shows that the risks for drivers in collisions between LTVs of the same type are always greater than that for drivers in collisions between two cars, 1.3 times for sport utility vehicles, 1.08 times for drivers of vans, and 2.5 times as great for drivers of pickup trucks. At first glance, this suggests that LTVs are less crashworthy than cars. However, there is the possibility that such collisions occur under different conditions, or that low speed collisions between sport utility vehicles or between pickup trucks result only in damage below the reporting threshold.

The body style codes allow from 1992 on a finer classification of LTVs. We used one shown in Table 3.3.1-4. It is striking that the driver death rates for the "other or unknown" subclasses were extremely low, where as those for the other two subclasses were much higher than those for the main classes in Table 3.3.1-4. A closer inspection of the data shows that in the NASS GES data files codes 19, 29 and 39 for unknown subclasses within each of the major vehicle classes are very frequent, whereas they are rare in the FARS data files. Therefore, matching FARS and NASS GES at the more detailed level of body codes is meaningless. If one needs a finer classification of the vehicles, one has to base it on the VIN.

Table 3.3.1-4 Collision between cars and LTVs, fine classifications of LTVs. Rates of drivers killed per 1000 involvements. Data for 1992-97 for all states.

vehicle car in colliding with	driver death rate per 1000 involvements		ratio of deaths
	in car	in LTV	
car	0.63		1
sport utility			
compact	2.84	0.55	5.1
large	4.26	0.41	10.4
other, unknown	0.50	0.06	8.3
van			
compact	2.15	0.52	4.1
large	6.86	0.75	9.2
other, unknown	0.24	0.03	9.1
pickup truck			
compact	2.35	0.88	2.7
large	5.60	0.82	6.9
other, unknown	0.07	0.03	2.5

3.3.2 Comparing nationwide estimates with those from selected states.

To assess whether the data from only part of the NASS-GES sample, together with matched FARS data, allow realistic estimates of fatality rates, the analyses of section 3.3.1 were repeated, using NASS GES data for the South and Central regions, and FARS data from the corresponding states. Table 3.3.2-1 shows the resulting rates which correspond to those in Table 3.3.1-2 which hold for the entire U.S.. In Figure 3.3.1-1, the regional rates are plotted versus the national rates. If the rates were equal, the points

Table 3.3.2-1. Drivers killed per 1000 driver involved, by types of vehicle colliding. The upper numbers are for drivers of vehicle 1, the lower ones for those of vehicle of type 2. Data for 1991-97 from the NASS regions South and Central.

vehicle 1	vehicle 2			
	car	sport utility vehicle	van	pickup truck
car	0.62	1.81 0.34	1.45 0.27	2.04 0.51
sport utility vehicle		0.84	0.91 0.74	1.10 1.32
van			0.64	0.89 1.21
pickup truck				1.67

would fall on the straight line, or scatter around it. Actually, they are close to the line, but a larger number of points falls below the line than above it. The death rates for car drivers, shown by asterisks, fall all below it. However, the points are still close to a straight line which shows lower values for the South and Central states than for the U.S. rates. One can think of a number of reasons for this. The vehicle population in the South and Central may differ from that in the Northeast and West. Indeed, small cars are somewhat more popular in the Northeast and on the West coast. That would cause real differences in the fatality risks. Another reason could be reporting thresholds which differ among the states; that would affect only the NASS GES data, because fatal crashes are reported everywhere. This question can be addressed by looking at Table 3.3.2-2 which corresponds to 3.3.1-3. The ratios shown in these tables depend only on FARS data and are therefore not affected by reporting thresholds. In Figure

Table 3.3.2-2. Ratios of drivers killed in vehicle 1 to those killed in vehicle 2. Data for 1991-97 from the NASS regions South and Central.

vehicle 1	vehicle 2			
	car	sport utility vehicle	van	pickup truck
car	1	5.4	5.4	4.0
sport utility vehicle		1	1.22	0.83
van			1	0.74
pickup truck				1

3.3.2-2, corresponding values from Table 3.3.2-2 and 3.3.1-3 are plotted. Again, as in Figure 3.3.2-1, the points fell close to, but not symmetrically around the line representing equality, though they could be represented by a straight line which is not much different. Noteworthy is that the three points on the right which represent collisions between cars and LTVs are similarly positioned relative to the line as the three asterisks in Figure 3.3-1. This suggests that systematic differences between the points and the line in Figure 3.3-1 are not primarily due to reporting differences, but to real differences in fatality risks. Therefore, findings from the study of the South and Central region can not be exactly applied to the entire U.S., though they seem to be reasonable approximations.

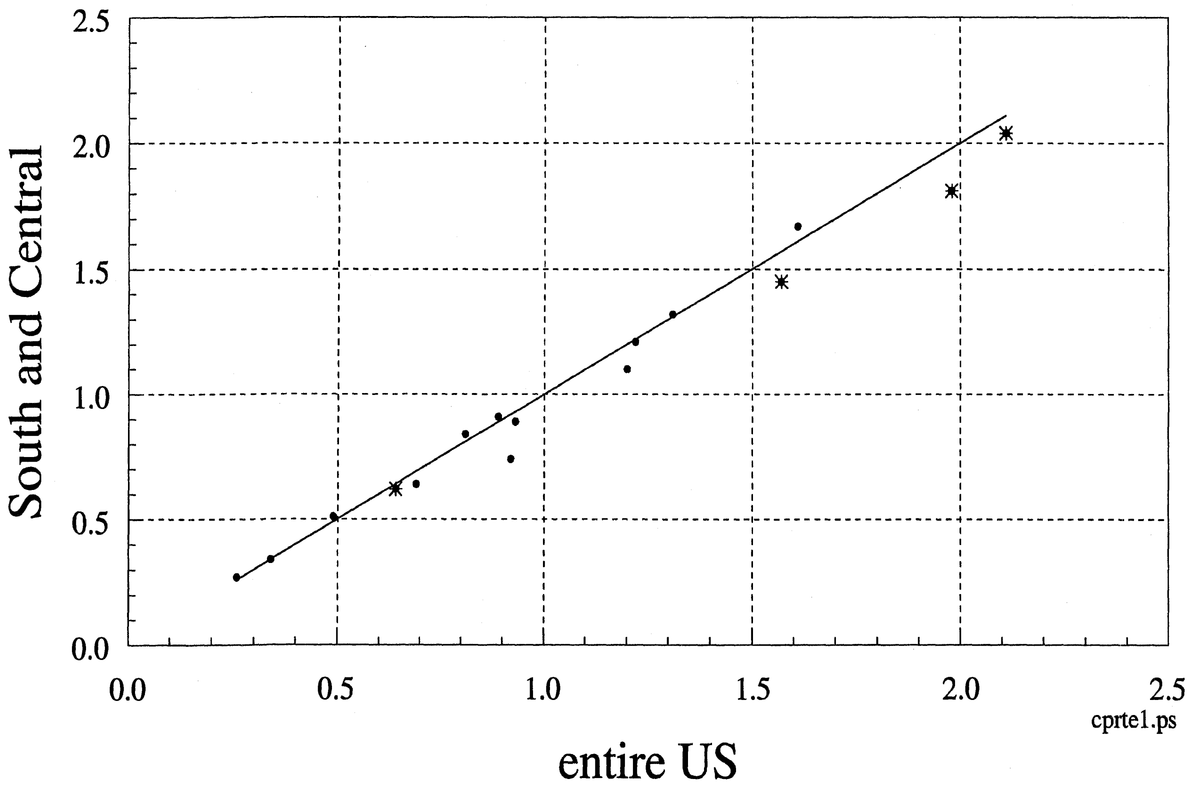

Figure 3.3.2-1 Driver fatality rates per 1000 involvements for the 16 combinations of 4 vehicle types in collisions. Estimates from the NASS regions South and Central versus estimates from the entire U.S. data. Asterisks indicate fatality rates for car drivers. The line represents equality of the estimates.

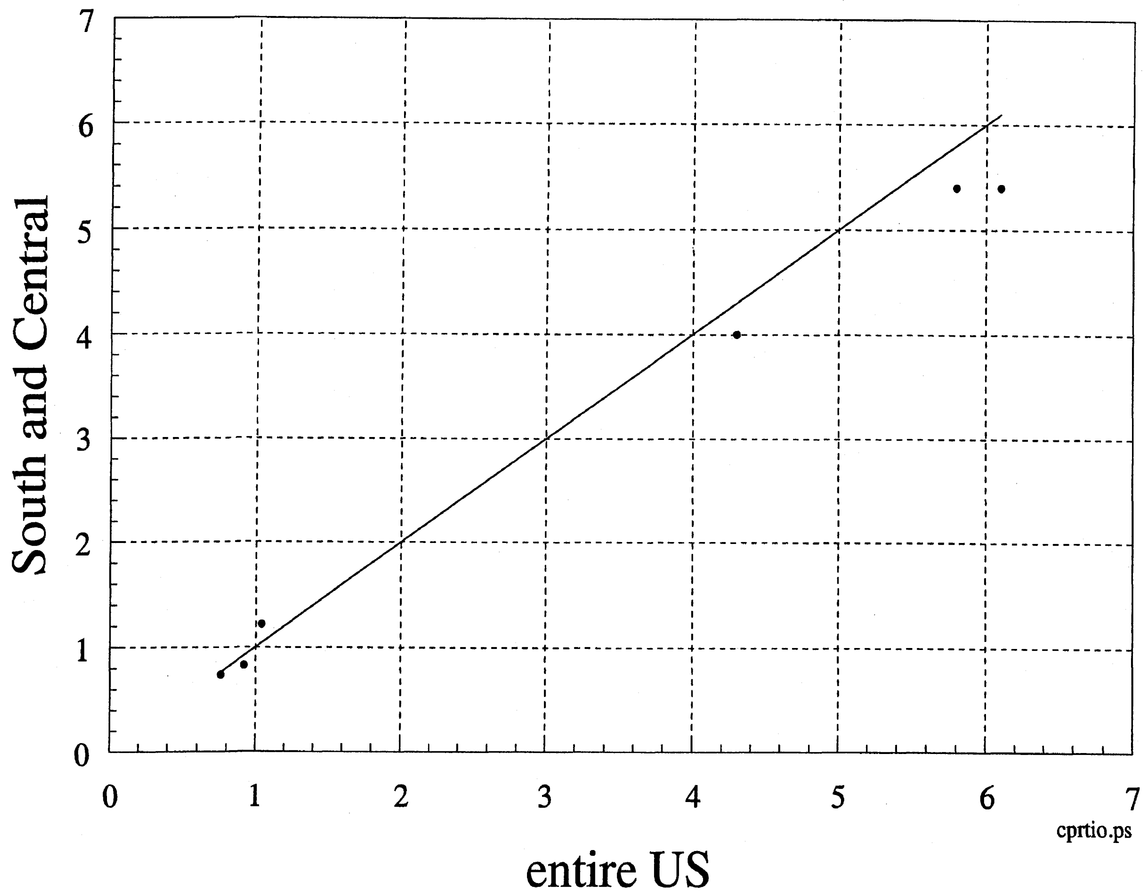

Figure 3.3.2-2. Ratio of driver fatalities in 6 types of collisions, involving the combinations of 4 types of vehicles. Estimates from the NASS regions South and Central versus estimates from the entire U.S. data. The three points to the right represent collisions between car and the three LTV types. The line represents equality of the estimates.

Such differences can be due to factors such as the composition of the vehicle populations in terms of weight and age (which reflect differences in safety standards), differences in exposure in terms of speed environments, collision configurations, and accessibility of emergency medical services, driver characteristics, such as age, sex, belt use, and alcohol involvements. Some of these factors are being controlled for in the more detailed analyses. This should reduce the discrepancies between estimates based on the South and Central, and those based on the entire U.S.

The same analyses were performed using data from the South, Central, and West and from the South, Central and truncated West, the latter being ultimately used in the analyses. Tables 3.3.2-3 through 6 show data corresponding to 3.3.2-1 and 2.

Table 3.3.2-3 Driver killed per 1,000 drivers involved. The upper numbers are for drivers of vehicle 1, the lower one for driver of vehicle 2. Data for 1991-97 for the NASS regions South, Central, and West

vehicle 1	vehicle 2			
	car	sport utility vehicle	van	pickup truck
car	0.64	1.98 0.34	1.57 0.26	2.11 0.49
sport utility vehicle		0.81	0.92 0.89	1.20 1.31
van			0.69	0.93 1.22
pickup truck				1.61

Table 3.3.2-4 Ratio of driver killed in vehicle 1 to those killed in vehicle 2. Data for 1991-97 from the NASS regions South, Central, and West.

vehicle 1	vehicle 2			
	car	sport utility vehicle	van	pickup truck
car	1	5.8	6.0	4.3
sport utility vehicle		1	1.3	0.92
van			1	0.76
pickup truck				1

Table 3.3.2-5 Driver killed per 1,000 drivers involved. The upper number are for drivers of vehicle 1, the lower ones for driver of vehicle 2. Data for 1991-97 for the NASS regions South, Central, and West excluding California.

vehicle 1	vehicle 2			
	car	sport utility vehicle	van	pickup truck
car	0.62	1.86 0.34	1.47 0.26	2.04 0.50
sport utility vehicle		0.84	0.92 0.88	1.18 1.37
van			0.62	0.89 1.20
pickup truck				1.63

Table 3.3.2-6 Ratio of drivers killed in vehicle 1 to those killed in vehicle 2. Data for 1991-97 from the NASS regions South, Central and West excluding California.

vehicle 1	vehicle 2			
	car	sport utility vehicle	van	pickup truck
car	1	5.5	5.7	4.1
sport utility vehicle		1	1.05	0.86
van			1	0.74
pickup truck				1

In sum, it appears that the combination of NASS GES data for the regions South, Central, and West excluding California results in driver death rates by which type close to those for the entire country, at least for the selected vehicle types and two-vehicle collisions.

Figures 3.3.2-3 and 3.3.2-4 correspond to Figure 3.3.2-1. The difference is that Figure 3.3.2-3 shows only the points for vehicle 1, Figure 3.3.2-4 only the points for vehicle 2. Distinguished by symbols are data for the South and Central region, for South, Central, and West, and South, Central and West excluding California. In both Figures, the points for the South, Central, and West excluding California tend to be closest to the line representing equality. Surprising is that, whereas there is a slight systematic deviation from the line in the case for vehicle 1, there is practically none for vehicle 2.

Figure 3.3.2-5 corresponds to 3.3.2-2. In this case, the points for the South, Central and the entire West are slightly closer to the line than those for the South, Central, and West excluding California. This is not surprising, because the ratios depend only on FARS, not on NASS GES data,

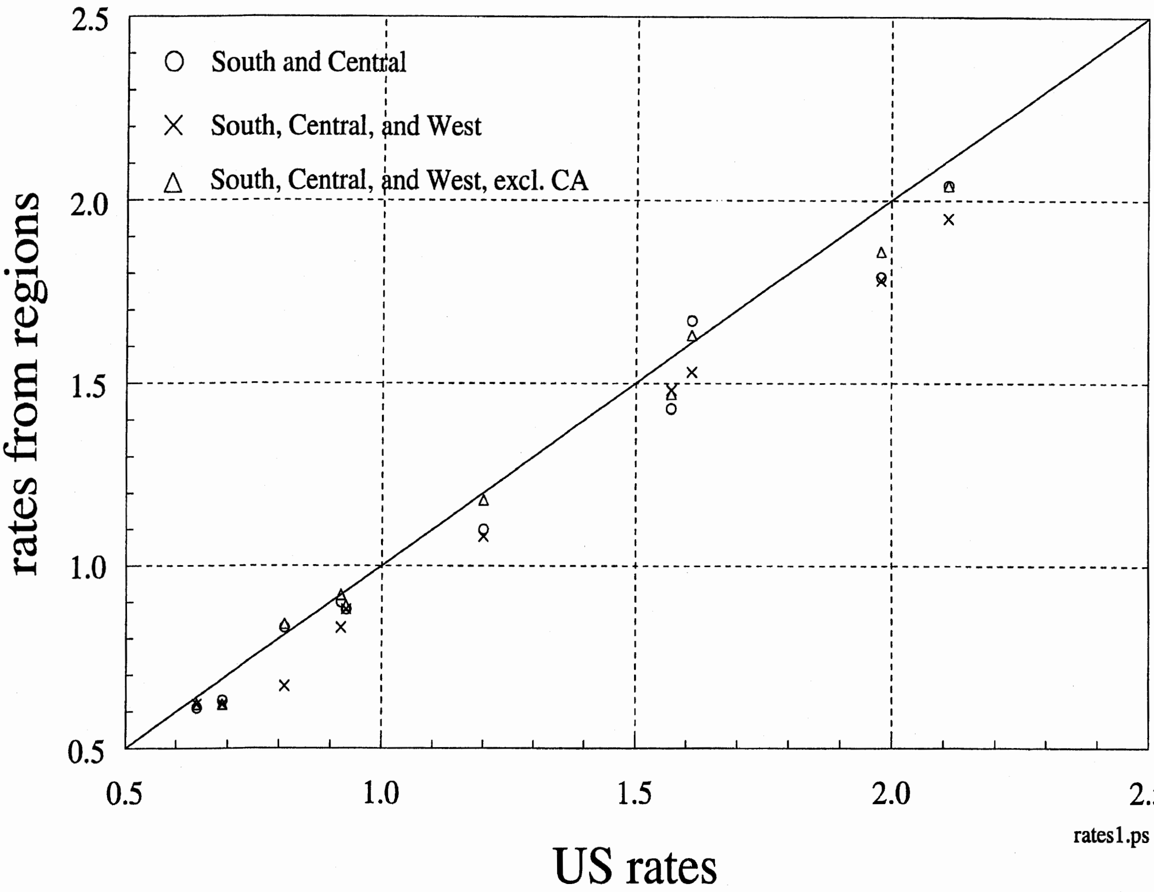

Figure 3.3.2-3 Fatality rates per 1000 involvements for drivers of vehicle 1 in collisions involving car and for LTVs, estimated from data for selected regions, versus estimates for the entire U.S. The line represents equality of the estimates.

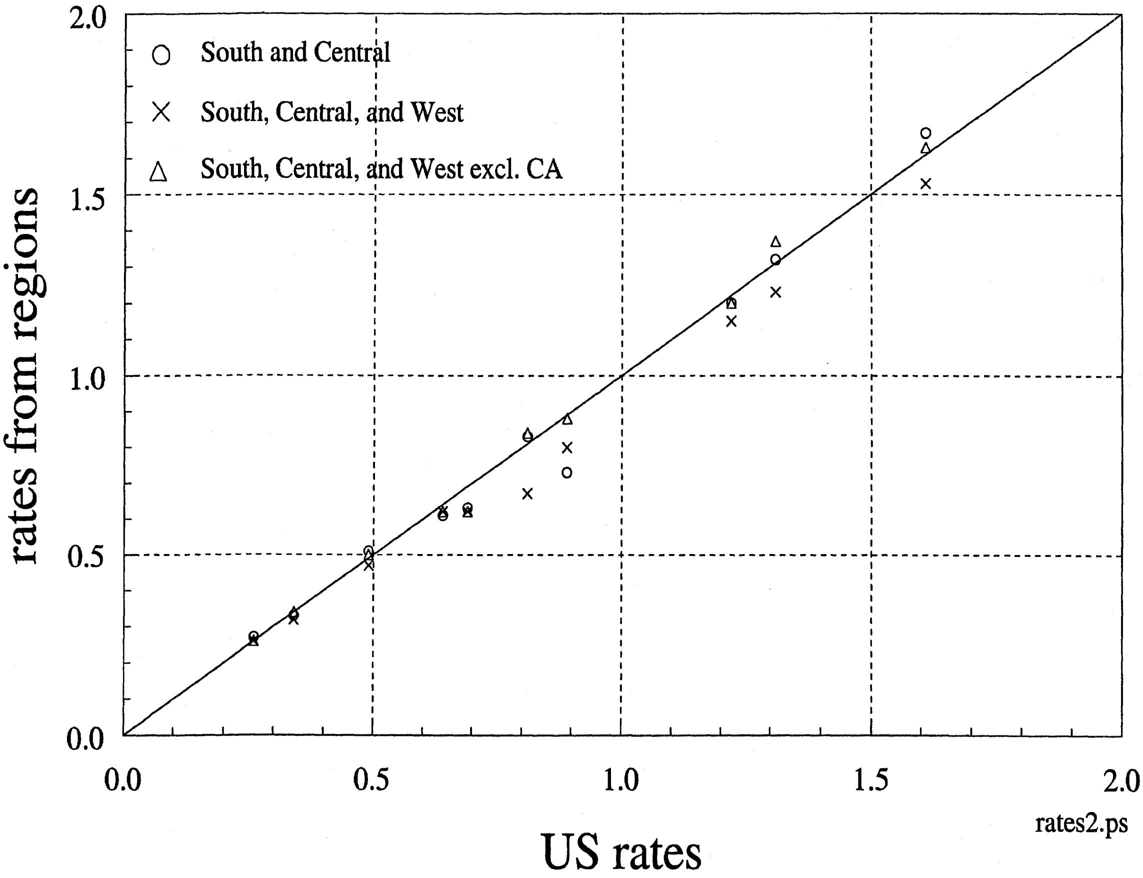

Figure 3.3.2-4 Fatality rates per 1000 involvements for driver of vehicle 2 in collisions involving car and/or LTVs, estimated from data for selected regions, versus estimates for the entire U.S. The line represents equality of the estimates.

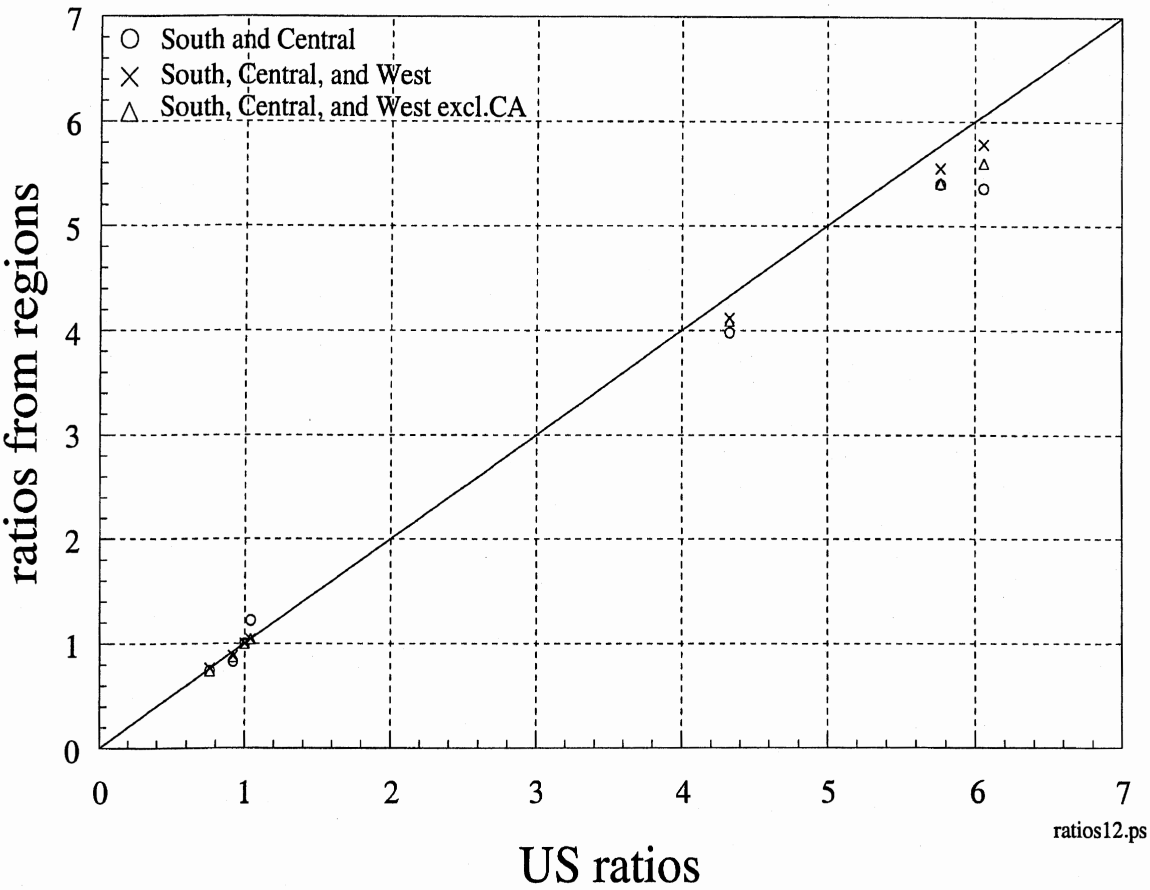

Figure 3.3.2-5 Ratio of driver fatalities in collisions involving car and LTVs. Estimates from selected regions versus those for the entire U.S. The line represents equality of the estimates.

4. Analysis

4.1 Analytical Approaches

The objective of the analysis is to estimate the aggressivity of cars and LTVs, and to determine how the aggressivity depends on selected vehicle characteristics. Aggressivity is measured by the fatality risk to one vehicle's driver, in relation to the other vehicle's class or physical characteristics. Many factors influence the fatality risk of a driver. Known are the effects of driver age, suspected are effects of driver sex, known are effects of seat belts, if used, of air bags, and of the crashworthiness of his/her vehicle. It is known that - aside from its effect on crash occurrence and possibly crash severity in physical terms - alcohol increases the risk of dying from injuries, after controlling for injury severity. Also known are effects of the two vehicles' weights, of collision speed, and of collision configuration. Knowledge about these effects, however, is disparate, often quantitatively very crude, and practically nothing is known about their inter-actions. However, some of these effects are probably larger than the aggressivity to be studied, therefore, they should be controlled for.

There are several ways to control the effects of such confounding factors. The conceptually simplest one is case matching. If one wants to compare the aggressivity of two LTV types, one selects two sets of collisions, one containing collision involving cars and one of the LTV types, the other set with collisions of cars and the other LTV type. One identifies the factors one wants to control for, and selects from each of the sets a collision so that the studied factors are equal or sufficiently similar. Comparing the number of deaths in cars in the two sets, shows the relative aggressivity of the two LTV types. This approach requires minimal assumptions, but a very large computational effort. The closer one requires the matching to be, the lower the number of cases one can match. That reduces the accuracy of the comparison. Another shortcoming is that it compares aggressivity only for the types of collision which are "overlapping" in terms of the control factors. If one extends the comparison to more than two vehicle types, the overlapping sets can differ and the pairwise comparisons become inconsistent.

Another approach is to develop a model for the driver fatality risk, as a function of personal characteristics, the characteristics of the vehicle, collision characteristics, and the characteristics of the other vehicle, including those suspected to cause aggressivity. While this approach is conceptually sound, it has some serious disadvantages. One is that a realistic model must be mathematically complicated and that one has no theoretical basis for assuming any mathematically function and interactions between such functions. The common approach in such a situation is to use an additive linear model, perhaps including some quadratic terms and product terms for interactions, but experience shows that such models may at best represent adequately a narrow range of the parameters, where the majority of cases is concentrated, but can show gross systematic deviations for vehicles which differ more from the average. A similar effect occurs in a population which is dominated by one collision type, in this case collisions between two cars. Then, though the model may appear to be well fitting, it may in fact, show gross systematic directions for the rarer collisions of, e.g., cars and pickup trucks. Such effects of poor model specifications may falsely be interpreted as effects of aggressivity.

Therefore, a third approach may be considered. A "baseline" model for the collision between two cars is developed. It is based on a large number of collisions. Therefore, the model fit can be tested also for systematic deviations. This model is then applied to collisions between a car and a LTV. It gives the probability of the car driver fatality, if the car had, under the same conditions, collided with a car instead of a LTV. The difference between this probability, and the outcome of the collision - 0 if the car driver survived, 1 if he was killed - is used as dependent variable in a second level analyses relating it to characteristics of the LTV. This variable will be called "risk increase".

This approach has a subtle statistical weakness compared with using a model incorporating the characteristics of both vehicles and the collision simultaneously, but we consider it less important than the potential pitfalls of that approach.

If one is interested in the effects of certain parameters, which quantify aggressive features of the "other" vehicle, the direct approach is to relate these parameters to the risk increase (or perhaps the risk itself, if the confounding factors are included with the parameters), without regard to the type of other vehicle. The rational would be that the selected parameters capture all features contributing to aggressivity.

This direct approach is illustrated in Figure 4.1-1 where the risk increase (and also the risk) for a car driver in a collision is plotted versus the height of the center of force of the other vehicle, be it a car or an LTV. A very clear, non-linear relation appears (the large fluctuations for the greatest heights of the center of force are explained by the low case numbers on which the points are based). However, a look at Figure 4.4.1-4 where 4 types of other vehicles are distinguished shows that the smooth relation in Figure 4.1-1 is the result of averaging four very different relations. To avoid such pitfalls, the following analyses are performed separately for the four types of "other" vehicles.

Another important aspect is that the aggressivity of vehicles might depend on where they impact a car. In a frontal impact, the effects of a parameter might be different from that in a near-side (left for the driver) impact, and that might be different from that in a far-side (right for the driver) impact. If a factor has a strong effect in several types of impacts, one should recognize it in the set of all collisions. If the effect is primarily in one type of impact, one might be able to recognize it only in the specific cases affected. Studying those cases separately will show the "undetected" effect of the factor, but the smaller case number will increase the random errors and thereby make it more difficult to recognize an effect.

Therefore, in addition to all collisions without regard to configuration, front-front, front-left, and front-right collisions were studied separately. Identifying these collision configurations is not straightforward. FARS codes planar impact points on a "clock" scale from 1-12. NASS GES provides codes for front, left, right, and back, and for the four corners. There is no unambiguous correspondence between the two coding schemes. A closer inspection of the police accident report forms, which are the ultimate source of FARS and NASS GES data shows that the original codes differ among states and that not all are unambiguously translatable into the FARS, or the NASS GES codes, except perhaps if the officer provided a detailed sketch of vehicle damage. Experiments with various definition of "front", etc. were conducted to determine which ones gave consistent and plausible results. It was decided that 12 in FARS, and "front" in NASS GES was used to define the frontal impact, 8,9,10 and "left" the left side, and 2,3,4 and "right" the right side. Cases with codes 11 and 1, and "front left" and "front right" corners were omitted because they seemed to be not unambiguously defined.

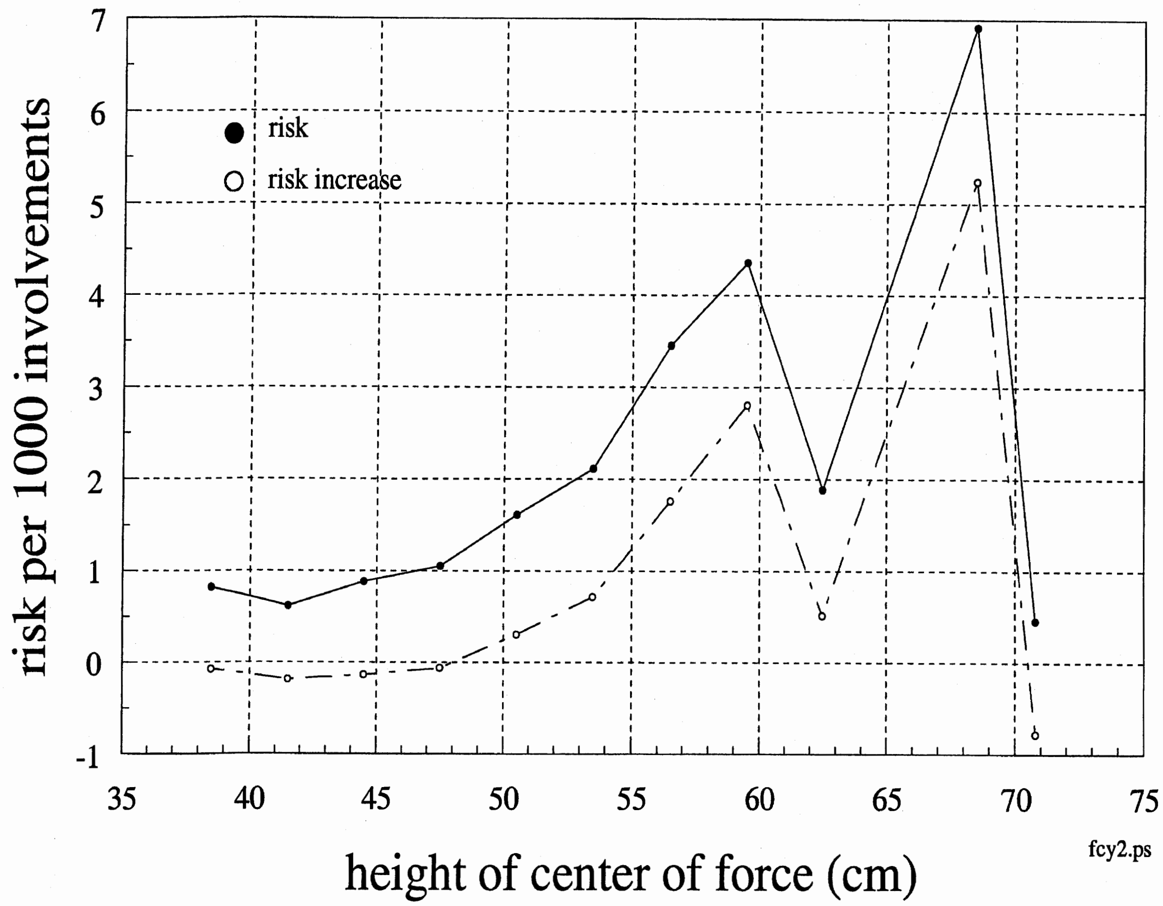

Figure 4.1-1 A misleading apparent relation between car driver risk, and risk increase per 1000 collision involvements and height of the center of force of the other vehicle. The different types of the other vehicle are not distinguished. Figure 4.4.1-4 shows how the relation is composed of different relations for the four vehicle types.

4.2 Controlling for confounding factors

The factors of interest which were used in this study are vehicle characteristics which influence the fatality risk of occupants of the other vehicle in the collision. In this study, static and dynamic stiffness were obtained by NHTSA from barrier crash tests, as was the height of the center of force - which was used as proxy for the height of the main structural elements of a vehicle. Vehicle weight was also included, though it may also be considered a confounding variable rather than of primary interest.

Confounding variables express other factors that influence the fatality risk but are not of primary interest for the study. One wants to control for their influences in order to better recognize any effect of the factors of interest. It is useful to distinguish internal and external confounding factors. Internal factors relate to the study vehicle and its occupants. Examples are vehicle weight, presence and deployment of air bags, crashworthiness as measured in crash tests, and even vehicle age - not because age itself has a physical effect on the fatality risk, but because it can be related to more subtle factor which have a physical effect. Occupant factors are age and sex, presence of blood alcohol, restraint use, and possibly even height.

If one has large numbers of collisions involving vehicles of each type (or make/model in more detailed analyses) the effects of such factors will tend to average out, except if there are correlations between driver characteristics and collision speeds and configuration, and perhaps even the type of LTVs they are colliding with. In such cases, ignoring the confounding factor leads to biases. Otherwise, ignoring the confounding factor leads only to greater random variability, and therefore to greater uncertainty of the findings.

External confounding factors are collision configuration, travel speed, and possibly the availability of emergency medical services which reduce the risk of deaths from injuries suffered in a collision.

Again, it could be that the effects of these factors average out if case numbers are large, only increasing the uncertainty of the findings. However, it appears plausible that these factors differ systematically between car-car and car-LTV collisions, and possibly also between collisions with different types of LTVs. Therefore, more attention was paid to these factors.

A large number of analyses was performed, using the weights of the two vehicles, the speed limit as an indicator of travel and impact speeds, collision configuration, the presence of air bags, and driver age and sex. Some illustrative findings are shown in Appendix 1. Safety belt use was not considered because it is considered unreliable in reports for non-fatal crashes, and even for many fatal ones. Similarly, information on blood alcohol is not complete and lack of an indication of alcohol does not mean that alcohol was not involved. Crashworthiness was initially considered, but not used because it is more complex than the other factors and would have required extensive modeling effort.

The result of the extensive exploratory analyses and modeling was that within the scope of this study, one could not develop a model which satisfactorily incorporated all the factors that, each by itself, showed a relation with driver fatality risk.

Retained were the collision configuration, the weights of the two vehicles, and the speed limit. With these factors, a "baseline" model as defined in the preceding section - for collisions between two cars was developed.

A first finding was that it was not necessary to use both weights separately in the models using the ratio of the two weights gave nearly as good a model. Adding one vehicle's weight did not improve the model noticeably, and adding both leads to a largely indeterminate model, as to be expected because of the correlations between weights and their ratio. Surprising was that the fatality risk for the driver of one car was, over a wide range of weight ratios, practically a linear function of the ratio of the other vehicle's weight to his vehicle's weight.

The fatality risk increases with the speed limit. Overall, the increases is highly non-linear and cannot be represented by a simple mathematical function. There is also some "fine structure": the risks at 35 mph are often only little higher than those at 30 mph, and sometimes they are lower. There is a "jump" between 50 and 55 mph, and at the higher speeds the increase is not always monotone. This is not surprising because daily experience shows that speed limits and actual travel speeds, especially speeding, are not closely correlated. One can only expect that, on the average, collisions on a road with a 55 mph limit have higher impact speeds than on a road with 30, 35, and 40 mph, and perhaps even 45 and 50 mph.

Attempts to develop a bivariate model combining the weight ratio and speed limit in an analytical model were not more successful. Therefore, a series of models was developed, one for each of certain ranges of speed limits. Figures 4.2-1 to 4 show the basis for such models for the speed limits of 25, 30 and 35, 40 through 50, and 55 and above. In all figures the points representing the majority of cases fall closely around straight lines. Only points for very low or high weight ratios sometimes deviate widely, but they are based on few cases. These figures are based on "binned" data with each point combining cases with weight ratios in ranges of 0.4.

Figure 4.2-5 shows the final model for all collision configurations. It was derived by fitting for each speed limit range a linear model based on individual cases,

$$p=a+b*x \qquad (4.2-1)$$

where *x* is the weight ratio. The speed limits 40, 45 , and 50 were treated differently.

For them, a model

$$p=a+b*x*(y-c) \tag{4.2-2}$$

fitted the data well. *x* is the weight ratio, and *y* the speed limit.

Figures 4.2-6 through 8 shows the corresponding models for the front-front, front-left, and front-right collisions. In the case of front-left collisions, a model of the form (4.2-2) did not fit the data satisfactorily, but a model of the form

$$p=a+b*x+c*y \tag{4.2-3}$$

did.

Table 4.2-1 shows the coefficients of the models used in the subsequent analyses.

Table 4.2-1 Coefficients for baseline models relating driver fatality risk to weight ratio in car-car collisions and speed limits. Models defined by (4.2-1) and (4.2-2). The coefficients marked with an asterisk are for model (4.2-3).

configuration	speed limit	coefficients		
		a	b	c
all	25	-0.08	0.20	
	30,35	-0.02	0.54	
	40,45,50	-0.31	0.076	29.4
	>=55	0.33	5.2	
front-front	25	-0.54	0.97	
	30,35	-1.7	3.8	
	40,45,50	-3.3	1.0	34.7
	>=55	14.5	38.4	
front-left	25	-0.25	0.70	
	30,35	-0.13	1.1	
	40,45,50	-9.8*	2.4*	0.22*
	>=55	-3.9	19.6	
front-right	25	-0.1	0.2	
	30,35	-0.8	1.3	
	40,45,50	-1.5	0.17	27.3
	>=55	-4.1	14.9	

While the models do not differentiate speed limits of 55 mph or higher, this does not imply that there is no effect of speed in this range. There is a suggestion that the risk is increasing with the speed limit, but no satisfactory simple bivariate model could be fitted to the sparse data. Since we considered the weight ratio more important for this study, we placed more emphasis on developing a simple model with regard to weight ratio.

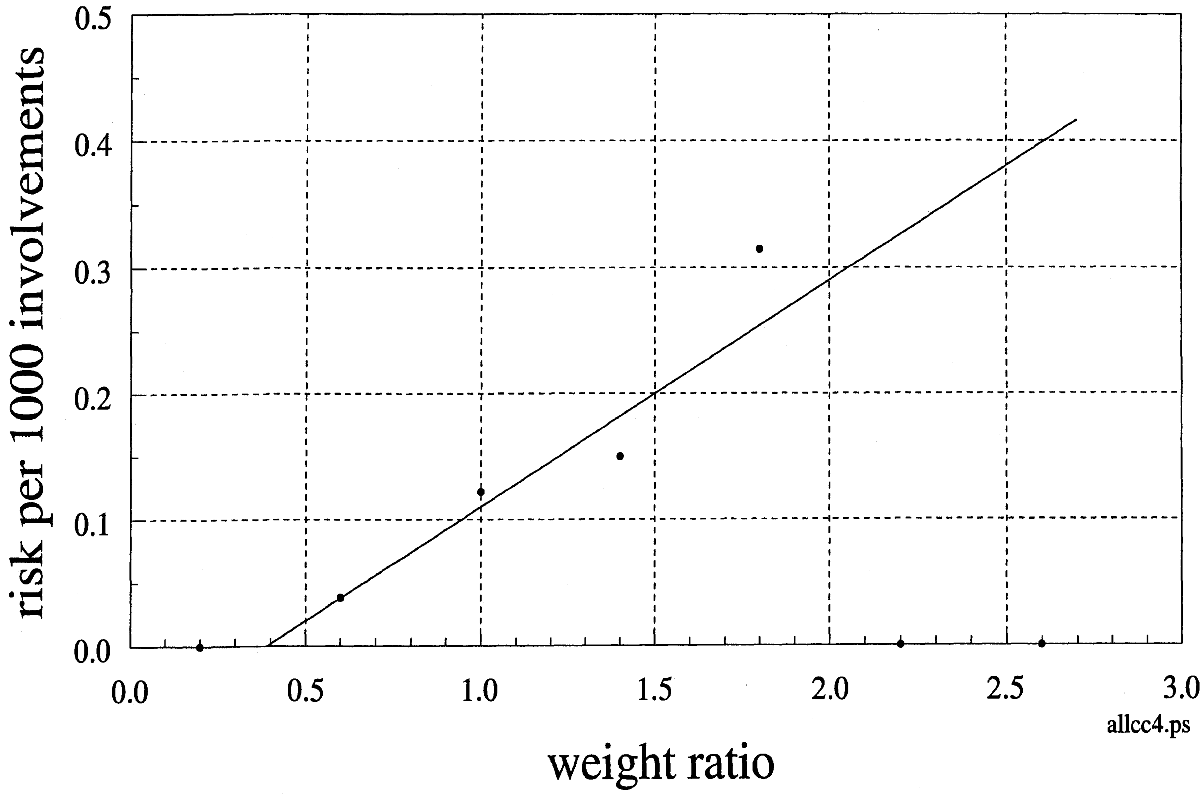

Figure 4.2-1 Driver fatality risk in car-car collisions versus vehicle weight ratios, when the speed limit was 25 mph. The points with high or low weight ratios are based on few cases.

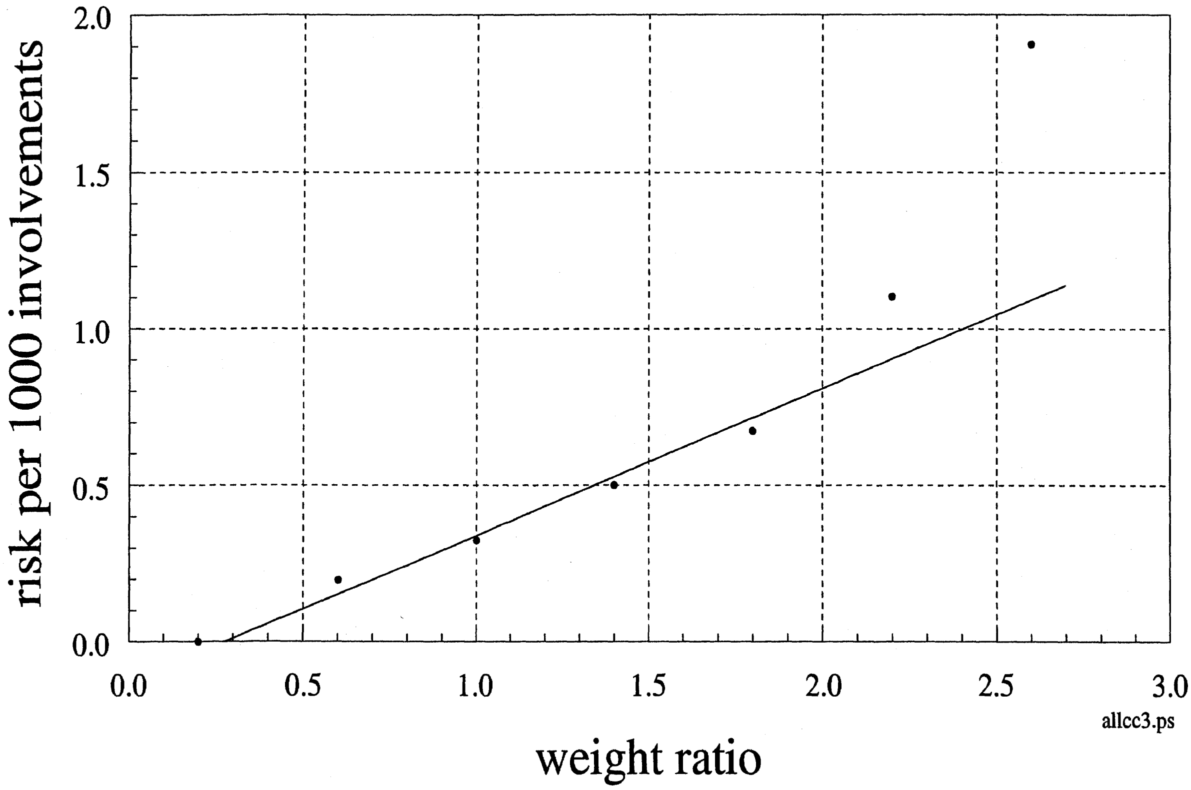

Figure 4.2-2 Driver fatality risk in car-car collision versus vehicle weight ratio, when the speed limit was 30 or 35 mph. The points with high or low weight ratios are based on few cases.

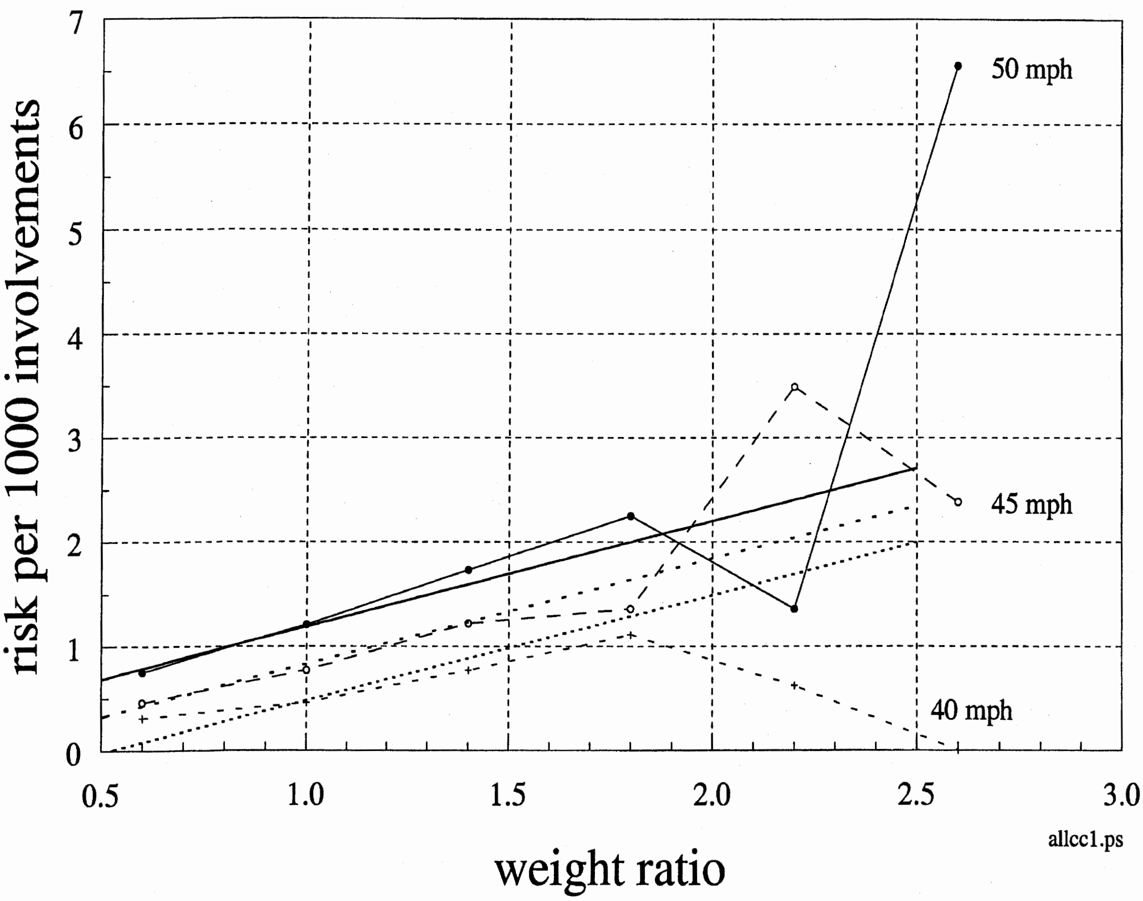

Figure 4.2-3 Driver fatality risk in car-car collisions versus vehicle weight ratio, when the speed limit was 40, 45, or 50 mph. Points with high or low weight ratios are based on few cases.

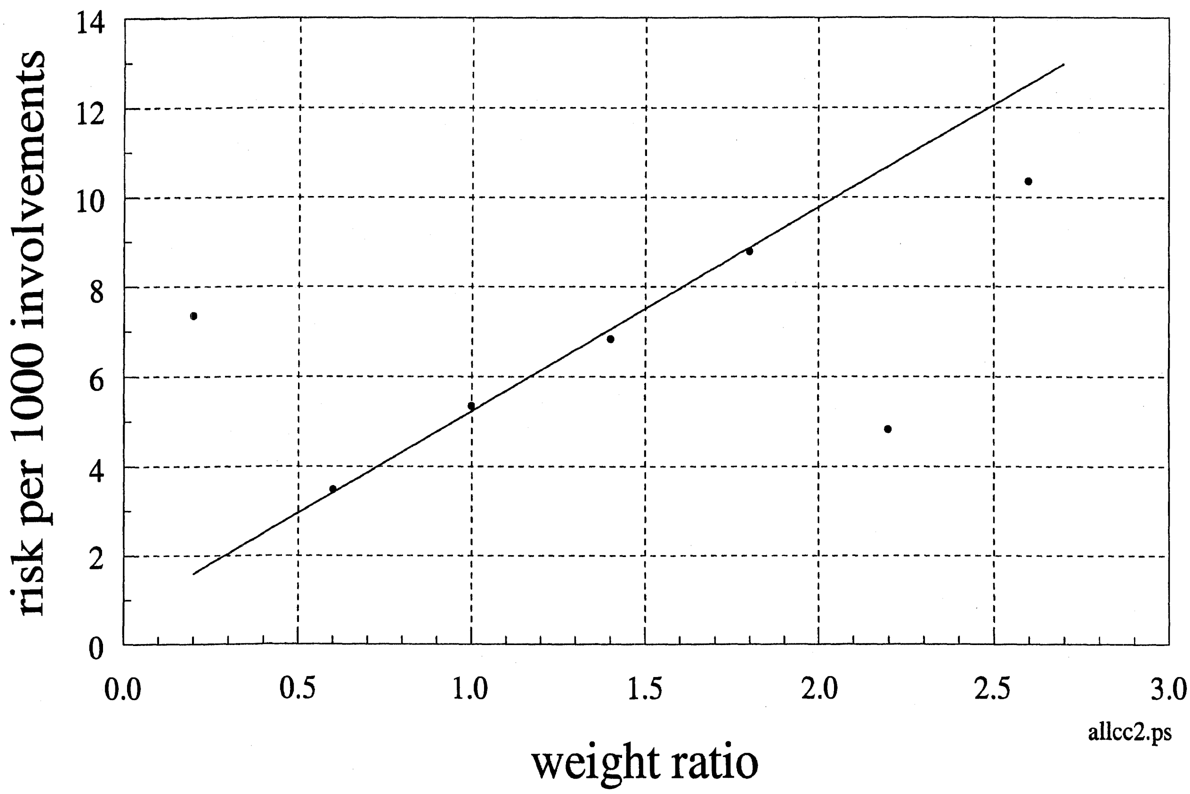

Figure 4.2-4 Driver fatality risk in car-car collisions versus vehicle weight ratio, where the speed limit was 55 mph or higher. Points with high or low weight ratios are based on few cases.

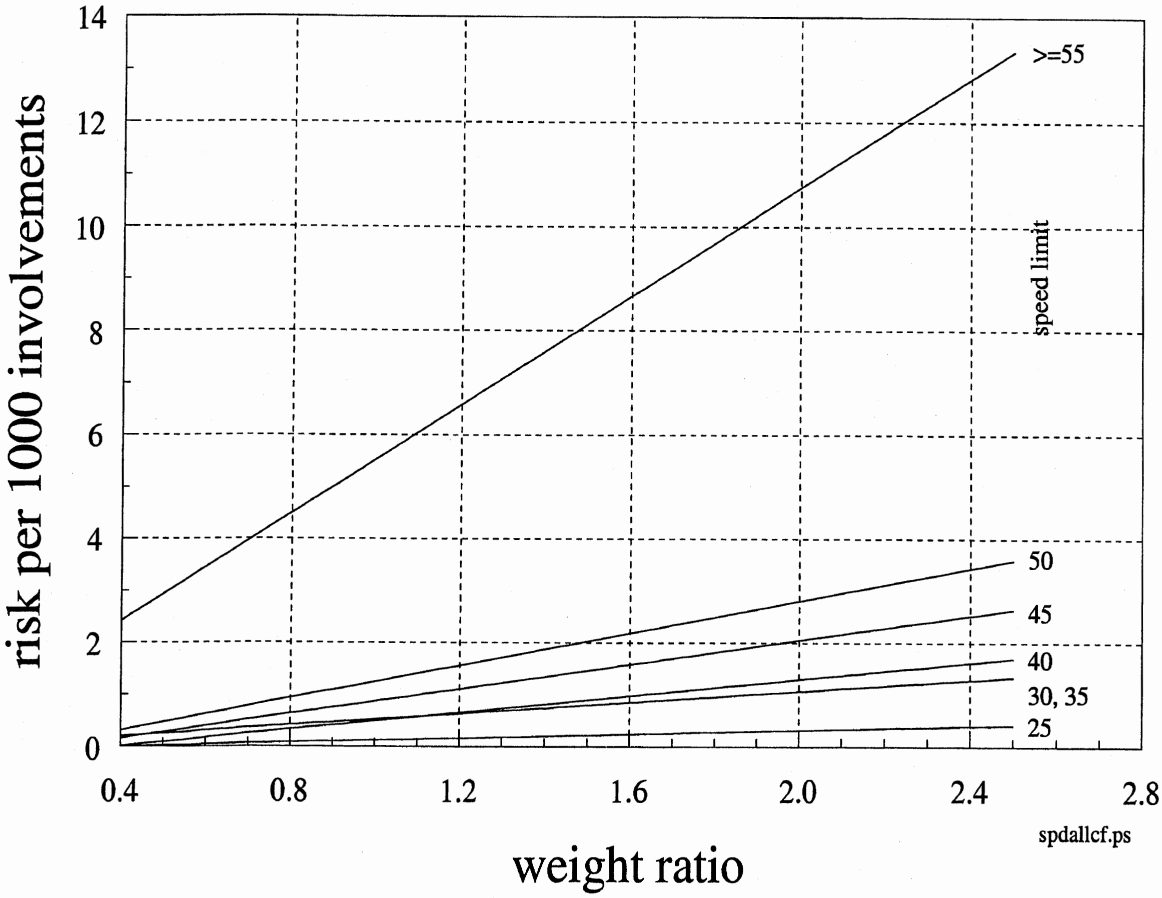

Figure 4.2-5 Model for driver fatality risk in car-car collisions, for all configurations.

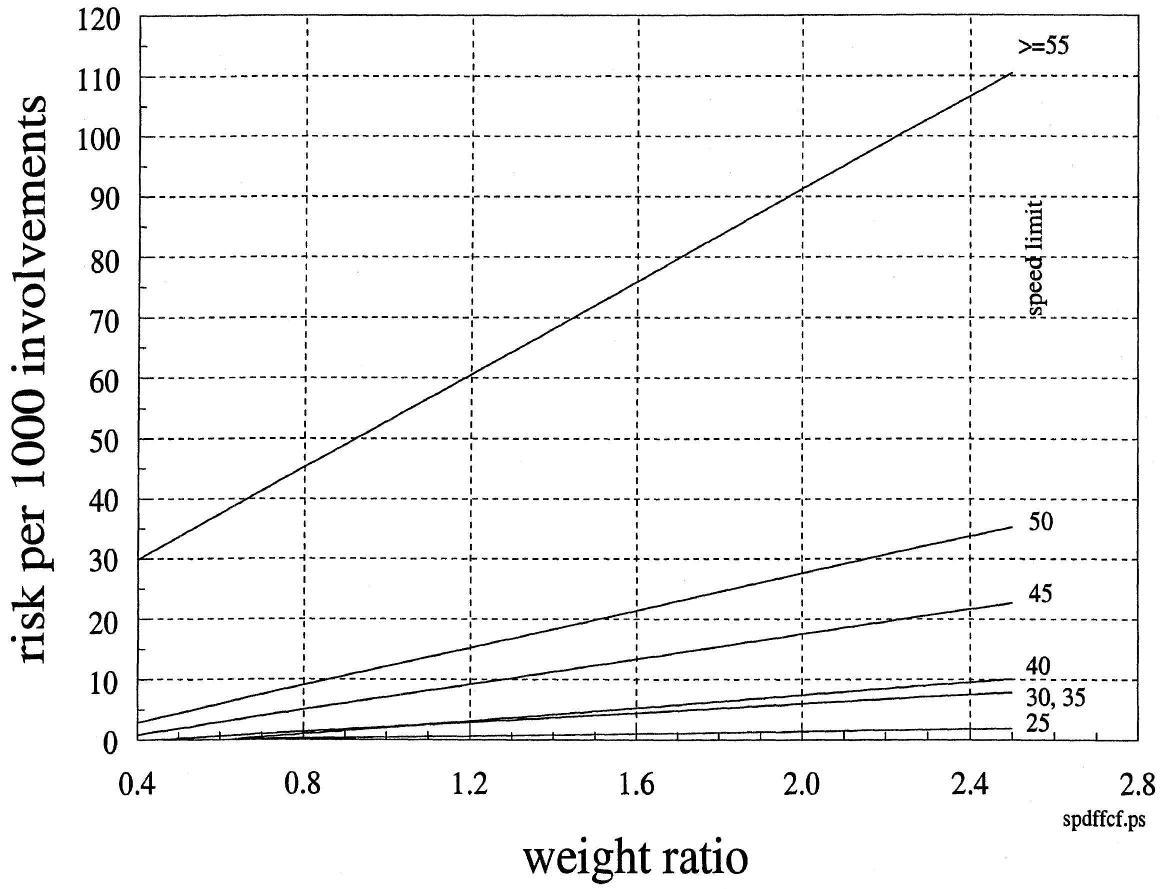

Figure 4.2-6 Model for driver fatality risk in car-car collisions front-to-front.

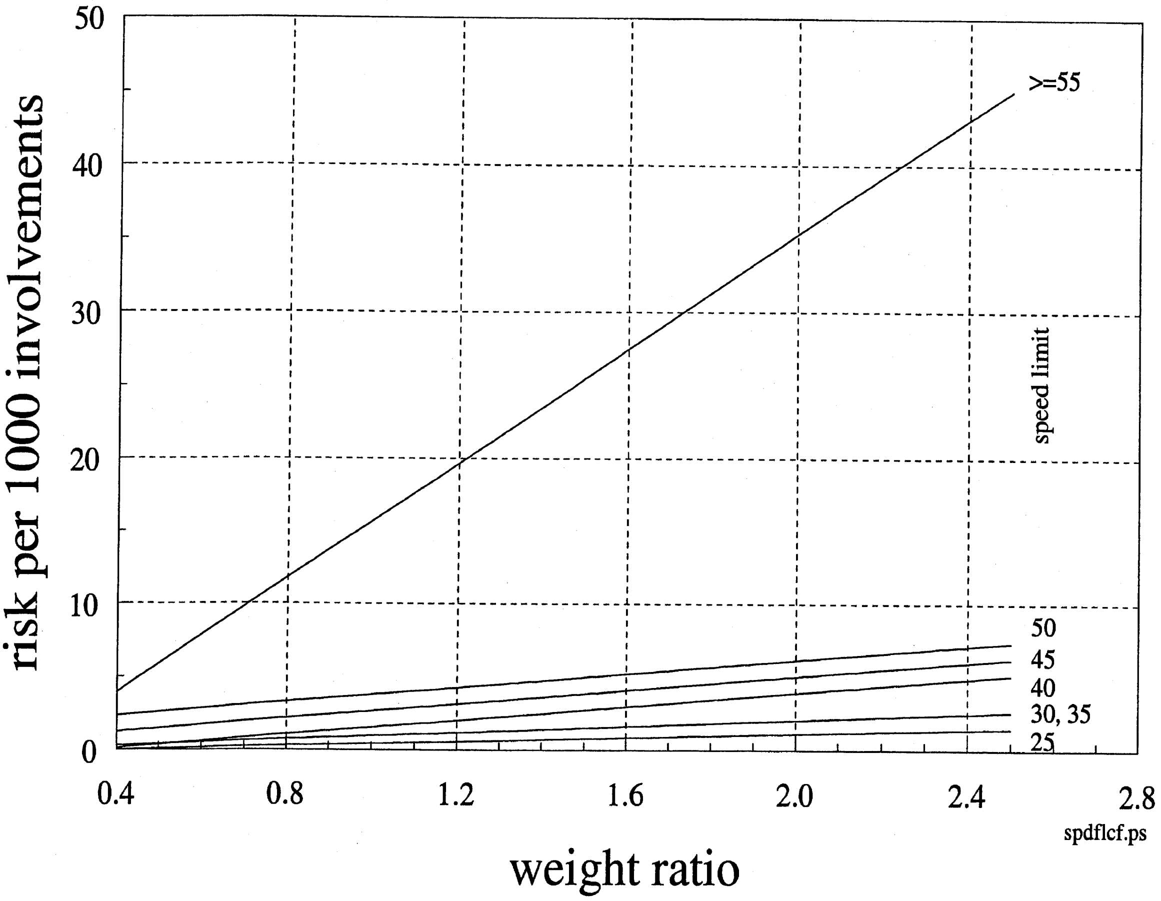

Figure 4.2-7 Model for driver fatality risk in car-car collisions, front-to-left.

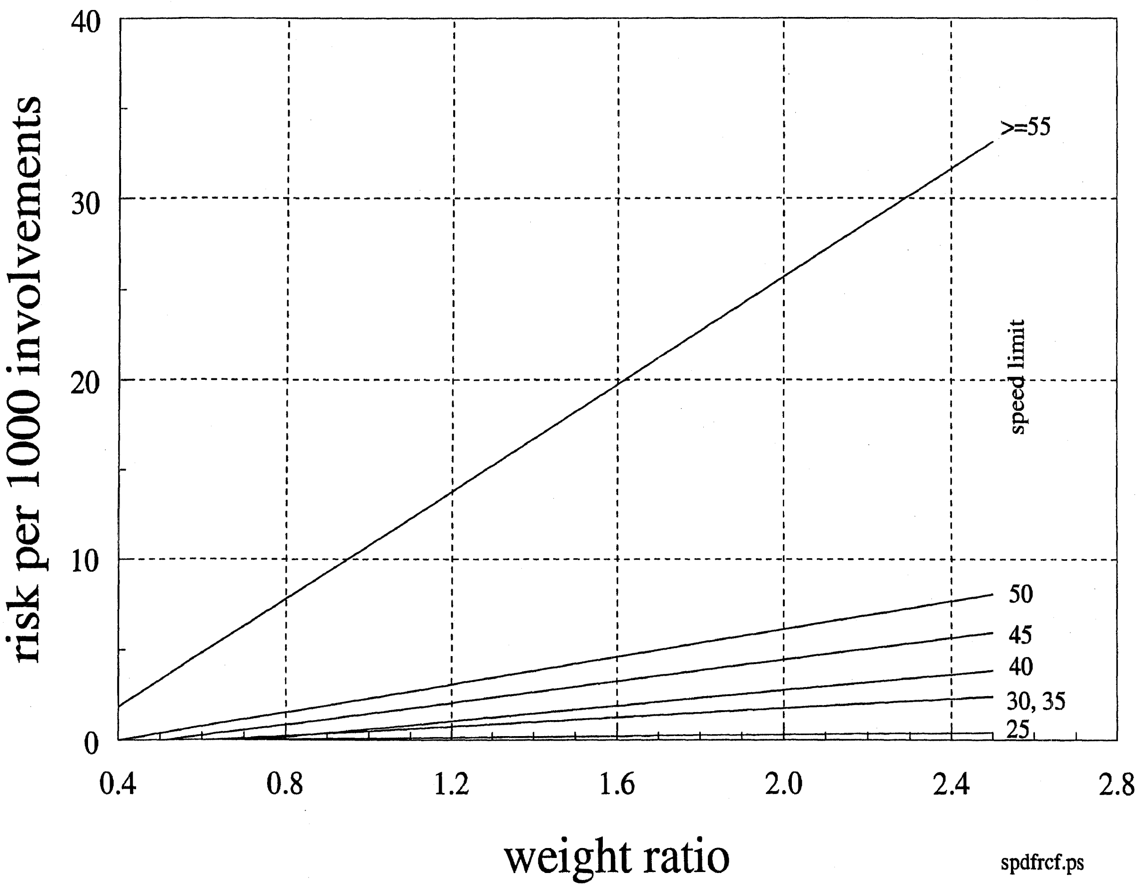

Figure 4.2-8 Model for driver fatality risk in car-car collisions, front-to-right.

4.3 Comparing vehicle classes

As a first step in the analyses, the overall aggressivities of the three classes of LTVs - sport utility vehicles, vans, and light trucks - were estimated and compared. For each case, the probability of the car driver's death in a collision with another car was calculated using the models described in section 4.2, assuming the same speed environment, and the other car having the same weight as the LTV in this collision. These probabilities were combined using the NASS GES weights for NASS GES cases, for each class of "other vehicle", giving the expected numbers of deaths in these collisions if the "other vehicle" had been a car of the same weight of the LTV. These numbers were compared with the actual numbers of deaths in these collisions.

Table 4.3-1 shows the results. To check the validity of the approach, car-car collision were also included. They show for all collision configurations practically the same expected numbers as actual numbers. In collisions between cars and LTVs, the actual numbers are always substantially higher than the expected numbers. For example, in all collisions with sport utility vehicles, the actual number of death was 441, compared with the expected number of 129 - 3.4 times as many. In frontal collisions with sport utility vehicles, the ratio is even greater: 120/19=6.4. The ratio is lower in frontal collisions with vans: 133/95=1.4.

Table 4.3-1. Number of car drivers killed by other vehicle in the collision, and by collision configuration, and numbers which would have been killed if the other vehicle had been a car of the same weight as the LTV, and the collision had occurred under the same speed limit according to the models of section 4.2. The actual number in the upper, the modeled the lower number. This ratio is the upper right number. Ratios were calculated from numbers not rounded.

collision configuration	other vehicle			
	car	sport utility vehicle	van	pickup truck
all	6927 1.0 6917	441 3.4 129	471 1.9 246	1559 2.3 680
front-front	2378 1.0 2377	120 6.4 19	133 1.4 95	491 2.0 250
front-left	1635 1.0 1634	157 4.2 37	121 1.7 70	479 2.8 171
front-right	919 1.0 920	58 3.6 16	62 2.4 26	200 1.5 135

The overall pattern is that the aggressivity of vans is lowest - inflicting slightly less than twice the risk of car-car collisions, followed by pickup trucks with somewhat more than twice the risk of car-car collisions. The aggressivity of sport utility vehicles is highest: more than three times that of cars.

Figure 4.3-1 shows very similar information as Table 4.3-1 in geometrical form. What is shown on the actual driver death rates per 1000 involvements.

Also shown are the rates for the corresponding car-car collisions. The second part of the figure, for front-front collisions, shows that if frontal collisions between car and sport utility vehicles had been replaced by collisions between two cars, the fatality risk for one car driver would have been lower than in car-car collisions, because of differences in vehicle weight and speed environment between car-car collisions and car-utility vehicle collisions. The actual risk, however, was a multiple of this, presumably because of the higher aggressivity of sport utility vehicles. In the case of vans, the situation is different: if vans had been replaced by cars in the collisions, the fatality risk would have been

65% higher than in car-car collisions. Thus, the aggressivity of vans causes only a 40% increase in risk to the car driver, while a comparison of the unadjusted rates of 20.2 and 8.8 would suggest an increase of 130%.

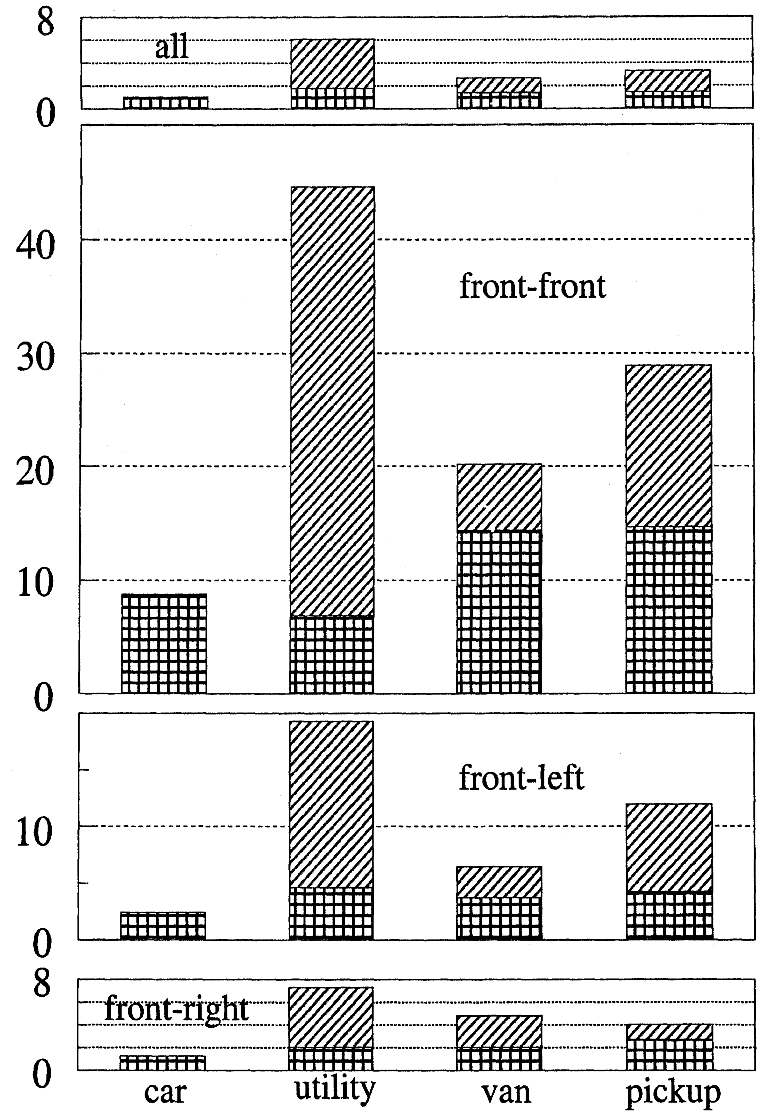

Figure 4.3-1 Comparison of risks and adjusted risks by collision configuration and vehicle type. The bars "car" show the average driver fatality risk in collisions with another car. The other bars show this average risk to car driver in collisions with a type

of LTV. The cross-hatched parts of the bar show the average risk car drivers would have faced if they had collided with cars of the weights of the LTVs in the same speed environments.

Table 4.3-2 shows data corresponding to Table 4.3-1, but separating collisions at speed limits of less than 55 mph, and 55 or higher mph. The overall pattern is similar to that in Table 4.3-1. For vans and pickup, the aggressivity seems to be generally slightly less in the higher speed environment. For sport utility vehicles, there is no consistent pattern.

Table 4.3-2 Number of car drivers killed by other vehicle in the collision, by collision configuration and by speed limit, and the number which would have been killed if the other vehicle had been a car of the same weight as the LTV, and the collision had occurred at the same speed limit, according to the models of section 4.2. The actual number is the upper, the modeled, the lower number. Their ratio is the upper right number. Ratios were calculated from numbers not rounded.

collision configuration speed limit	other vehicle							
	car		sport utility vehicle		van		pickup truck	
all								
<55	2966	1.0	207	4.1	199	2.1	631	2.5
	2856		50		97		249	
≥55	3931	1.0	234	3.0	272	1.8	928	2.2
	3930		79		149		431	
front-front								
<55	752	1.0	45	5.0	51	2.9	149	2.2
	751		9		17		67	
≥55	1626	1.0	75	7.9	82	1.1	342	1.9
	1626		10		78		183	
front-left								
<55	866	1.0	96	5.4	57	2.1	242	4.2
	866		18		27		57	
≥55	769	1.0	61	3.1	64	1.5	237	2.1
	768		20		43		114	
front-right								
<55	450	1.0	24	3.0	24	3.0	86	1.8
	451		7.9		11		49	
≤55	469	1.0	34	4.2	38	2.4	114	1.3
	469		8.1		16		86	

Table 4.3-3 Car driver fatality rates, per 1000 involvements by other vehicle, collision configuration, and speed limit.

collision configuration speed limit	other vehicle: car	sport utility vehicle	van	pickup truck
all				
<55	0.5	3.3	1.3	1.6
≥55	5.6	22.9	12.2	13.2
front-front				
<55	3.1	17.5	9.6	10.7
≥55	54.3	525.2	63.8	112.0
front-left				
<55	1.4	12.9	3.4	7.2
≥55	15.4	88.5	28.1	36.5
front-right				
<55	0.7	3.2	2.0	2.0
≤55	10.7	68.4	34.5	17.4

Table 4.3-3 shows the actual fatality rates per 1000 collision involvement.

The rates in the higher speed environment are higher by a factor of the order of magnitude 10. If comparing the rates with the data in Table 4.3-1, one has to keep in mind that Table 4.3-2 shows data adjusted for speed limit and weight differences, which is not done in Table 4.3-3.

Is there a simple explanation for the apparent differences in aggressivity in terms of vehicle parameter? Table 4.3-4 shows the values of the selected four parameters, averaged over the vehicles involved in the studied collisions. It was tried to relate the risk increase - the actual risk less the risk in comparable car-car collisions - to the four parameters, individually and in combinations by running linear regressions. With four data points, this is speculative even with one independent variable, with two variables it becomes even more questionable, and with three, one can fit the data points exactly without any possibility to assess the quality of the model. Even with two variables, problems arise because weight and the height of the centers of force are correlated, as are static and dynamic stiffness.

Table 4.3-4 Average vehicle parameters in the studied collisions.

vehicle type	weight (lb)	height of center of force (cm)	static stiffness (10^6 N/m)	dynamic stiffness (10^6 N/m)
car	2840	47	1.12	0.64
sport utility vehicle	3770	58	1.74	1.18
van	3390	52	1.78	1.25
pickup truck	3130	54	1.35	0.92

What the regressions showed was that all of the four variables individually were positively correlated with aggressivity. When one of the stiffness measures was combined with weight or height of the center of force, its coefficient became negative, contrary to what one would expect. When the height of the center of force and weight were both included, their coefficient became very unreliable.

Even if there was a positive correlation between risk and a parameter, the data points usually scattered widely. Only in the following cases appeared a "smooth" relation where the risk increased monotonous with the parameter: height of the center of force for all collisions, front-front, and front-left collisions, and weight for front-right collisions. Figures 4.3-2 through 5 shows these relations.

It is not implausible that the height of the center of force plays a key role in left side impacts. However, it does not appear plausible that an increase of as little as 5 cm increases the risk by 70%, and an increase of 11 cm by a factor of more than 4. This is even less plausible for frontal impacts where the increases are 40%, and over 6, respectively.

The large effect of vehicle weight in front-right impacts is puzzling, because the effect of weight on the weight ratio and thereby on delta-v is already accounted for by the adjustment model. Thus, it is more likely that other vehicle characteristics which are correlated with weight have the apparent effect.

In sum, while it is clear that pickup trucks, vans, and sport utility vehicles - especially the latter ones - are much more aggressive than cars, the simplistic comparison of the observed aggressivity patterns with the selected vehicle parameters give no plausible explanation.

4.4 Effects of vehicle parameters

To determine how the selected vehicle parameters might influence aggressivity, the following was done. Each case, whether a FARS or NASS GES case was treated as one observation. An identifying variable was defined as 1 if the case was from FARS, 0 if the case was from NASS GES. Using the weight ratio of the vehicles in the collision, and the speed limit, the formula from section 4.2 was used to calculate what the fatality risk p would have been, if the collision had been between two cars. Then, 1-p, or -p respectively was used as value of the dependent variable in the second step of the analysis. This new variable measures how much greater the risk in the case collision was compared with a collision between two cars of the weights of the two vehicles in the same speed environment. This variable is called "risk increase". To eliminate leading zeroes, it is expressed as increase per 1000 involvements (note that the basic risk is of the order of 1 per 1000 involvements). The NASS GES cases include fatal crashes. Therefore, this approach implicitly doubles the number of fatal cases among those with *x=o*. This reduces the estimated fatality risks slightly - by between about 0.1 and 1 percent.

Finally, the dependent variable was used in linear regression analyses, with the selected vehicle parameters, and with combinations of them as independent variables. NASS GES cases were weighted with their adjusted expansion factors, because each case represents that many actual collisions. This requires some care when interpreting errors of the coefficients. The software package STATA allows the specification of "probability weights", and calculates "robust" standard errors which account for the nature of such weights. However, because the complex sampling plan could not be incorporated, the obtained errors are not really "robust" in any of the common statistical senses and we will refer to them as "non-standard". Also, for the analysis of car-car collisions, the number of cases used was doubled by adding the symmetric collisions to the data set. Therefore, the non-standard errors should be interpreted with great caution.

The first set of analyses deals with all collision configurations combined, which gives the most comprehensive picture. Subsequent analyses deal with front-front, front-left, and front-rear collisions separately, because vehicle characteristics could have different effects in different impact configurations. On the other hand, case numbers are smaller and collisions configurations involving corners or the rear end are excluded. The resulting lower case numbers increase the errors of the resulting estimates.

For visual inspection, data were "binned" by value of each studied vehicle characteristic, and averages of the risk increases within each bin plotted. Different binnings sometimes resulted in apparently different, sometimes very nonlinear relations, mainly for very low and for very high values of the independent variables. This shows that where the density of data points is low, the apparent relation depends strongly on which specific cases are combined in a bin.

One procedure which avoids this problem is smoothing. All relations were also studied by kernel smoothing, using a Gaussian or a Cauchy kernel. The kernel parameters were varied until a smooth relation was obtained, but any simple non-linearity which appeared to be present still remained. The result was that if a sufficiently smooth relation was obtained, the relations differed at most little from a linear fit, and these deviations often depended critically on very few data points. Most of this work was done on screen and the results not saved. The figures in the following sections show these averages of the risk increases by bin, where those for low and especially high parameter values may contain only few cases. The bold straight lines are the regression lines fitted to the individual cases and they extend from the 5th to the 95th percentile of the expanded cases. Though the lines are determined by all data points, those beyond the shown part have relatively little influence and one should not expect that any relation should fit them well.

4.4.1 All collision configurations combined

Because the data for cars require a very different scale to display than those for the LTVs, they are also shown on separate figures.

Figure 4.4.1-1 shows the risk increase in car-car collisions per 1000 involvements versus the weight of the other car. In the preliminary analyses developing the risk adjustment model, no consistent contribution of the other car's weight, beyond its effect on the weight ratio was found. Apparently, the adjustment model including both the weight ratio and the speed limit revealed an effect of the other car's weight. It is a risk increase of 0.1 per 1000 lbs of weight, while the average risk is 0.64 (Table 3.2-2).

Figure 4.4-1-2 shows the risk increase versus weight for all four classes of the other vehicle. On this scale, the weight effect of the car is very small. It is clearly far too small to explain any appreciable part of the much higher risk increases for vans, pickups and especially sport utility vehicles.

For pickups, the points show only a very weak trend with weight, for vans an unexpected negative trend, but for sport utility vehicles a very strong weight effect. It is a risk increase of 2.7 per 1000 lbs of weight, 27 times that of cars: It should again be emphasized that the straight lines are intended to be descriptive summaries of the data, and that no statistical significance is implied.

Figure 4.4.1-3 shows the relation between the risk increase versus height of the center of force in car-car collisions, and Figure 4.4.1-4 in collisions with cars and the three classes of LTVs. The patterns are similar to those in Figure 4.4.1-1 and 2, which is not surprising since weight and the height of the center of force are somewhat correlated. Again, the apparent relation found in car-car collisions - about 0.3 per 10 cars - is too weak to explain differences in aggressivity between cars and the three LTV types. The slope of the line for pickups is practically the same as that for cars, but at a much higher level. That for vans is, surprisingly negative, where that for sport utility vehicles is more than twice that of cars (0.75 per cars), but at a much higher level.

Figure 4.4.1-5 shows the relations between risk increase and static stiffness for all four vehicle types. The line for cars is practically horizontal and not shown. For the LTV classes, the pattern is again similar to those in Figure 4.4.1-2 and 4, which is not surprising because static stiffness is also correlated with weight and with the height of the center of force.

Figure 4.4.1-6 shows a surprise: the slope of the apparent relation between risk increase and dynamic stiffness in car-car collisions is negative, though dynamic stiffness if positively correlated with static stiffness. Even more surprising is that the trend continues in the upper 5th percentile of the data points, far beyond the line shown. For the LTVs, however, the pattern is again similar to those in Figure 4.1.1-2,4, and 5.

Table 4.4.1-1 shows the slopes of the lines shown in the figures, together with their non-standard errors. Those for collisions with cars are artificially reduced by the doubling of the data set. To get a more realistic but still not necessarily a realistic one idea of the errors, one should add 40% to them.

For cars, the effect of weight, of the height of the center of force, and of the dynamic stiffness appear to have "significant" effects, though that of dynamic stiffness has the "wrong" direction.

For sport utility vehicles, all slopes are large, that of weight is more than three times its non-standard-error, and those of static and dynamic-stiffness are 60% greater than their non-standard-errors. This suggests the possibility of a real effect, not necessarily of the factor studied, but perhaps of an unknown factor which is correlated with the studied factor.

All coefficients for vans are negative, and all are less than or equal to their non-standard error. Thus, no conclusion could be drawn.

For pickup trucks, the coefficients for weight and the height of the center of force are fairly close to those for cars, but much less than their non-standard errors. Therefore, conclusions from the similarity would be speculative.

It is disappointing not to recognize a clear relation. However, if there is not a simple factor or a few factors with strong effects in all or most collision configurations, no clear factor might emerge. Therefore the front-front, front-left, and front-right collisions, in which the various vehicle factor might have very different effects, are studied separately in the following sections.

Table 4.4.1-1 Regression coefficients of risk increase per 1000 involvements versus each parameter of the other vehicle separately. All collision configurations. For interpretation of errors in brackets, see text.

Other vehicle types	parameter of other vehicle			
	weight	height of center of force	static stiffness	dynamic stiffness
car	0.11 [0.04]	0.032 [0.005]	0.00 [0.06]	-0.52 [0.13]
sport utility vehicle	2.7 [0.8]	0.075 [0.082]	1.6 [1.0]	2.8 [2.7]
van	-0.60 [0.59]	-0.40 [0.55]	-0.15 [0.24]	-0.44 [0.45]
pickup truck	0.16 [0.24]	0.030 [0.043]	0.54 [0.30]	0.64 [0.57]

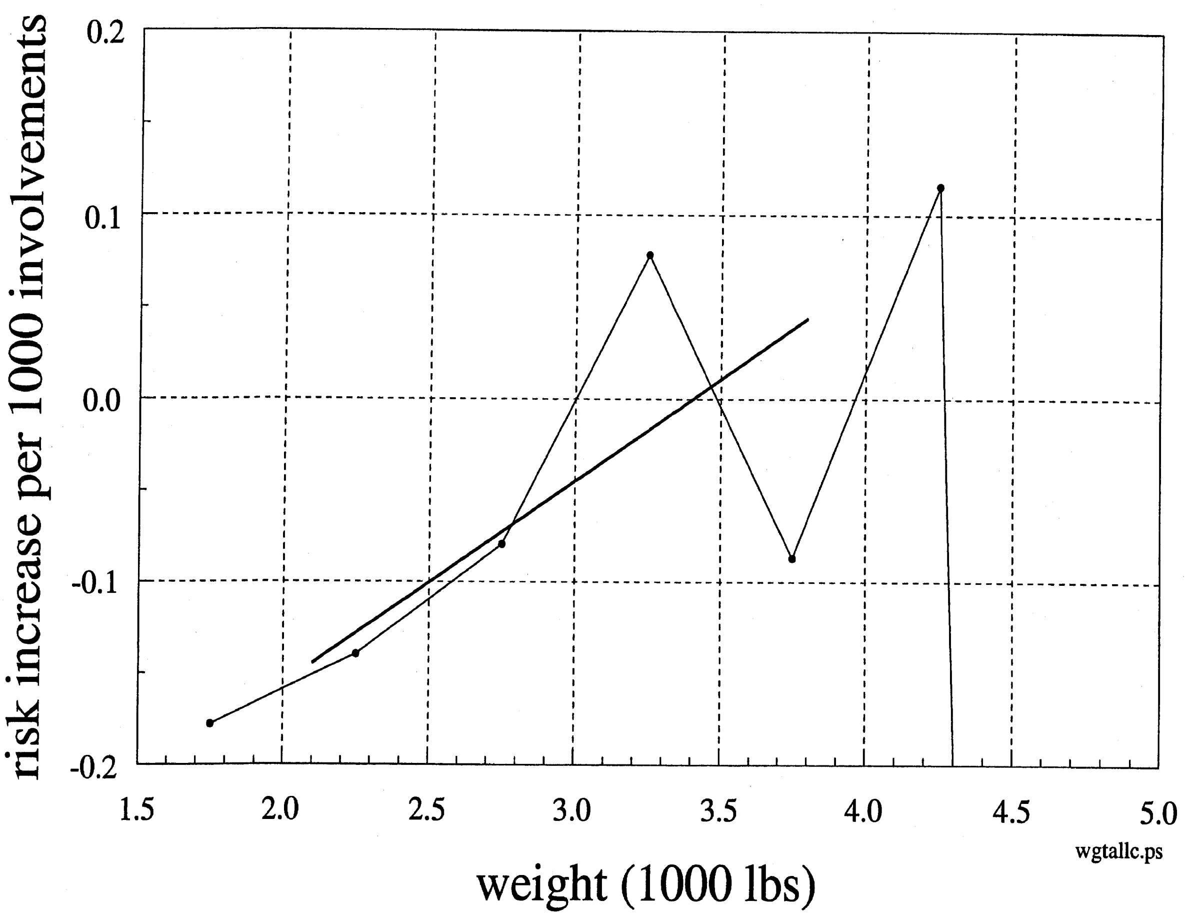

Figure 4.4.1-1. Risk increase per 1000 involvement in car-car collisions, by weight of the other car. Dots show averages over 500 lb weight ranges. The straight line is a regression line fitted to the individual cases. It extends over the weight range within which 90% of all cases are. The line should be interpreted as a summarization of the data, not necessarily as representing a physical relation.

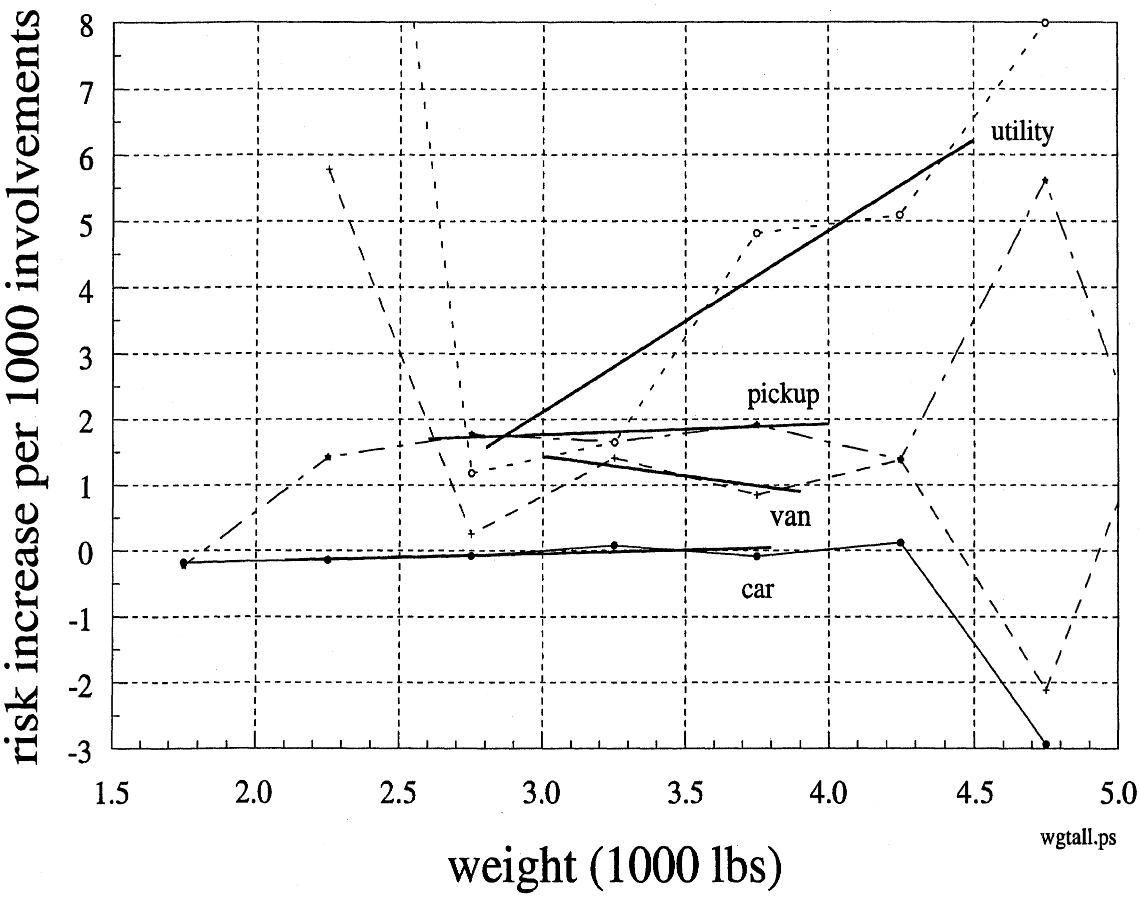

Figure 4.4.1-2. Risk increases for the car drivers per 1000 involvements in two-vehicle collisions, by weight of the other vehicle. The symbols show averages over 500 lb weight ranges. The straight lines are regression lines fitted to the individual cases. The lines extend over the weight ranges within which 90% of the cases are. They should be interpreted as summarizations of the data, not necessarily as representing physical relations.

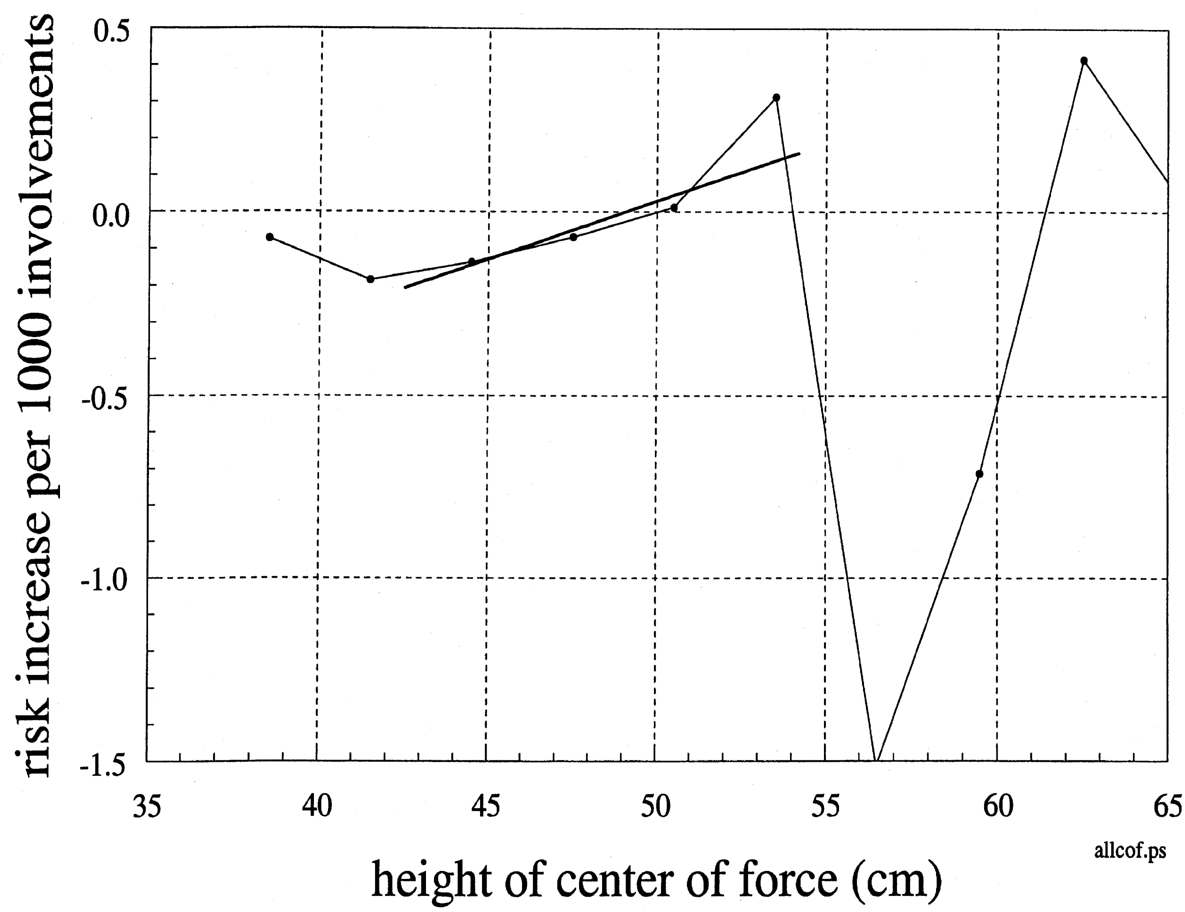

Figure 4.4.1-3 Risk increase per 1000 involvements in car-car collisions, by height of the center of force of the other car. Both show averages over 3 cm ranges in the height of the center of force. The straight line is a regression line fitted to the individual cases. It extends over the range within which 90% of all cases are. The line should be interpreted as a summarization of the data, not necessarily as representing a physical relation.

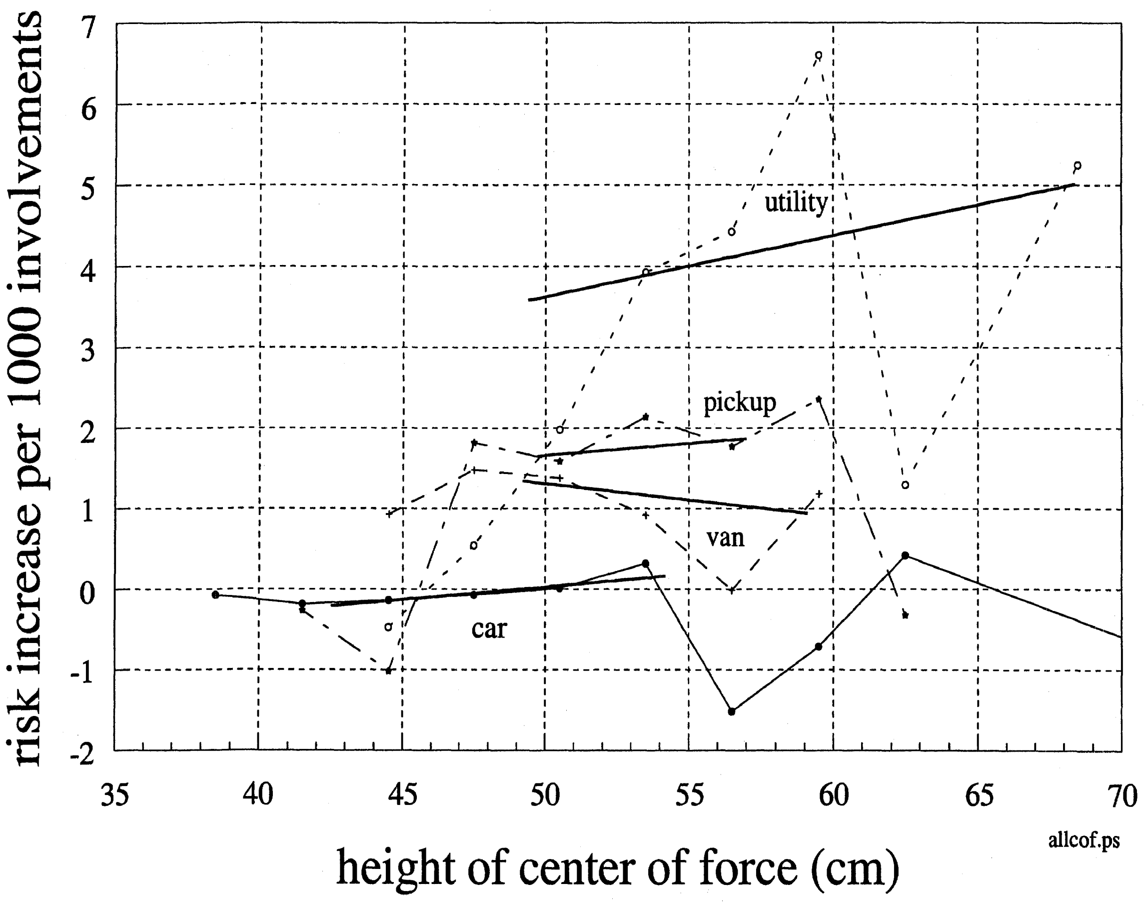

Figure 4.4.1-4. Risk increases for the car drivers per 1000 involvements in two-vehicle collisions, by height of the center of force of the other vehicle. This symbols show averages over 3 cm ranges of the height of the center of force. The lines extend over the ranges within which 90% of all cases are. They should be interpreted as summarizations of the data, not necessarily as representing physical relations.

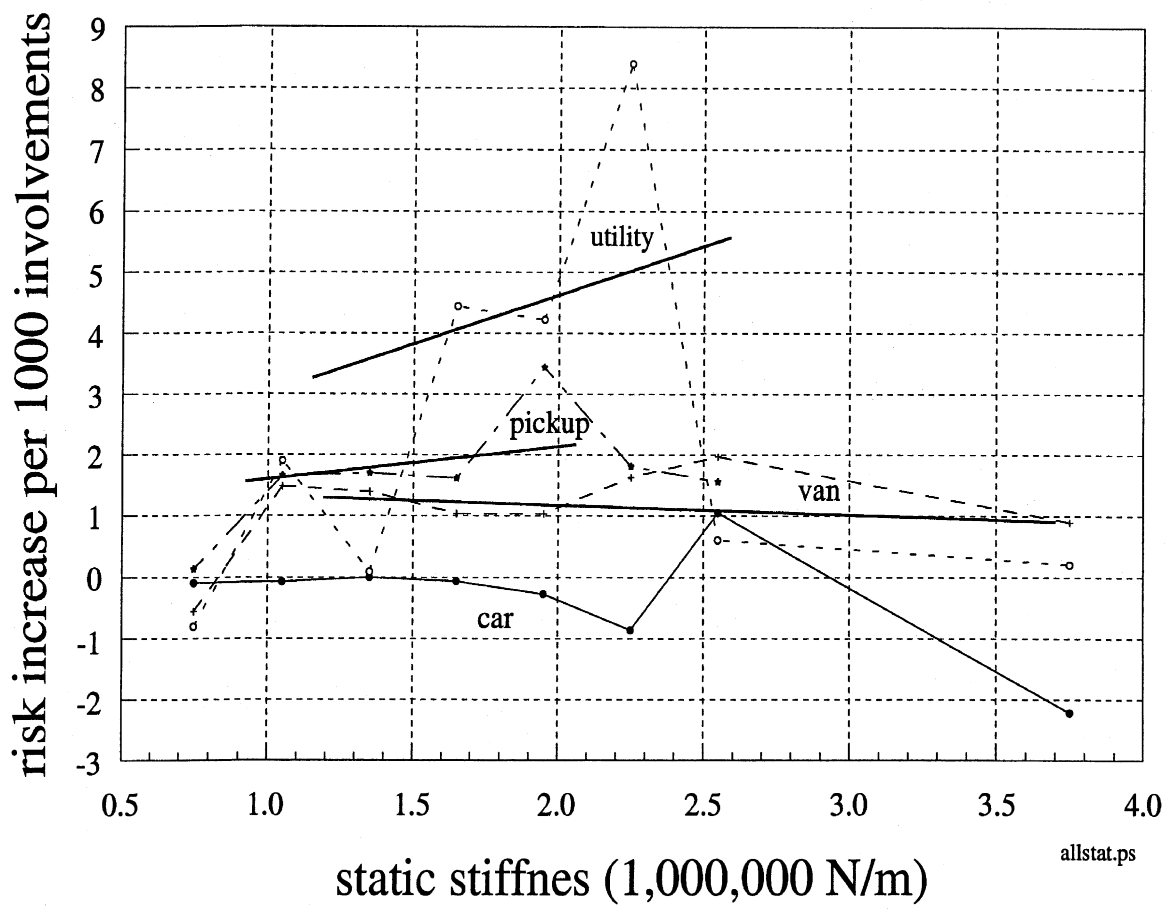

Figure 4.4.1-5. Risk increases for the car drivers per 1000 involvements in two-vehicle collisions, by static stiffness of the other vehicle. The symbols show averages over 3000,000 N/m ranges of static stiffness. The straight lines are regression lines fitted to the individual cases. The lines extend over the range within which 90% of the cases are. They should be interpreted as summarization of the data, not necessarily as representing physical relations.

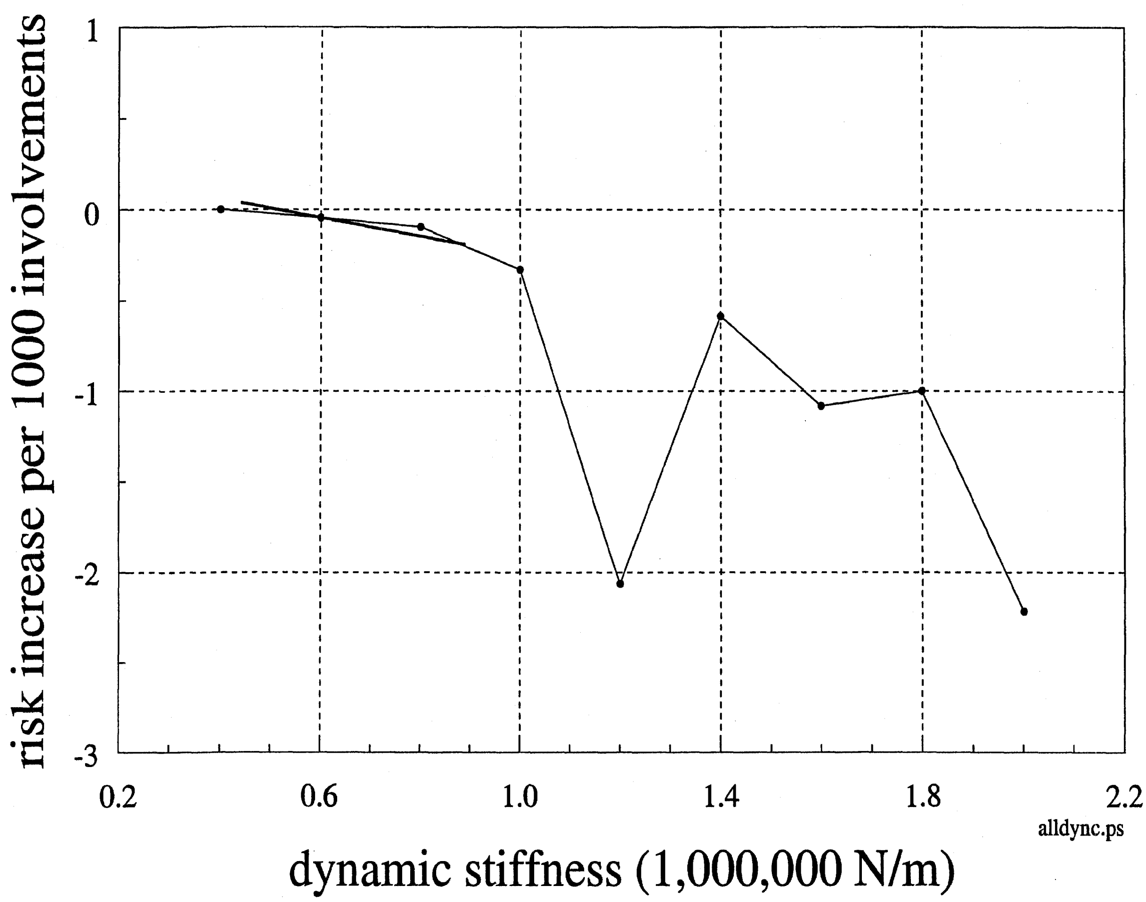

Figure 4.4.1-6. Risk increase per 1000 involvement in car-car collisions by dynamic stiffness of the other car. Dots show averages over 200,000 N/m ranges of dynamic stiffness. The straight line is a regression line fitted to the individual cases. It extends over the range within which 90% of the cases are. The line should be interpreted as a summarization of the data, not necessarily as representing a physical relation.

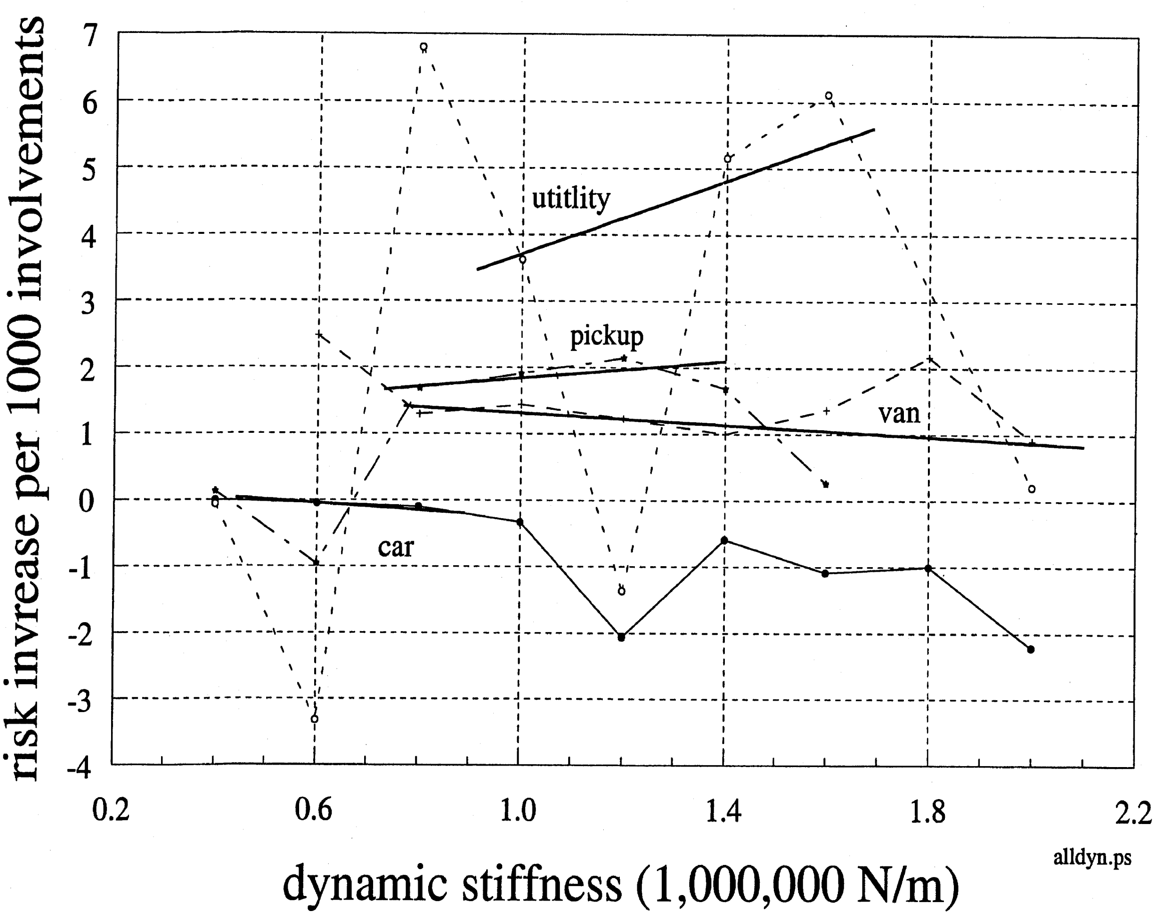

Figure 4.4.1-7. Risk increases for car drivers per 1000 involvements in two-vehicle collisions by dynamic stiffness of the other vehicle. Symbols show averages over 200,000 N/m ranges of dynamic-stiffness. The straight lines are regression lines fitted to the individual cases. The lines extend over the range within which 90% of the cases are. They should be interpreted as summarizations of the data, not necessarily as representing physical relations.

4.4.2 Front-front collision

Front-front collisions are defined as coded 12 and 12 in FARS, 1 and 1 in NASS GES. Figure 4.4.2-1 shows the risk increase for car drivers in 1000 collisions by weight of the other vehicle. Separately by type of the other vehicle, regression lines were fitted to the data. In the cases of cars, they reflect the overall trend of these data points, as they do in the case of pickup trucks. For vans, the scatter of points is too large to make any assessment, and for pickup trucks there is little similarity between the pattern of grouped data shown as dots, and the regression line based on individual data. This indicates high uncertainty of the regression line. The slopes for car, vanes, and pickup trucks are fairly similar, but that for sport utility vehicles is much greater. All this suggests an effect of weight, but the large offsets between the lines indicate that other factor differing between the vehicle types have greater effects.

Figure 4.4.2-2 shows the apparent relations between risk increases and the height of the center of force. Vans, pickups, and sport utility vehicles show similar slopes, but large offsets. Cars have a slight negative slope.

There is no suggestion of a consistent relation between risk increase and static or dynamic stiffness (Figures 4.4.2-3 and 4).

Many regression analyses were run, using various combinations of the four parameters, as well as interactions. A few of them appeared "significant" by conventional standards, but considering the large number of regressions run, that is not surprising. Also, in some cases the data may have been over fitted. Therefore, only the slopes of the relations using one single vehicle parameter at are time or shown in Table 4.4.2-1. While the coefficients reflect the patterns observed in the Figures, only a few of the slopes are appreciably greater than their non-standard error.

Table 4.4.2-1 Separate regression coefficients of risk increase per 1000 involvements versus each parameter of the other vehicle. Front-front collisions. For interpretation of errors in brackets, see text.

Other vehicle types	parameter of other vehicle			
	weight	height of center of force	static stiffness	dynamic stiffness
car	1.8 [1.0]	-0.10 [0.16]	0.6 [1.5]	1.8 [3.6]
sport utility vehicle	60 [32]	0.9 [2.5]	13 [27]	-21 [44]
van	10 [19]	1.2 [2.3]	-1.3 [4.3]	-9.9 [10.1]
pickup truck	5.7 [7.0]	0.8 [1.3]	22 [9]	35 [20]

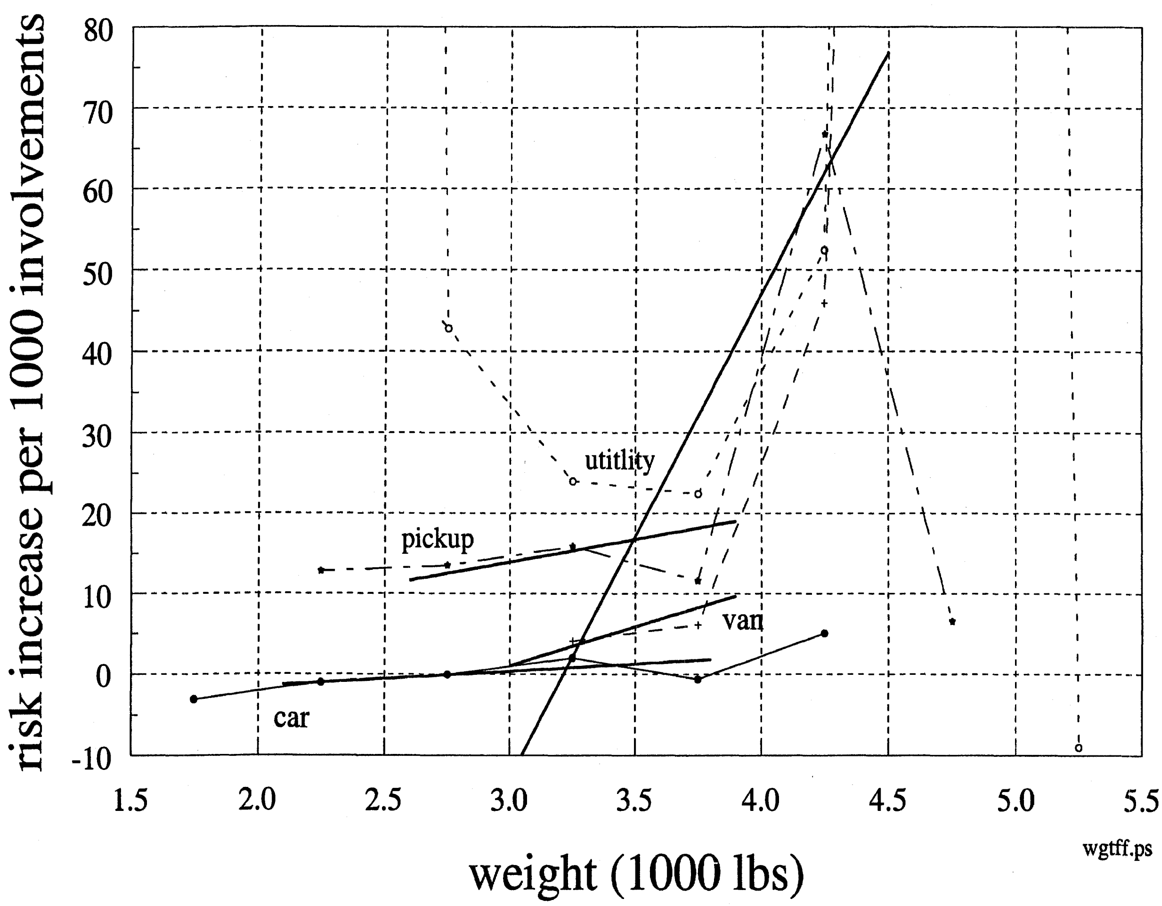

Figure 4.4.2-1 Risk increase for car drivers per 1000 involvement in front-front collisions, by weight of the other vehicle. The symbols show averages over 500 lb weight ranges. Some points based on very few cases are outside the range of the graph. The straight lines are regression lines fitted to the individual cases. The lines extend over the weight ranges within which 90% of the cases are. They should be interpreted as summarizations of the data, not necessarily as physical relations.

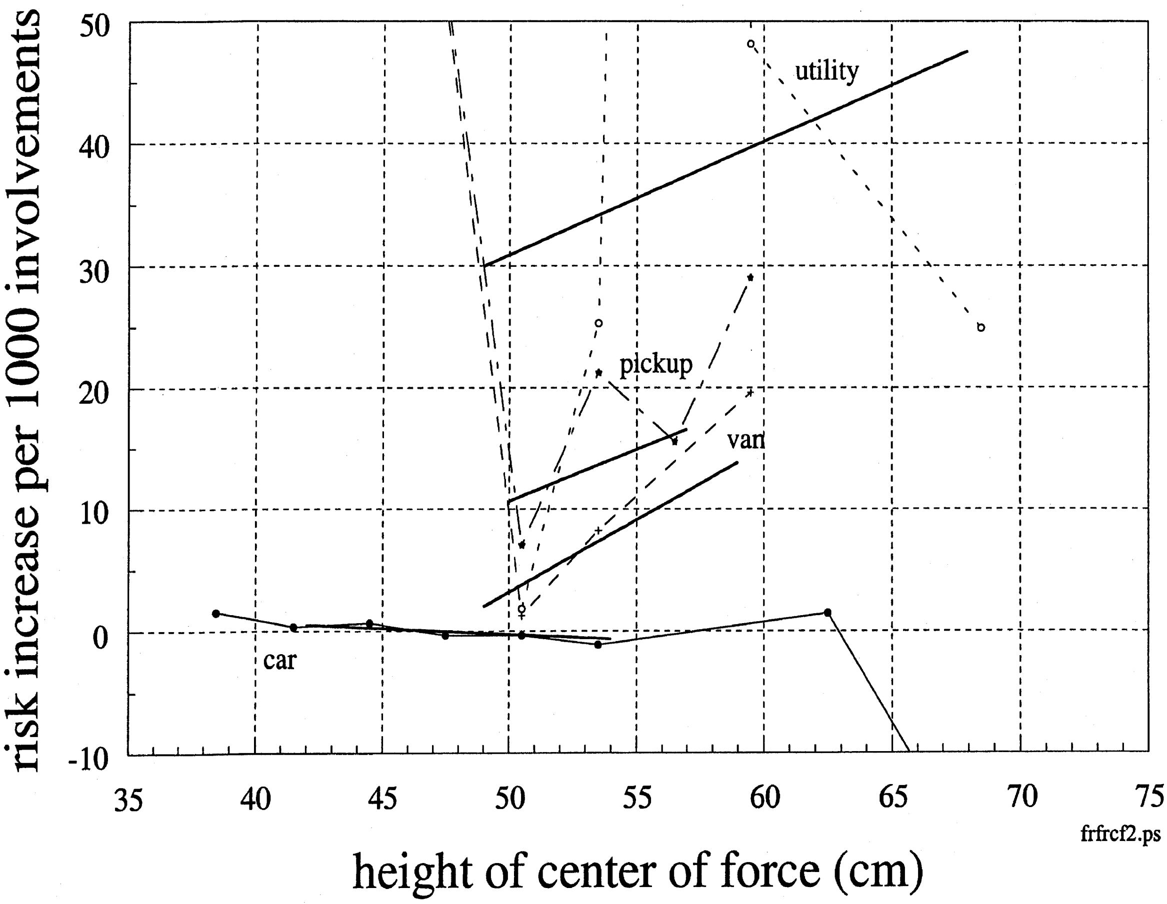

Figure 4.4.2-2 Risk increase for car drivers per 1000 involvements in front-front collisions, by height of the center of force of the other vehicle. The symbols show averages over 3 cm ranges in the height of the center of force. Some points based on very few cases are outside the range of the graph. The straight lines are regression lines fitted to the individual cases. The lines extend over the weight ranges in which 90% of the cases are. They should be interpreted as summarizations of the data, not necessarily as physical relations.

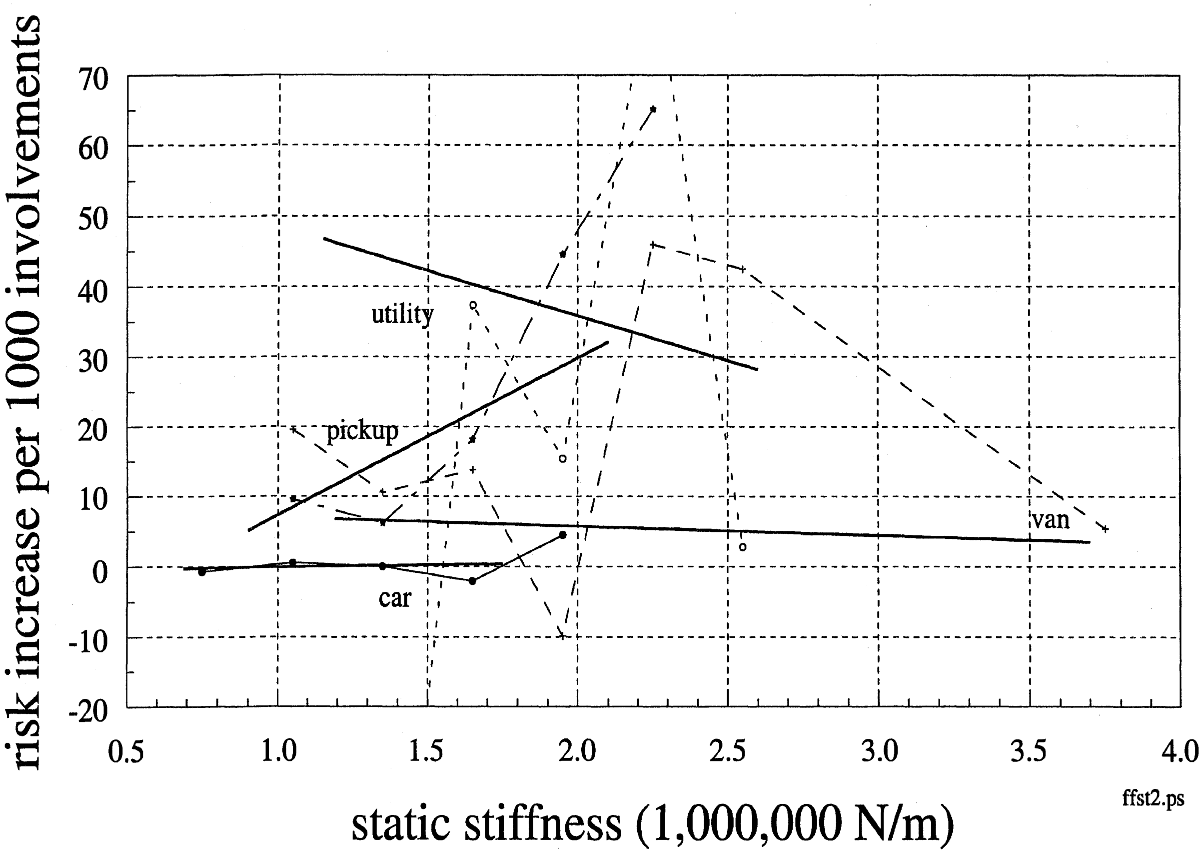

Figure 4.4.2-3 Risk increase for car drivers per 1000 involvements in front-front collisions, by static stiffness of the other vehicle. The symbols show averages over 300,000 N/m ranges of static stiffness. Some points based on very few cases are outside the range of the graph. The straight lines are regression lines fitted to the individual cases. The lines extend over the stiffness ranges within which 90% of the cases are. They should be interpreted as summarizations of the data, not necessarily as physical relations.

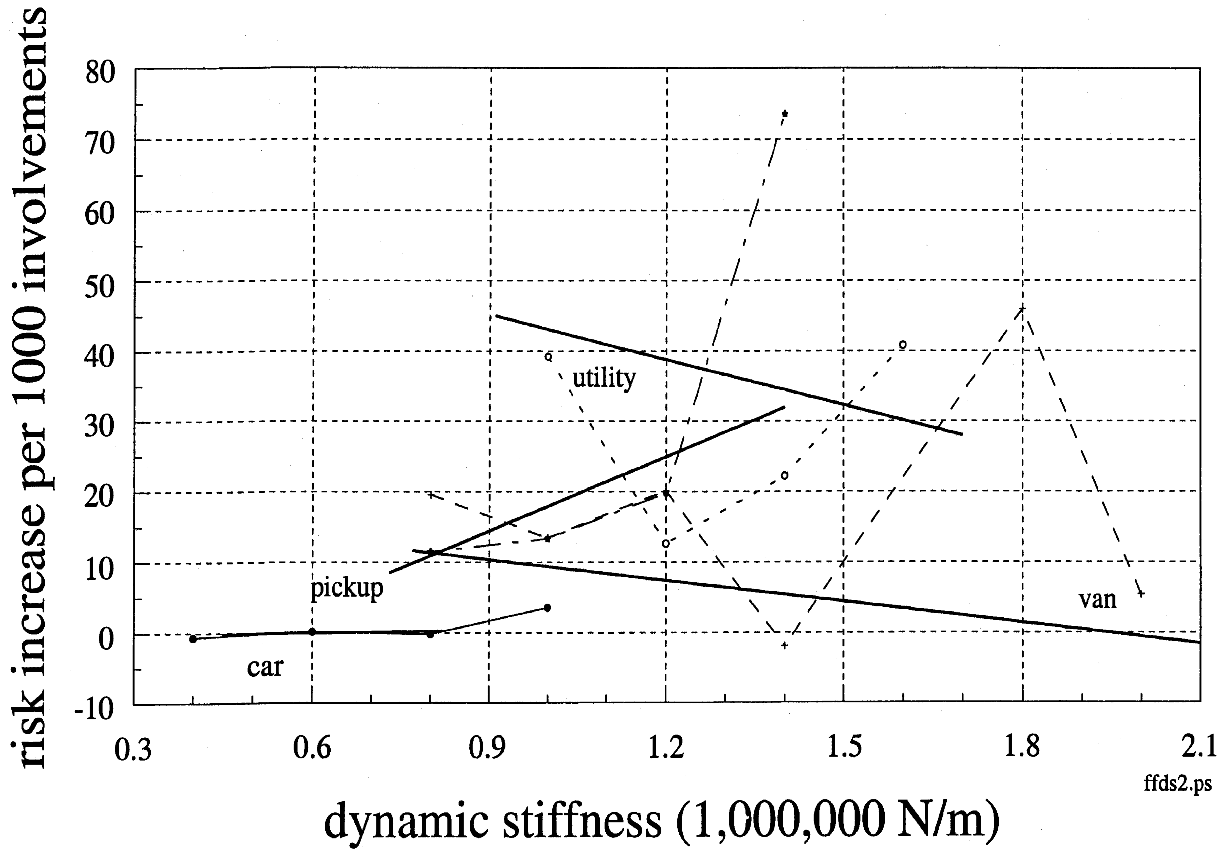

Figure 4.4.2-4 Risk increase for car drivers per 1000 involvements in front-front collisions, by dynamic stiffness of the other vehicle. The symbols show averages over 200,000 N/m ranges of dynamic stiffness. Some points based on very few cases are outside the range of the graph. The straight lines are regression lines fitted to the individual cases. The lines extend over the range within which90% of the cases are. They should be interpreted as summarizations of the data, not necessarily as physical relations.

4.4.3 Front-left collisions

Front-left collisions were defined by codes 12, the striking for vehicle and 8, 9 and 10 for the car in FARS, and 1 (front) and 3 (left side) in NASS GES. Figure 4.4.3-1 through 4 show the risk increases in relation to weight, height of the center of force, static, and dynamic stiffness, as obtained by univariate regressions.

No consistent pattern appears in Figure 4.4.3-1, relating to weight. Indeed, the aggregated data points scatter very widely. The same holds for the height of center of force (Figure 4.4.3-2), and dynamic-stiffness (Figure 4.4.3-4), though with less scatter. Only for static stiffness (Figure 4.4.3-3) is the scatter less, but again no consistent pattern appears.

The slopes of the regression lines are shown in Table 4.4.3-1. Only those for the weight, height of the center of force, and static stiffness of cars would be "significant" if the error were real standard errors. Those for the static stiffness of vans, and dynamic stiffness of pickup trucks are 1.6 times their non-standard errors, and may thus be considered "marginally significant".

Table 4.4.3-1 Regression coefficients of risk increase per 1000 involvements versus each parameter of the other vehicle separately. Front-left collisions. Non-standard errors are shown in square brackets.

Other vehicle types	parameter of other vehicle			
	weight	height of center of force	static stiffness	dynamic stiffness
car	0.56 [0.20]	0.10 [0.03]	1.2 [0.4]	1.1 [0.8]
sport utility vehicle	-2.9 [7.2]	1.3 [1.1]	-2.7 [8.6]	-0.5 [15.2]
van	-5.4 [3.6]	-0.12 [0.33]	-2.8 [1.7]	-4.4 [3.2]
pickup truck	2.2 [2.4]	0.37 [0.40]	4.3 [2.8]	8.3 [5.2]

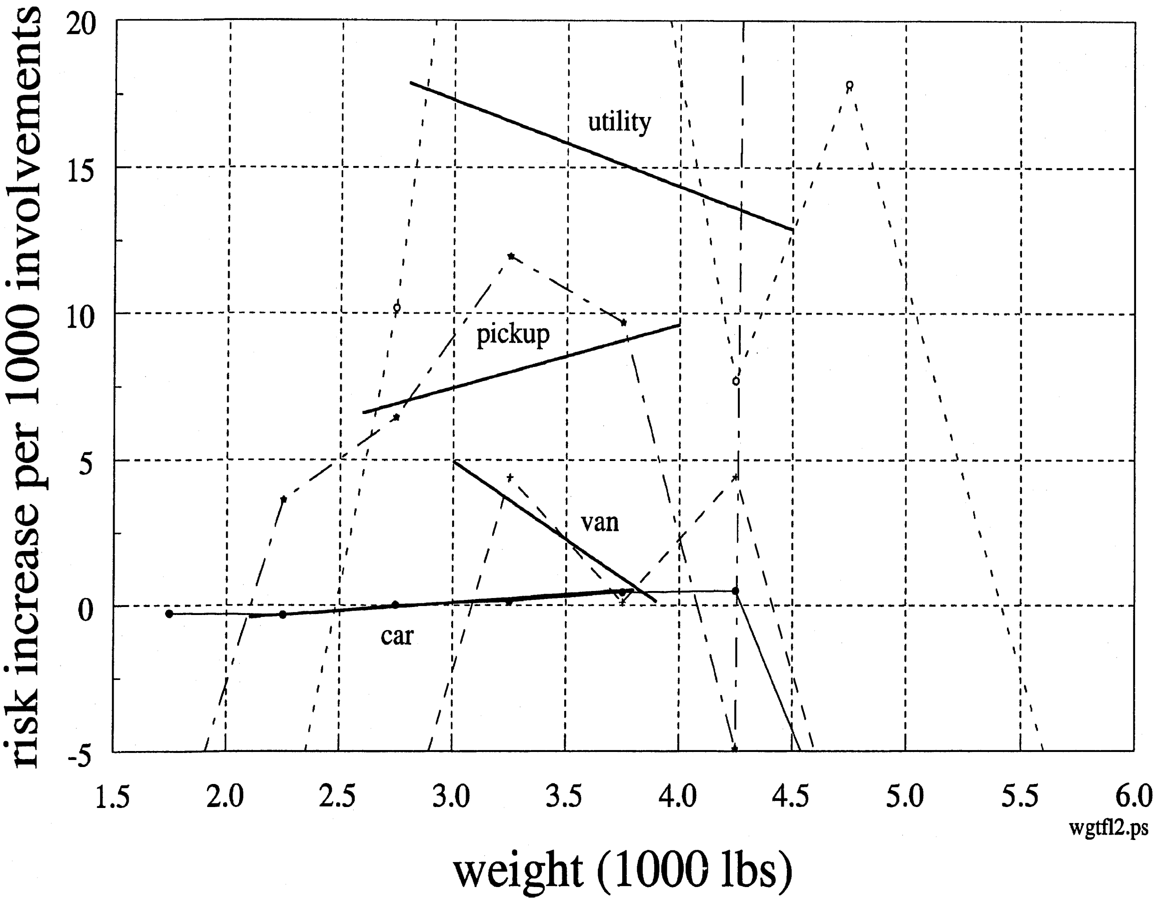

Figure 4.4.3-1 Risk increase for car drivers per 1000 involvement in front-left collisions, by weight of the other vehicle. The symbols show averages over 500 lb weight ranges. Same points on very few cases are outside the range of the graph. The straight lines are regression lines fitted to the individual cases. The lines extend over the weight ranges within which 90% of the cases are. They should be interpreted as summarizations of the data, not necessarily as physical relation.

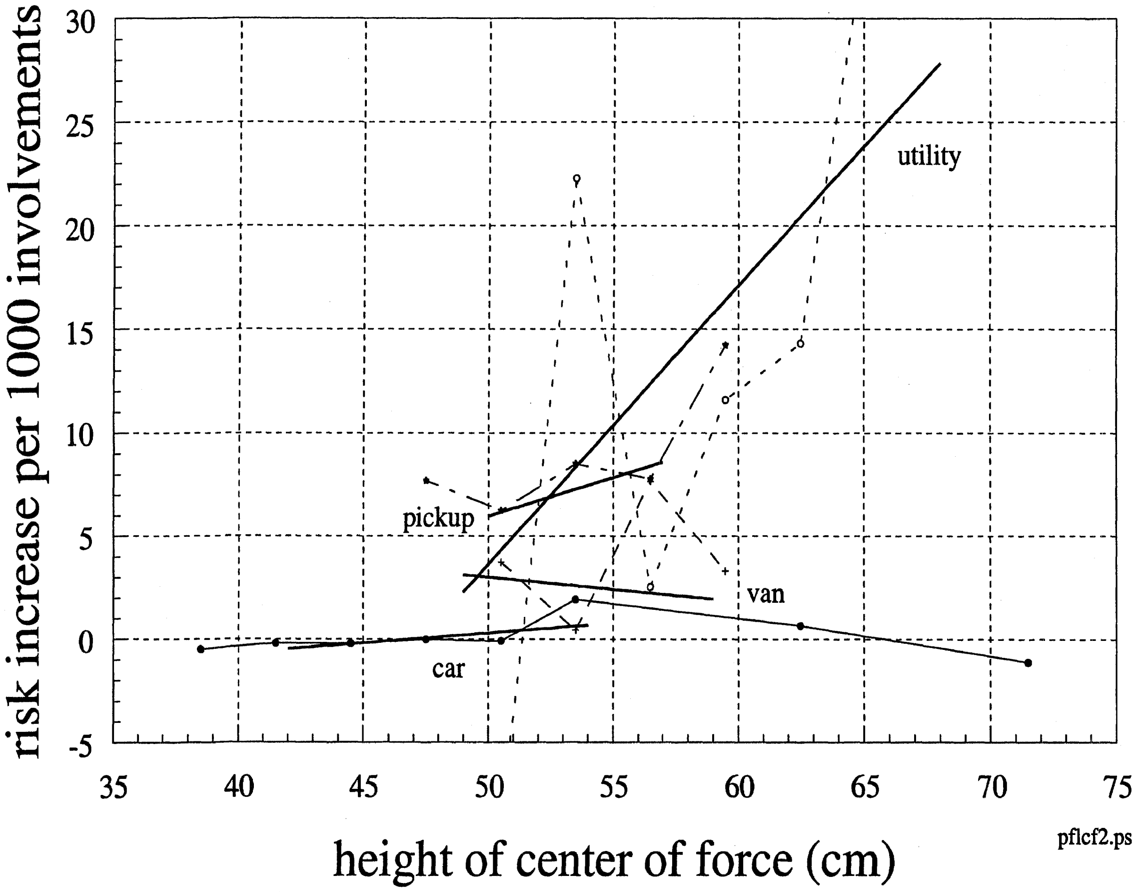

Figure 4.4.3-2 Risk increase for car drivers per 1000 involvements in front-left collisions, by height of the center of force of the other vehicle. The symbols are averages over 3 cm ranges in the height of the center of force. Some points based on very few cases are outside the range of the graph. The straight lines are regression lines fitted to the individual cases. The lines extend over the weight ranges in which 90% of the cases are. They should be interpreted as summarizations of the data, not necessarily as physical relations.

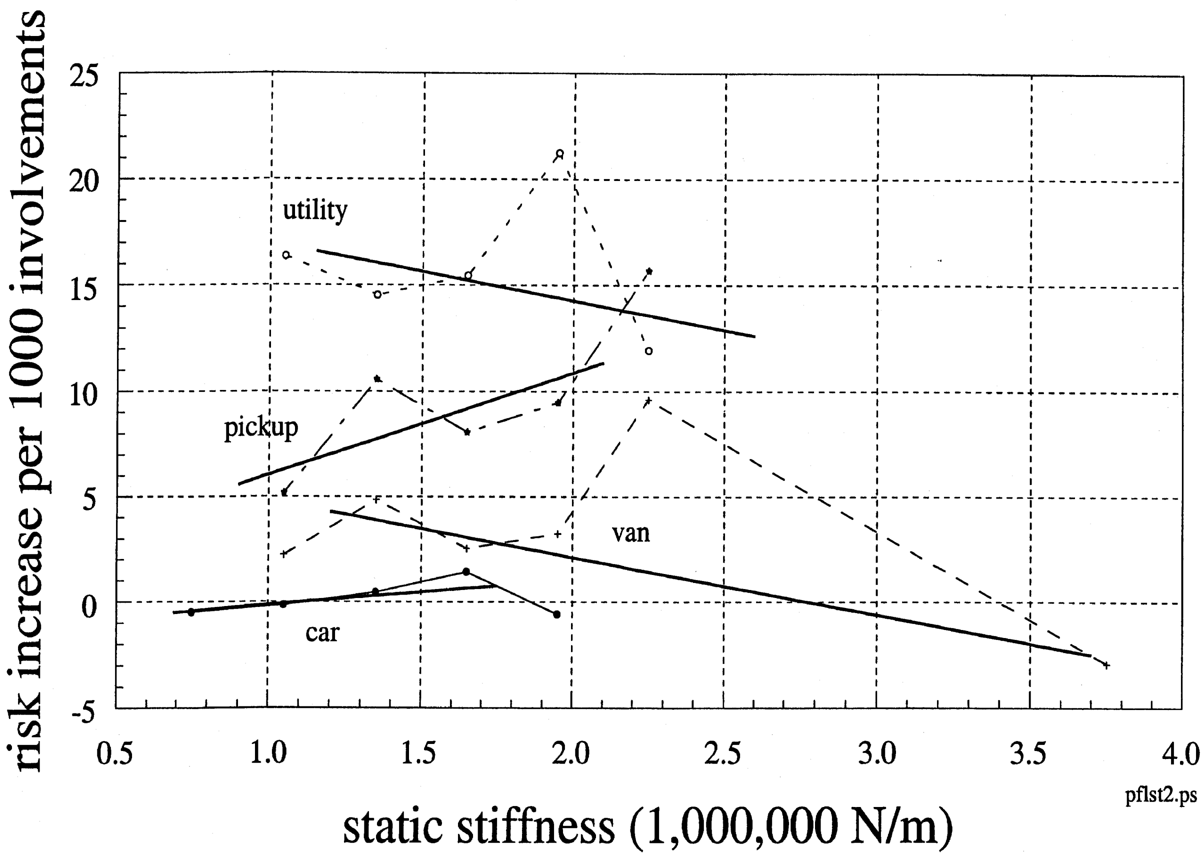

Figure 4.4.3-3 Risk increase for car drivers per 1000 involvements in front-left collisions by static stiffness of the other vehicle. The symbols are averages over 300,000 N/m ranges of static stiffness. Some points based on very few cases are outside the range of the graph. The straight lines are regression lines fitted to the individual cases. The lines extend over the range within which 90% of the cases are. They should be interpreted as summarizations of the data, not necessarily as physical relations.

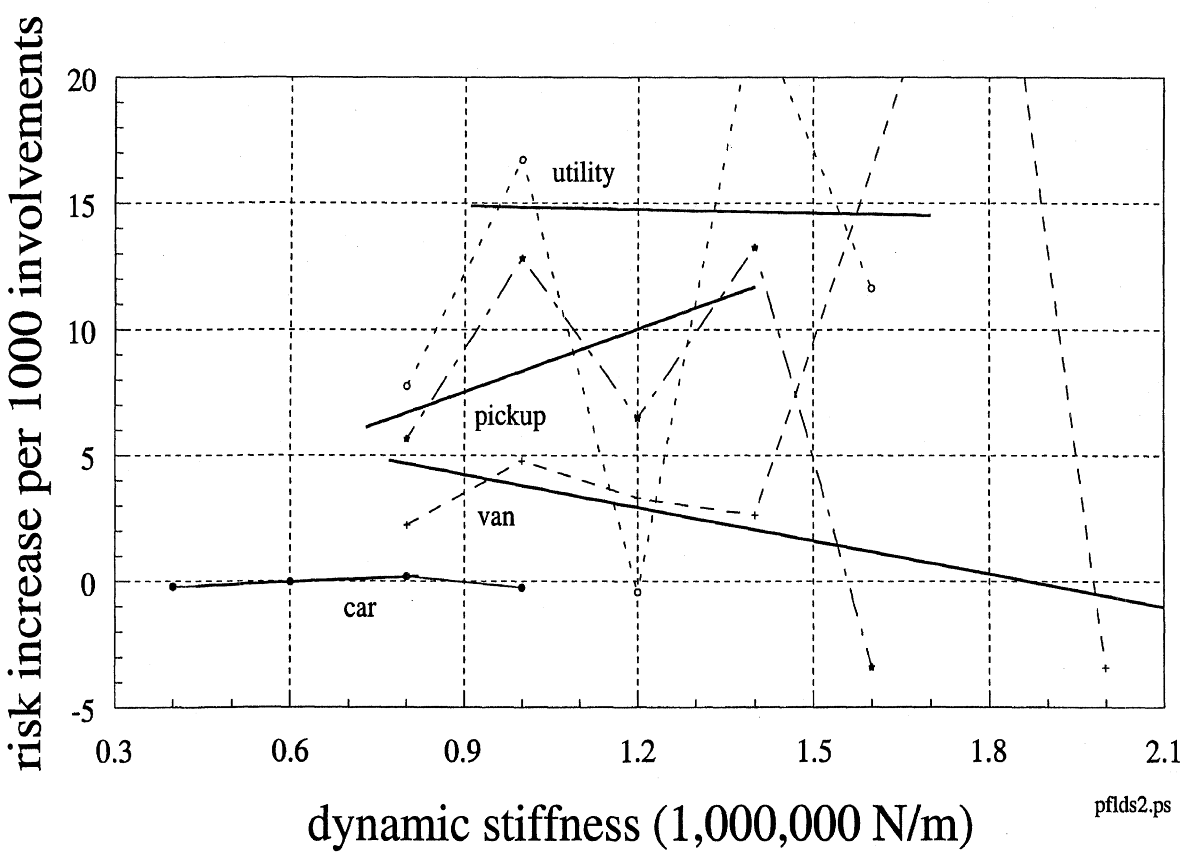

Figure 4.4.3-4 Risk increase for car drivers per 1000 involvements in two-vehicle collisions versus dynamic stiffness of the other vehicle. Data show averages over 200,000 N/m ranges of dynamic stiffness. Some points based on very few cases are outside the range of the graph. The straight lines are regression lines fitted to the individual cases. The lines extend over the range within which 90% of the cases are. They should be interpreted as summarizations of the data, not necessarily as physical relations.

4.4.4 Front-right collisions

Front-right collisions were defined by codes 12, for the striking vehicle and 2, 3, or 4 for the car in FARS, 1 (front) 2 (right side) in NASS GES. Figures 4.4.4-1 through 4 show the relations between risk increase and vehicle weight, height of the center of force, static, and dynamic stiffness.

The relations with weight (Figure 4.4.4-1) are dominated by the step slope for sport utility vehicles. The data front points themselves, however, show no similarity increasing trend, but a more complex pattern.

The relations with the height of the center of force show all positive slopes, but the points scatter very widely.

The pattern of the slopes for static (Figure 4.4.4-3), and dynamic stiffness (Figure 4.4.4-4) are fairly similar, but the points scatter widely, except those for cars.

Table 4.4.4-1 shows the slopes of the regression lines and their non-standard errors. No coefficient is much larger than its non-standard error (increase by 40% in the case of car).

Table 4.4.4-1 Regression coefficients of risk increase per 1000 involvements versus each parameter of the other vehicle separately. Front-right collisions. Non-standard errors are shown in square brackets, see text.

Other vehicle types	parameter of other vehicle			
	weight	height of center of force	static stiffness	dynamic stiffness
car	0.15 [0.14]	0.041 [0.025]	0.14 [0.23]	-0.09 [0.52]
sport utility vehicle	4.3 [2.7]	0.25 [0.31]	-2.1 [2.0]	-4.0 [3.8]
van	-1.1 [3.8]	0.09 [0.38]	3.4 [2.4]	3.8 [3.2]
pickup truck	-0.19 [0.95]	0.20 [0.21]	0.8 [1.4]	0.7 [2.6]

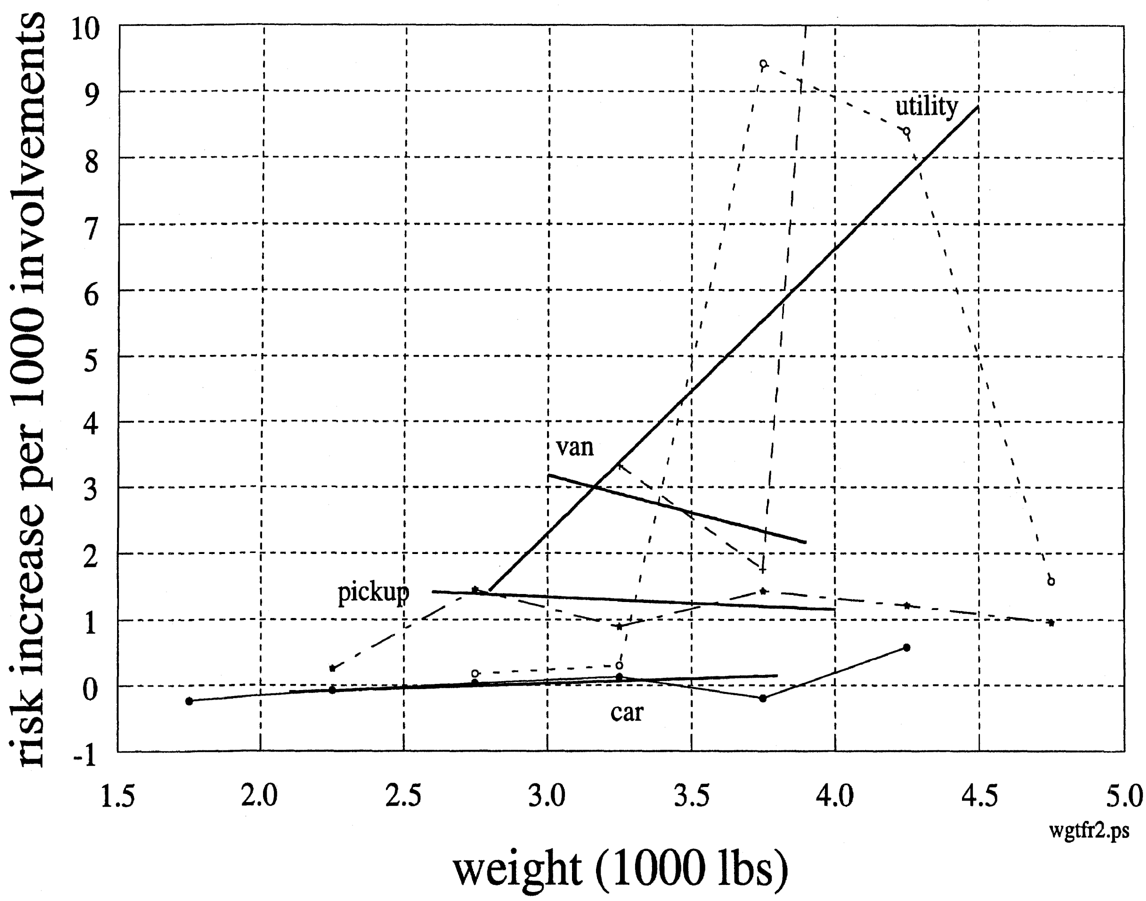

Figure 4.4.4-1 Risk increase for car drivers per 1000 involvements in front-right collisions, by weight of the other vehicle. The symbols show averages over 500 lb weight ranges. Some points based on very few cases are outside the range of the graph. The straight lines are regression lines fitted to the individual cases. The lines extend over the weight ranges within which 90% of the cases are. They should be interpreted as summarizations of the data, not necessarily as physical relations.

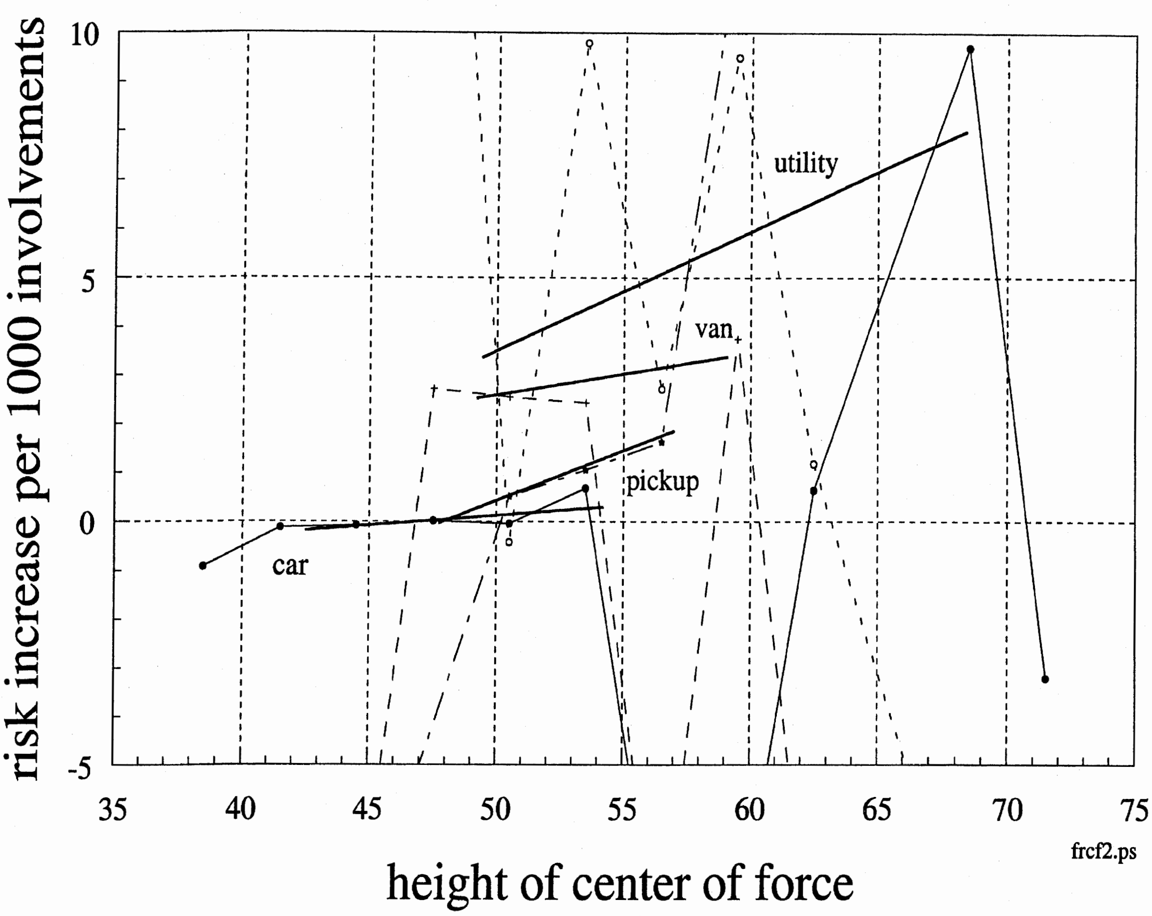

Figure 4.4.4-2 Risk increase for car drivers per 1000 involvements in front-right collisions, by height of the center of force of the other vehicle. The symbols are averages over 3 cm ranges in the height of the center of force. Some points based on very few cases are outside the range of the graph. The straight lines are regression lines fitted to the individual cases. The lines extend are the weight ranges in which 90% of the cases are. They should be interpreted as summarizations of the data, not necessarily as physical relations.

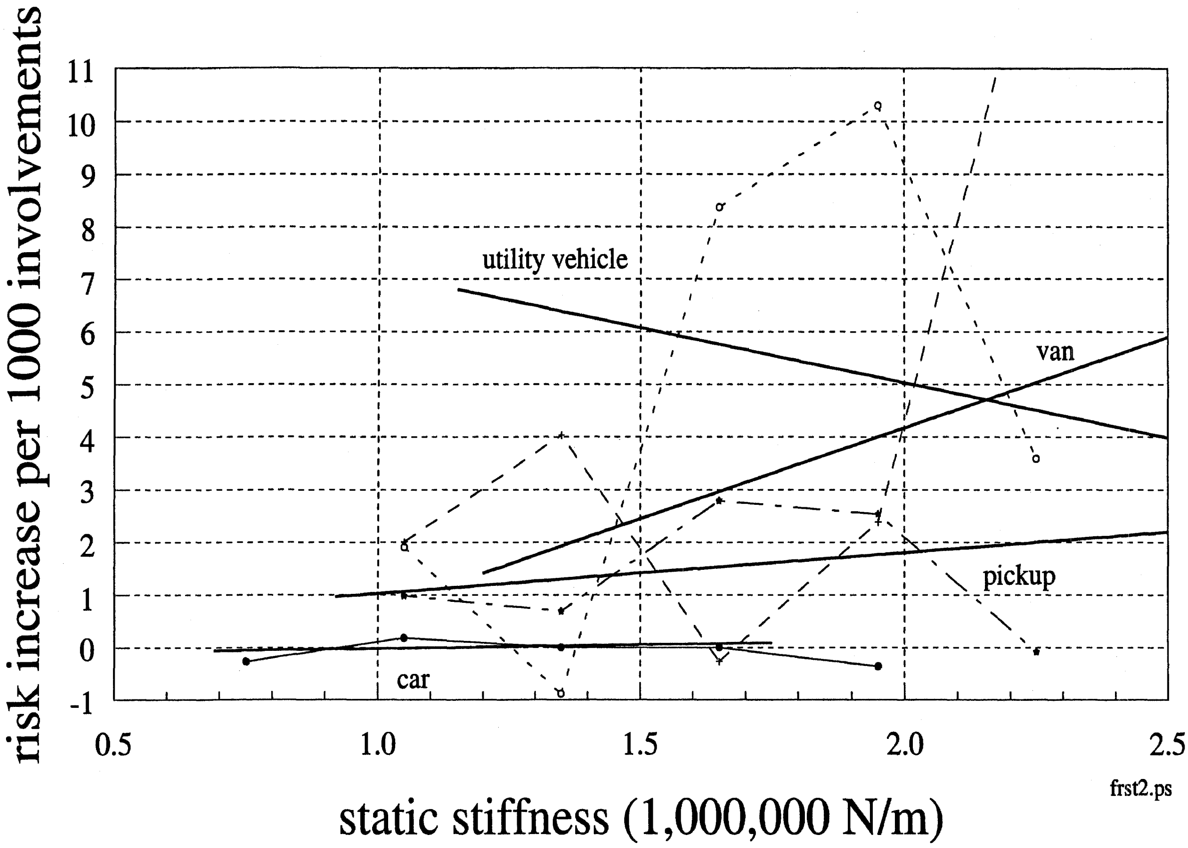

Figure 4.4.4-3 Risk increase for car drivers per 1000 involvements in front-right collisions by static stiffness of the other vehicle. The symbols are averages over 300,000 N/m ranges of static stiffness. Some points based on very few cases are outside the range of the graph. The straight lines are regression lines fitted to the individual cases. The lines extend over the range within which 90% of the cases are. They should be interpreted as summarizations of the data, not necessarily as physical relations.

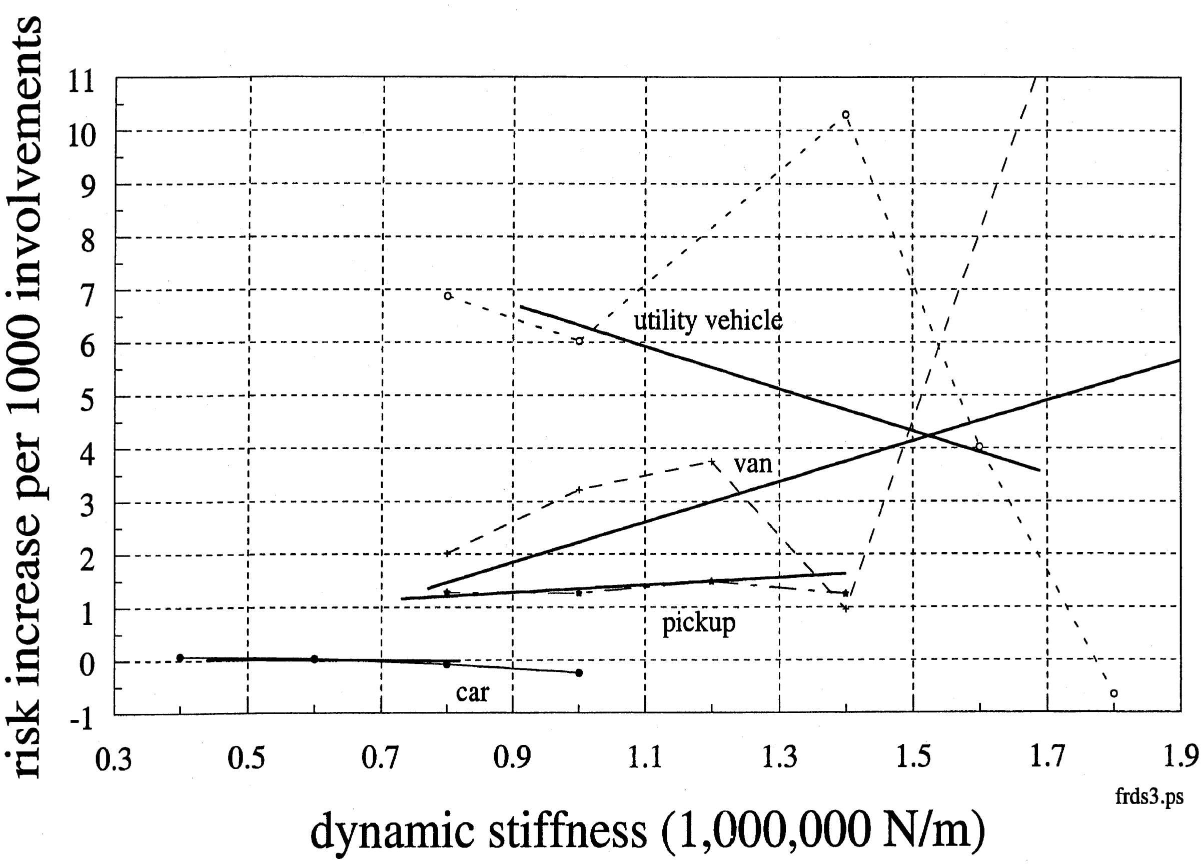

Figure 4.4.4-4 Risk increase for car drivers per 1000 involvements in two-vehicle collisions versus dynamic stiffness of the other vehicle. Data show averages over 200,000 N/m ranges of dynamic stiffness. Some points based on very few cases are outside the range of the graph. The straight lines are regression lines fitted to the individual cases. The lines extend over the range within which 90% of the cases are. They should be interpreted as summarizations of the data, not necessarily as physical relations.

4.4.5 Summary of analysis of vehicle parameters

The analysis of relations between vehicle parameters and risk increase, by type of other vehicles, for all collision configurations, as well as separately for the three primary collision configurations, gave no clear and convincing picture.

Many correlations are possible, and a number of them were "significant", if one could simply apply standard regression techniques. If more than one independent variable, and even more if interactions of variables were used, some independent variables appeared very highly significant by conventional standards. A closer look at the relations, and sometimes the data, however, suggested that these were effects of overfitting the data, or due to few influential points.

Therefore, we finally looked only at the relations between the risk increase and the four parameters separately. Then, a few weak patterns became apparent. Table 4.4.5-1 summarizes them. The ratio of each regression coefficient to its non-standard error was calculated (in the case of car-car collisions, the non-standard error was increased by 40% to compensate for the doubling of the data base to achieve symmetry). If it was 1.6 or higher, in absolute terms, it is shown in the table.

In car-car collisions, weight, the height of the center of force, and static stiffness appear. Dynamic stiffness appears with an unexpected negative coefficient. For sport utility vehicles, only weight appears, and for pickups static and dynamic stiffness. A total of 12 coefficients greater than 1.6 appears.

Table 4.4.5-1 Ratios of simple regression coefficients of risk increase versus vehicle parameter, to their non-standard error, by other vehicle's parameters, other vehicle type, and collision configuration. Dashes indicate a ratio less than 1.6. Vans are not shown because all entries are dashes.

		vehicle parameter			
other vehicle	collision configuration	weight	height of center of force	static stiffness	dynamic-stiffness
car	all	2.0	4.6	-	-2.9
	front-front	-	-	-	-
	front-left	2.0	2.4	2.1	-
	front-right	-	-	-	-
sport utility vehicle	all	3.4	-	-	-
	front-front	1.9	-	-	-
	front-left	-	-	-	-
	front-right	1.6	-	-	-
pickup truck	all	-	-	1.8	-
	front-front	-	-	2.4	1.8
	front-left	-	-	-	-
	front-right	-	-	-	-

However, a level of 1.6* σ corresponds to a 5.5% one-tailed probability, assuming a normal distribution. A total of 4*4*4 coefficients (including those for vans, not shown) were calculated. However, the 2*5.5% can not be applied to 4*4*4=64 values because lack of independence. "All" collisions include front-front, front-left, and front-right. Static and dynamic stiffness are fairly closely correlated. Thus, one should consider only the combinations of 4 vehicle types, 3 parameters, and 3 collision configurations, which result in 36 coefficients. Even then, coefficients are still not completely independent because weight, height of center of force, and static-stiffness are indirectly correlated.

If one applies this, two-tailed, 11% to 36 coefficient, one obtains 4. Actually, one has 6 which are greater than 1.6 times their non-standard error. This is not much greater. However, if one notices that all of these coefficients are positive, and most equal 2*σ or more, the pattern is much stronger.

Nonetheless, all one can conclude is that weight seems have an effect of the risk increase for cars and sport utility vehicles, though its effect on the weight ratio is already accounted for. The height of the center of force also seems to have an effect in car-car collisions, and stiffness seems to have an effect only for pickup trucks, possibly for cars in front-left collisions.

Table 4.4.5-2 is based on the same information, but presents it is a different manner. The magnitude of the regression coefficients, and their non-standard errors are ignored. Only the signs are shown. Here, some patterns emerge. In case of all collision configurations, for sport utility vehicles and pickup trucks, all parameters have positive correlations. For cars, only the weight and height of the center of force, and for vans only the weight have positive correlations.

If one looks at the more specific collision configurations, for cars 10 out of 11 non-zero these coefficients are positive. It is surprising that for static stiffness all coefficients in the specific collision configuration are positive, but that the coefficient for all collision configurations together is zero. This suggests that in the omitted configurations, the other factor mask any effect static stiffness might have.

In the case of pickup trucks, 10 out of 12 coefficients for the selected collision configurations are positive, confirming the pattern which appears for all configurations combined.

A strange pattern appears for sport utility vehicles: in none of the selected collision configurations does stiffness have a positive coefficient, but in all collisions together it is positive. The only plausible explanation is that stiffness plays a role in the omitted collision configuration.

Combining the information from Tables 4.4.5-1 and 2, one might conclude that all three parameters play a role in the aggressivity of sport utility vehicles and pickup trucks. For sport utility vehicles, the effect of weight appears to be strongest, for pickup trucks that of stiffness.

For cars, weight and the height of the center of force seem to have effects, both being strong.

For vans, only a very weak effect of weight appears.

Table 4.4.5-2 Signs of the simple regression coefficients of risk increase versus vehicle parameter, by collision configuration and other vehicle type.

other vehicle	collision configuration	vehicle parameter: weight	height of center of force	static stiffness	dynamic-stiffness
car	all	+	+	0	-
	front-front	+	-	+	+
	front-left	+	+	+	+
	front-right	+	+	+	0
sport utility vehicle	all	+	+	+	+
	front-front	+	+	-	-
	front-left	-	+	-	-
	front-right	+	+	-	-
van	all	+	-	-	-
	front-front	+	+	-	-
	front-left	-	-	-	-
	front-right	-	+	+	+
pickup truck	all	+	+	+	+
	front-front	+	+	+	+
	front-left	+	+	+	+
	front-right	-	+	-	+

4.5 Modeling based on make/models

In the preceding analyses, four vehicles classes were distinguished. Within vehicle classes, vehicles were characterized by weight, stiffness and height of center of force. Close inspection of these data show that most of them cluster at relatively few values. The reason is obvious: stiffness and height of center of force measured for one vehicle were applied to all vehicles of the same make and model. Therefore, these values cluster at those measured for the most common makes/models. For weight, the situation is similar, but the concentration is not as strong because weight was available, usually by model year and slight variation of body style, and possibly even for individual vehicles.

Vehicle factors other than weight, stiffness and the height of the center of force could influence the aggressivity of a vehicle. Some might not have been measured, others might be too complex to be described by a few simple measurements, for instance shapes. Sometimes such characteristics can be recognized by first comparing make/models and in a second step determining to what extent differences can be explained by the known vehicle parameters, and whether unexplained differences remain which one can try to relate to other vehicle characteristics.

Looking at the case numbers for the various LTVs in the data files, it was decided to select those with a combined number of at least 30 FARS and original - not expanded - NASS GES cases. They are listed in Tables 4.5-1, 4.5-2 and 4.5-3.

To assess differences in risks, one needs error estimates of the risk estimator. As discussed in Appendix 2, rigorous error estimates could not be made. However, some heuristic error estimates are described in A.2.3. Such estimates are used in the following sections. They will be referred to as "non-standard errors", to prevent their being used too literally.

Table 4.5-1 Selected Utility Vehicles. NASS GES cases is the actual, not expanded number of collisions. The selected models cover 408 out of 441 FARS, and 380 out of 419 NASS GES collisions.

Kahane's Code	make/model	model years	FARS cases	NASS GES cases
7006	Jeep Cherokee	1985-97	23	56
7018	Jeep Grand Cherokee 4x4	1993-96	63	49
7417	Ford Bronco 4x4	1985-96	73	61
7443	Ford Explorer 4 door 4x4	1991-95	119	75
7658	Chevrolet S10 4x4 Blazer 4 door	1991-97	91	83
8205	Isuzu Trooper II 4x4	1985-91	11	25
8507	Toyota 4 Runner	1985-95	28	31

Table 4.5-2 Selected Vans. NASS GES cases is the actual, not expanded number of collision. The selected models cover 442 out of 465 FARS, 891 out of 938 NASS GES cases.

Kahane's Code	make/model	model years	FARS cases	NASS GES cases
7117	Dodge B250 Ram Van	1985-97	45	97
7140	Dodge Caravan	1991-95	58	110
7144	Dodge Grand Caravan	1991-95	47	82
7201	Plymouth Voyager	1985-90	73	147
7430	Ford Aerostar Wagon	1987-97	80	180
7616	Chevrolet Astro cargo van	1985-94	58	109
7617	Chevrolet Astro passenger van	1985-94	68	142
8118	Nissan Quest passenger van	1993-97	13	24

Table 4.5-3 Selected pick-ups. NASS GES cases is the actual, not expanded number of collisions. The selected models cover 1533 out of 1549 FARS, and 2621 out of 2667 NASS GES collisions.

Kahane's Code	make/model	model year	FARS cases	NASS GES cases
7130	Dodge Dakota	1987-97	97	141
7131	Dodge Dakota 4x4	1987-97	31	31
7401	Ford Ranger	1985-92	198	369
7402	Ford Ranger 4x4	1985-92	36	50
7403	Ford F150 4x4 pickup	1985-96	276	401
7452	Ford Ranger 4x4	1993-97	103	190
7601	Chevrolet S10 pickup	1985-87	290	558
7631	Chevrolet C10 pickup	1988-97	257	400
7654	Chevrolet K10 4x4 x-cab pickup	1991-97	28	31
8107	Nissan standard bed pickup	1986-97	121	161
8208	Isuzu pickup standard bed	1988-95	18	36
8301	Mazda B2000/2200/2600 pickup standard bed	1986-93	38	87
8501	Toyota pickup short bed	1985-95	34	137
8604	Mitsubishi Mighty Max	1987-96	6	29

4.5-1 Utility vehicles

Figure 4.5.1-1 shows the increases of the car driver fatality risks in collisions with sport utility vehicles, compared with collisions with cars, controlling for the other vehicle's weight and the speed environment.

The Isuzu Trooper and Jeep Cherokee have much lower risk increases than the other vehicles, especially the Ford Explorer. If the non-standard errors were realistic estimates of the standard errors, the difference between these two vehicles and the Ford Explorer would be significant. The few vehicles with values in the middle range differ by much less than their non-standard errors.

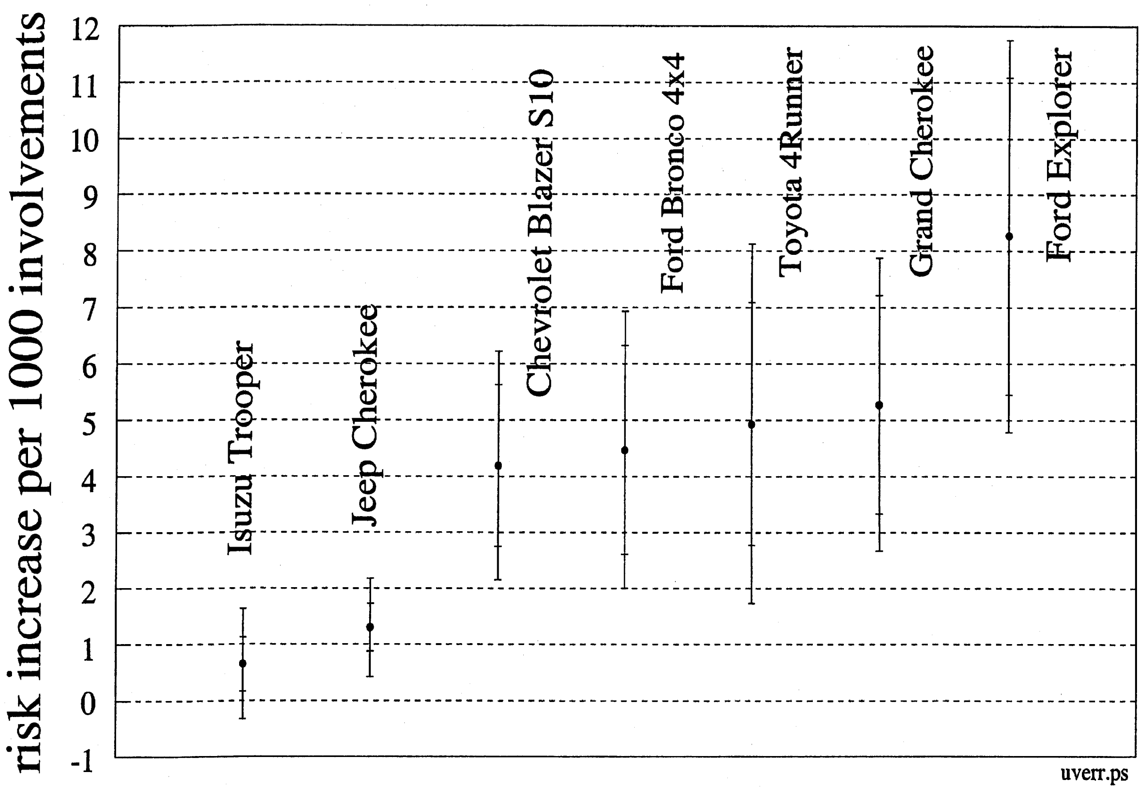

Figure 4.5.1-1 Risk differences against car-car collisions for selected sport utility vehicles. Vehicles are ordered by risk differences. Vertical lines show twice the estimates of non-standard errors (see A.2.3).

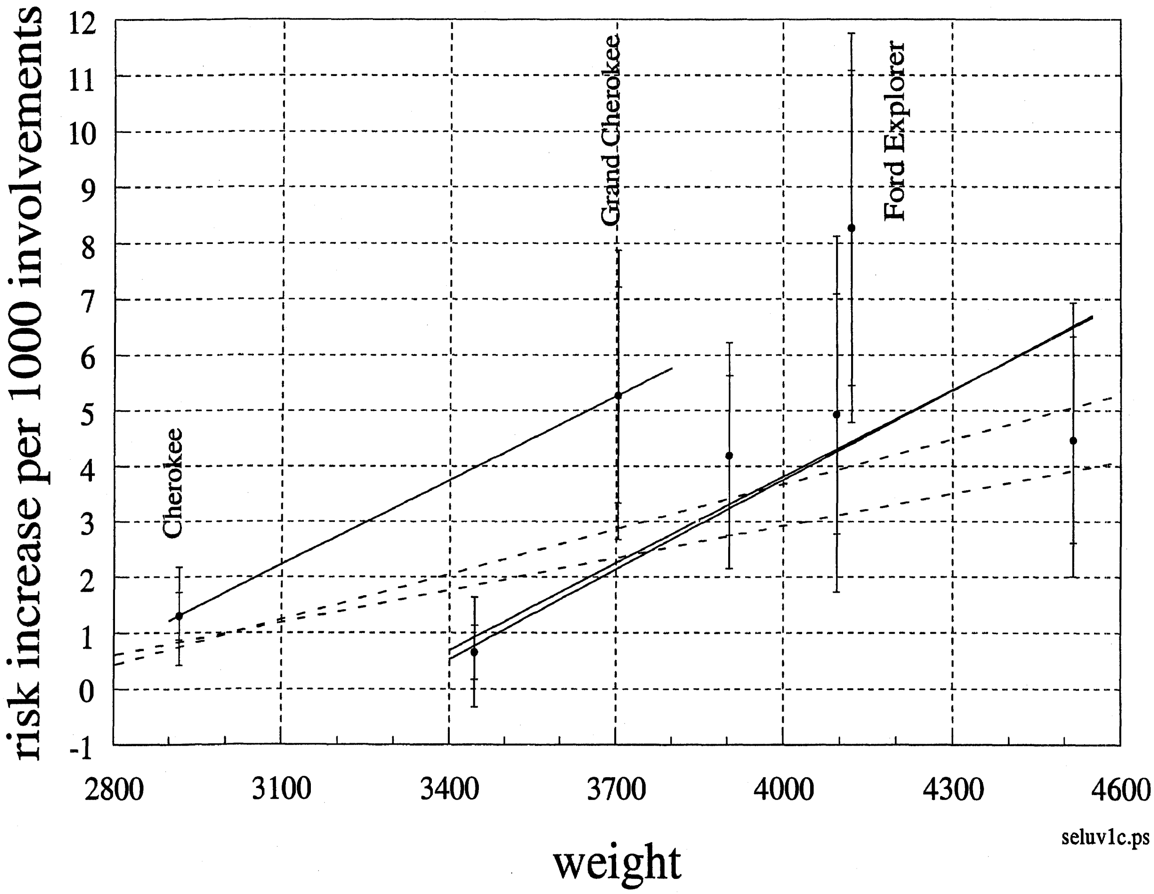

Figure 4.5.1-2 Car driver risk increase in collision with sport utility vehicles versus weight of the sport utility vehicle. Vertical lines show twice the estimates of the non-standard error. Dotted and dashed lines are regression lines fitted to all points, weighted according to the two non-standard error estimates. Solid lines show the regression lines fitted separately to a) Cherokee and Grand Cherokee, and b) the other vehicles. For interpretation of the vertical lines, see Figure 4.5.1-1 and section A.2.3.

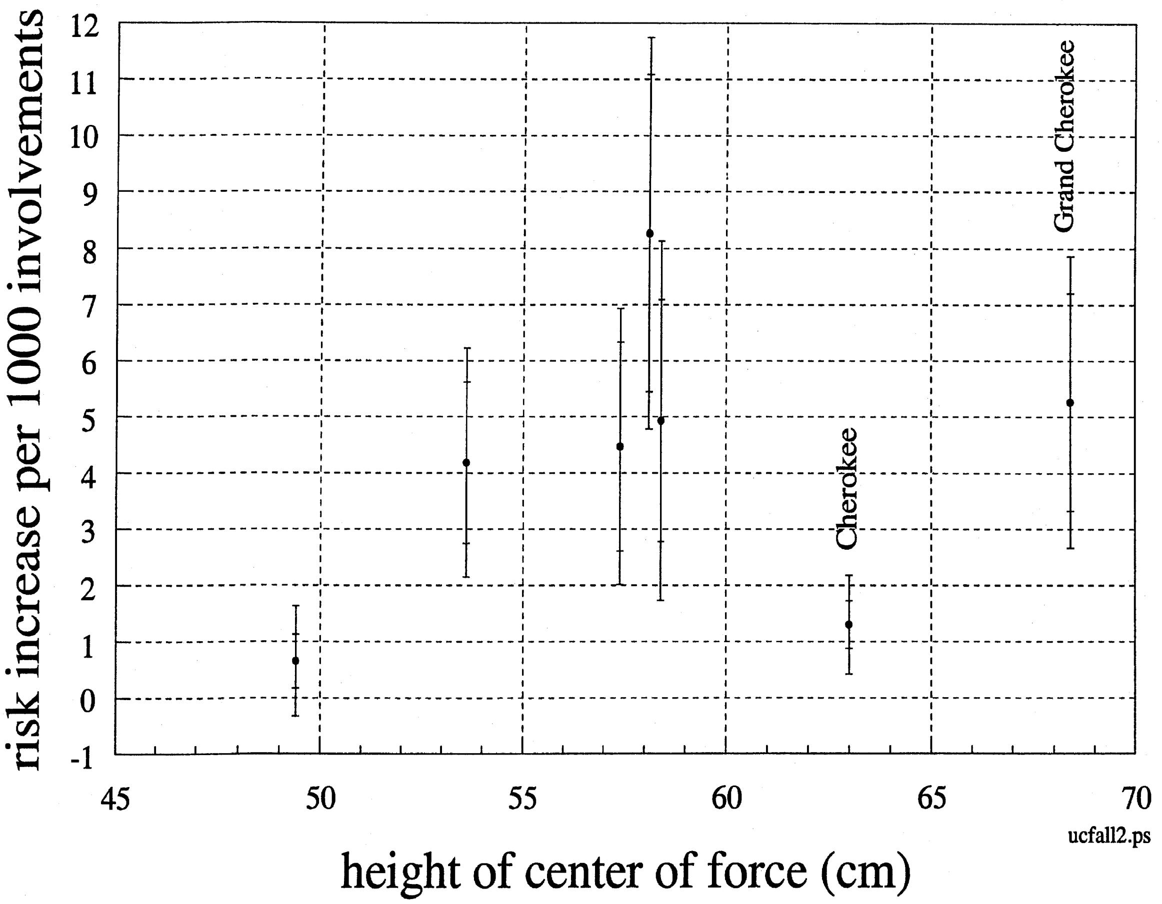

Figure 4.5.1-3 Car driver risk increase in collisions with sport utility vehicle versus height of the center of force of the sport utility vehicle. For interpretation of vertical lines see Figure 4.5.1-1 and section A.2.3.

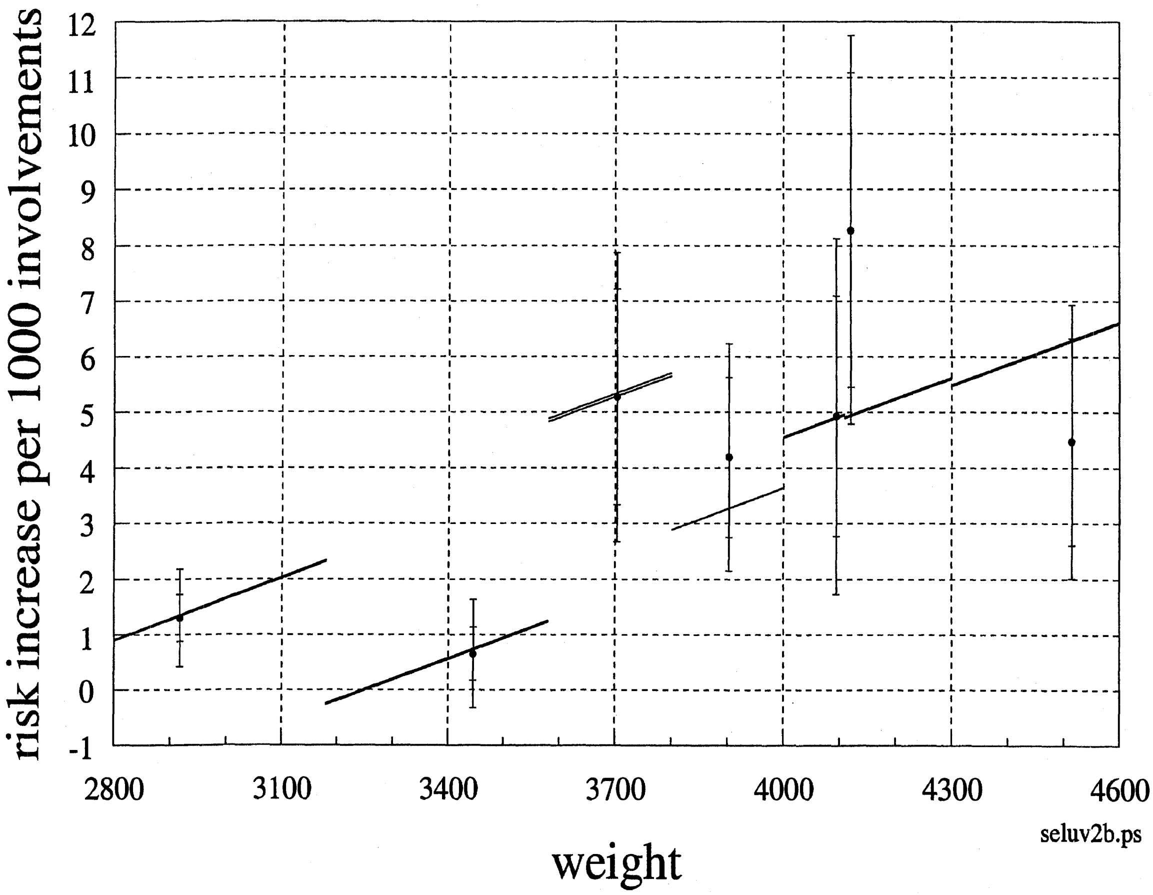

Figure 4.5.1-4 Car driver risk increase per 1000 collisions with sport utility vehicles. Dots are actual data, lines show the modeled values based on the sport utility vehicle's weight and height of the center of force. Two close lines are based on different statistical weighting; sometimes the two lines are undistinguishable. For interpretation of vertical lines see Figure 4.5.1-1 and section A.2.3.

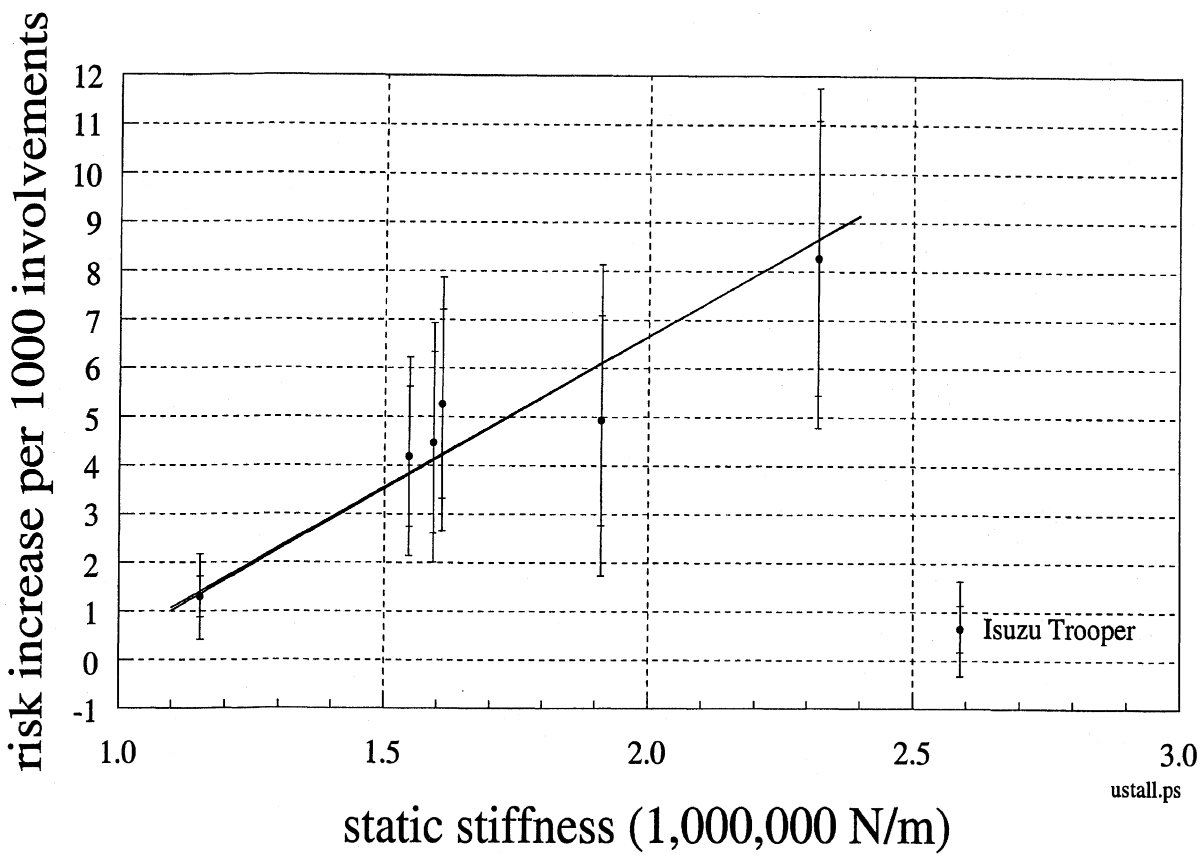

Figure 4.5.1-5 Car driver risk increase in collision with sport utility vehicles, by their static stiffness. For interpretation of vertical lines see Figure 4.5.1-1 and section A.2.3.

Figure 4.5.1-2 shows the risk increase versus the weight of the striking sport utility vehicle. There is a tendency of an increase with weight, but considerably scatter. The dashed and dotted lines are fitted regression lines, weighting the points according to the non-standard error estimates e1 and e2 section (A.2.3). The model coefficients are shown in Table 4.5.1-1. A closer look suggests that there might be two groups of vehicles: the two Jeep Cherokee models, and the Ford Explorer, and the other models. The slopes of the relations within both groups seem to be very similar. Though very different in weight, and slightly different in wheelbase, the two Jeep models are likely to be somewhat similar in the basic structure. Figure 4.5.1-2 shows that they have distinctly higher centers of force than the other vehicles, while the Ford Explorer fell well into the range of the other vehicles. Therefore, separate regressions were fitted to the two Jeep models - resulting in an exact fit - and the other models. They are shown as solid lines in Figure 4.5.1-2. The coefficients in Table 4.5.1-1 show that they are practically parallel. This indicates a consistent effect of weight for the sport utility vehicles, and an additional effect of a factor which separates the two Jeep models from the others. As mentioned, the height of the center of force is such a factor.

Figure 4.5.1-3 shows the risk increase vs. the height of the center of force. Again, two groups appear: the two Jeep models, and all others. The slopes of the relations within the groups are again about parallel, but the lines for the Jeeps are lower, corresponding to their, on the average, lower weight as is apparent in Figure 4.5.1-2.

These patterns suggest fitting a model containing both weight and the height of the center of force. Table 4.5.1-1 shows their coefficients. Their errors are not non-standard errors: they are estimated from the discrepancies between the data and the model, and therefore conventional standard errors. The non-standard error estimates enter only where weighting the data points; the two types of non-standard error give practically the same coefficients. However, correlations between the data points resulting from the complex sampling plan are ignored. All coefficients are at least three, some are four times their standard errors; thus they would be considered "significant". Figure 4.5.1-4 shows how well the models fit the data. To accommodate two independent variables without overloading the figure, a special display was selected. Near each data point, the model is represented by a straight line, using the height of the center of force for that specific vehicle model. Therefore, all lines are parallel, reflecting the effect of weight. The offsets between these lines reflect the difference in the height of the center of force. Near some points, two lines are recognizable; they show the two models with different weights resulting from the non-standard error. In some cases the two lines are so close that they are not recognizable.

Overall, the models fit the data quite well. The only suspect vehicle is the Ford Explorer, but the regression line is still within twice of one of the non-standard errors.

Table 4.5.1-1 Coefficients of models relating risk increase from sport utility vehicles to their weight and height of center of force. Errors are in parentheses; for their explanation see text.

vehicles	intercept	vehicle weight (1000 lbs)	height of cof (cm)	error model
all	-7.1 (4.4)	2.7 (1.3)		e1
all	-4.8 (4.3)	1.9 (1.3)		e2
Jeeps	-13.5 exact fit	5.1 exact fit		
all others	-17.0 (6.8)	5.2 (1.8)		e1
all others	-17.8	5.4 (1.6)		e2
all	-21.4 (5.5)	3.8 (0.9)	0.19 (0.06)	e1
all	-21.7 (4.6)	3.8 (0.8)	0.19 (0.05)	e2

Table 4.5.1-2 Coefficients of models relating risk increases from sport utility vehicles to their weight, height of center of force, and static stiffness. Errors are in parentheses, correlation coefficients are shown for the parentheses connected by brackets, and RMSE is the root-mean-square-error of the model. The first model is a repetition from Table 4.5.1-1.

vehicles	intercept	vehicle weight (1000 lbs)	height of cof (cm)	static stiffness (10^6 N/m)	RMSE
all	-2.2	3.8	0.19		0.7
	(5)	(0.8)	(0.05)		
		cc=0.57			
	2.3			-0.5	1.6
	(1.7)			(0.9)	
	-23	3.7	0.20	0.15	0.8
	(11)	(0.9)	(0.14)	(1.40)	
		cc=0.04	cc=0.93		
			cc=-0.19		
excluding Trooper	-15	3.4	0.10		0.8
	(12)	(1.0)	(0.16)		
		cc=0.67			
	-5.9			6.3	0.4
	(0.9)			(0.7)	
	-11	1.0	0.06	4.9	0.4
	(7)	(1.0)	(0.08)	(1.7)	
		cc=0.50	cc=0.18		
			cc=-0.84		

Figure 4.5.1-5 shows the risk increase vs. the static stiffness of the selected sport utility vehicles. A striking feature is that the Isuzu Trooper is an extreme outliner. If one fits a linear regression to the data points, then the coefficient of static-stiffness is only little more than half its nonstandard error (Table 4.5.1-2). If one omits the Trooper, the points fall closely around a straight line, and the lines fitted with the two sets of weight practically agree. The slope is 9 times its standard error. This raises the question whether a model including weight, height of center of force, and stiffness could represent the data, without leaving an outlier. Table 4.5.1-2 shows the coefficient of such models together with simpler ones for comparison.

If one uses all data points, adding stiffness to the model containing vehicle weight and height of center of force does not improve the fit (the root mean square error is actually greater than that of the model containing weight and height of center of force; the increase is due to the loss of one degree of freedom). Vehicle weight is the only reliable coefficient remaining. The standard errors of the coefficient of the height of the center of force and of stiffness are large, but their correlation coefficient is 0.93. That means that the data do not allow to separate the effects of the two factors.

If one excludes the Trooper, the model including the weight and the height of the center of force changes somewhat: the coefficient of the height of the center of force is reduced by one half and becomes much less than its standard error. Adding stiffness improves the model fit dramatically, but then stiffness is the only term whose coefficient is greater than its standard error. Dropping weight and the height of the center of force from the model does not worsen the fit, but the coefficient of stiffness becomes very large, 9 times its standard error.

Using dynamic stiffness (Figure 4.5.1-6) gives similar results. Therefore, they are not shown.

The conclusion is that the Isuzu Trooper is an extremely influential data point. When including it, weight and height of the center of force are strong predictors of the risk increase, and stiffness has no effect. When excluding the Trooper, stiffness alone is a very good predictor, and weight and height of the center of force add practically nothing.

Figure 4.5.1-7 explains this in mathematical, not physical terms. The scatterplots of weight and the height of the center of force shows a weak negative correlation (the correlation coefficient is -0.57, corresponding to the 0.57 in the first model of Table 4.5.1-2).

The correlation between weight and static stiffness is also weak, but that between static stiffness and height of the center of force is strongly negative. This is reflected by the very high correlation coefficient of 0.93 between the coefficient of the height of the center of force, and static stiffness in the second model of Table 4.5.1-2. If the point for the Isuzu Trooper which is to the extreme lower right in the right panel of Figure 4.5.1-7 is omitted, the correlation between height of the center of force and static stiffness becomes weak, resulting in the low correlation coefficient 0.18 of their coefficient in the last model of Table 4.5.1-2.

Omitting the Trooper, strengthens the correlation between the height of the center of force (upper left panel of Figure 4.5.1-7), and weight and static stiffness. These increases are reflected by the stronger correlation of the coefficient of these parameters in the fourth model of Table 4.5.1-2, compared with the second model.

This suggests an engineering review of the Isuzu Trooper to determine whether it has features which distinguish it from all the other models and whether some of those features are likely to affect aggressivity.

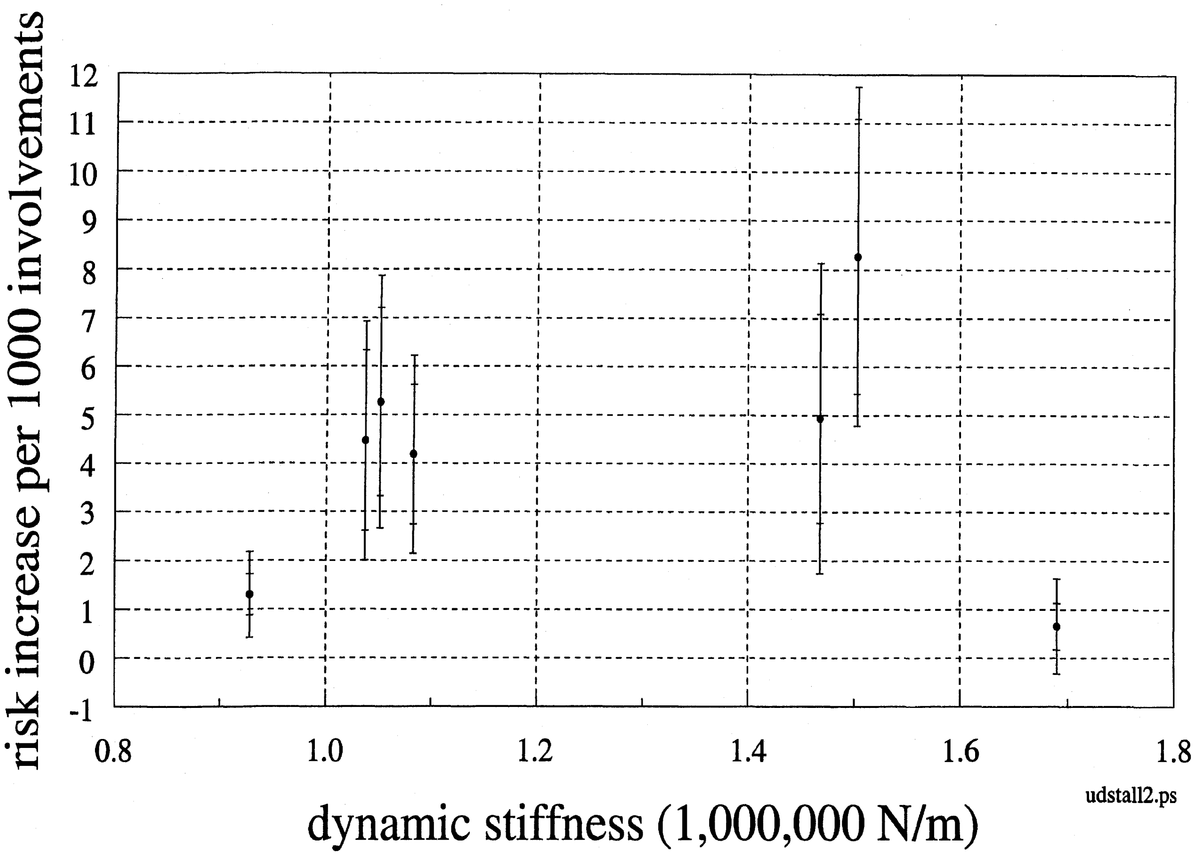

Figure 4.5.1-6 Car driver risk increase in collision with sport utility vehicles, by dynamic stiffness of the sport utility vehicle. For interpretation of the vertical lines see Figure 4.5.1-1 and section A.2.3.

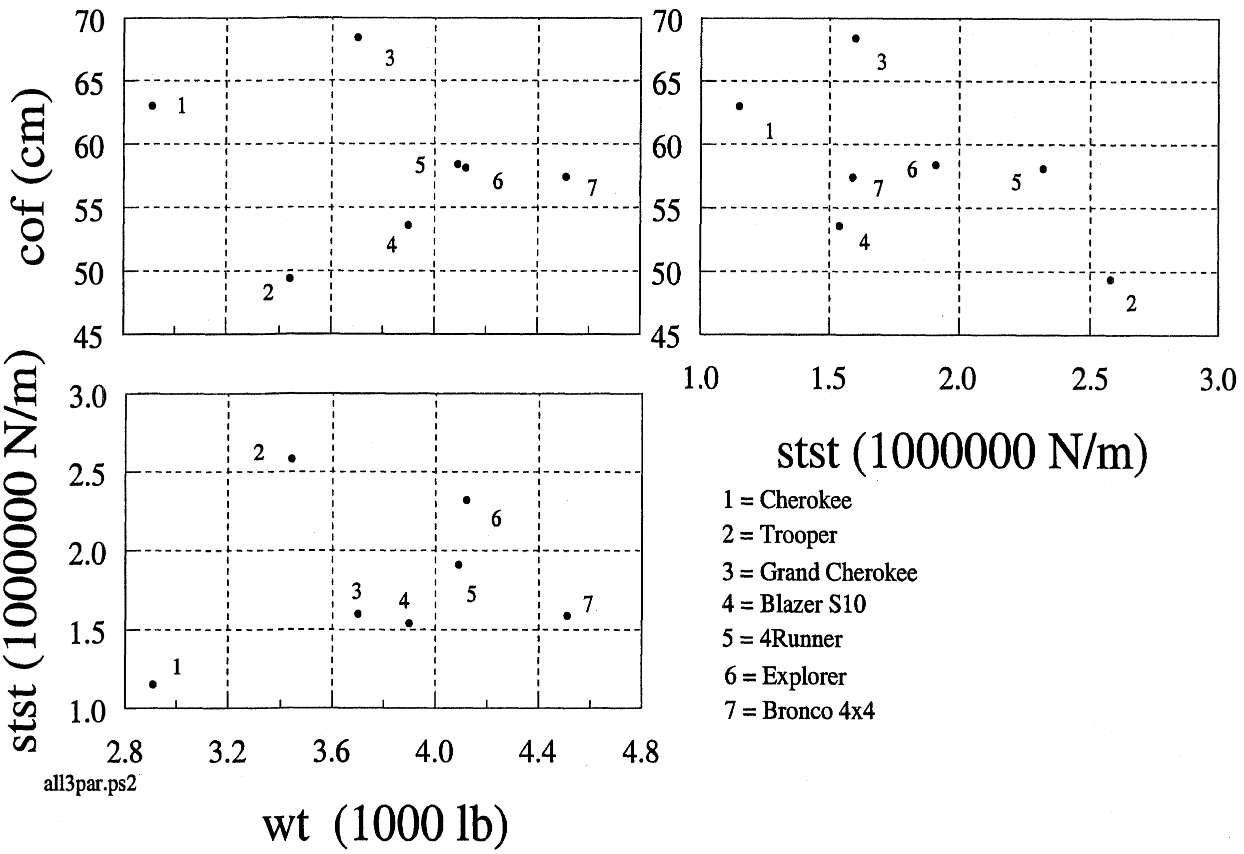

Figure 4.5.1-7 Bivariate scatterplots among weight (wt), height of the center of force (cof), and static stiffness (stst) of the selected sport utility vehicles.

4.5.2 Vans

Figure 4.5.2-1 shows the risk increase for the selected van models. They are all within or close to each other's ± 2-non-standard error ranges. Therefore, one can not expect a model to give meaningful results and no attempt at modeling was made.

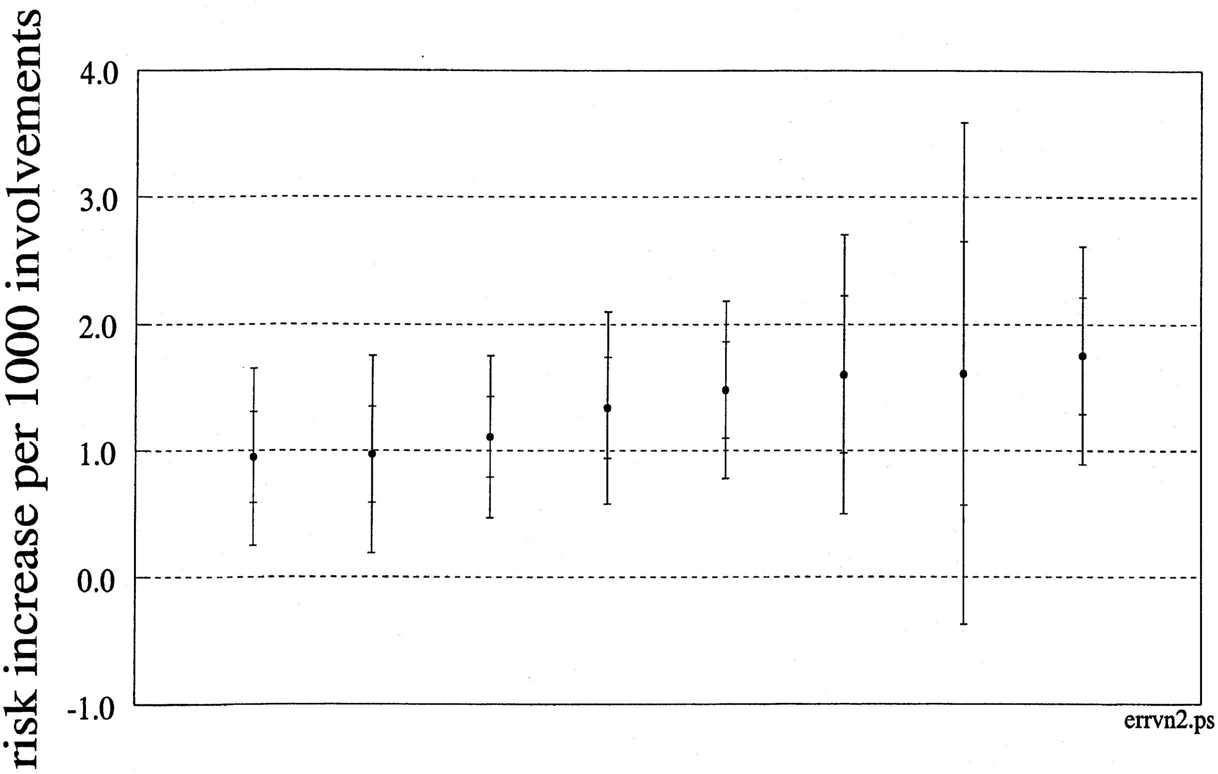

Figure 4.5.2-1 Risk increase against car-car collision for selected van models. Models as ordered by risk increase. Vertical lines show ± twice the estimates of non-standard error (see A.2.3)

4.5.3 Pickups

Figure 4.5.3-1 shows the risk increases for the selected pickups. For 11 of the models, the pseudo-confidence ranges[2] overlap widely. Only for the Toyota short bed truck with the lowest risk increase does it not overlap with the12 others. The range for the Mitsubishi Mighty Max with the second lowest value overlaps all but that of the model with the highest value the Nissan standard bed truck. This suggests that any relation found between risk increase and vehicle parameter could be strongly influenced by these three models.

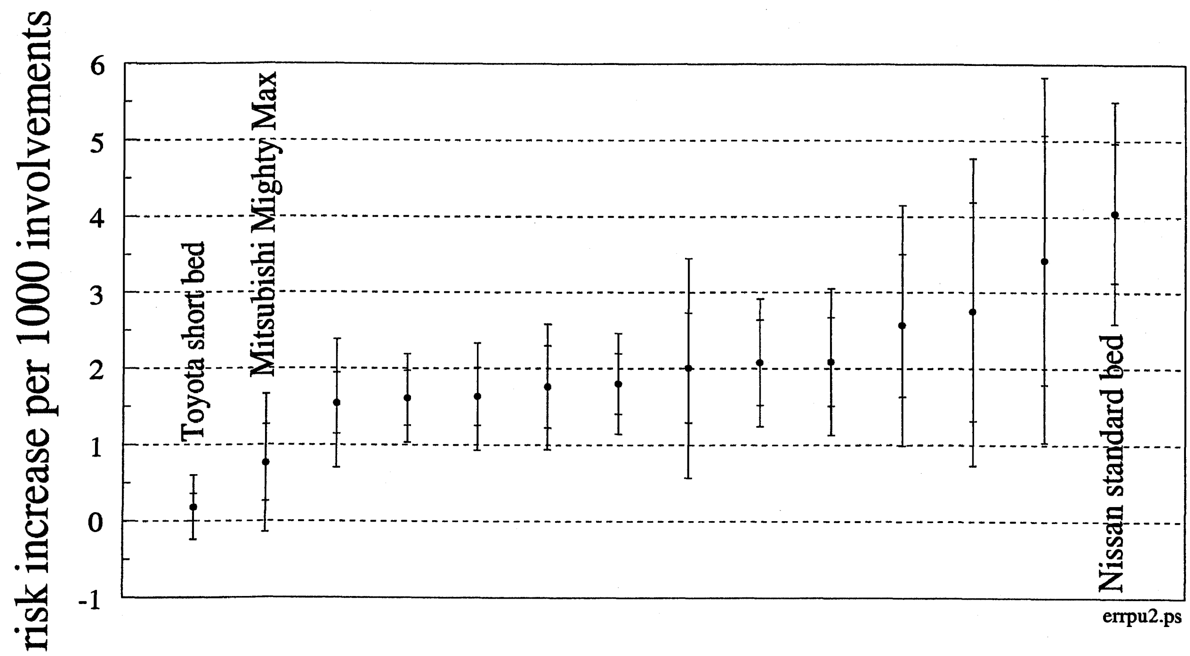

Figure 4.5.3-1 Risk increase in car-pickup collision against car-car collisions for selected pickup truck models. Vertical lines show the pseudo-confidence ranges (see text).

[2]We define a "pseudo-confidence" range a range of ± twice the non-standard error. Since we use two types of error estimates, we have two pseudo-confidence ranges.

In Figure 4.5.3-2, risk increases are plotted versus vehicle weight . Overall, there seems to be no relation with weight and a linear regression has no "significant" slope. A closer look suggests a non-linear relation; an initial rapid increase, followed by a nearly flat relation for higher weights. Some experimentation leads to the relations shown in the Figure: one through the points below 3100 lbs, and another through the points above 2900 lbs. Two sets of relations are shown, the heavy lines being regressions using the second type of error estimates for weighting, the light lines using equal weights for all points. None of the regressions have "significant" coefficients, and the slope in the weight range below 3100 depends strongly on the three extreme vehicle models; the two with the lowest risk increase and the one with the highest risk increase.

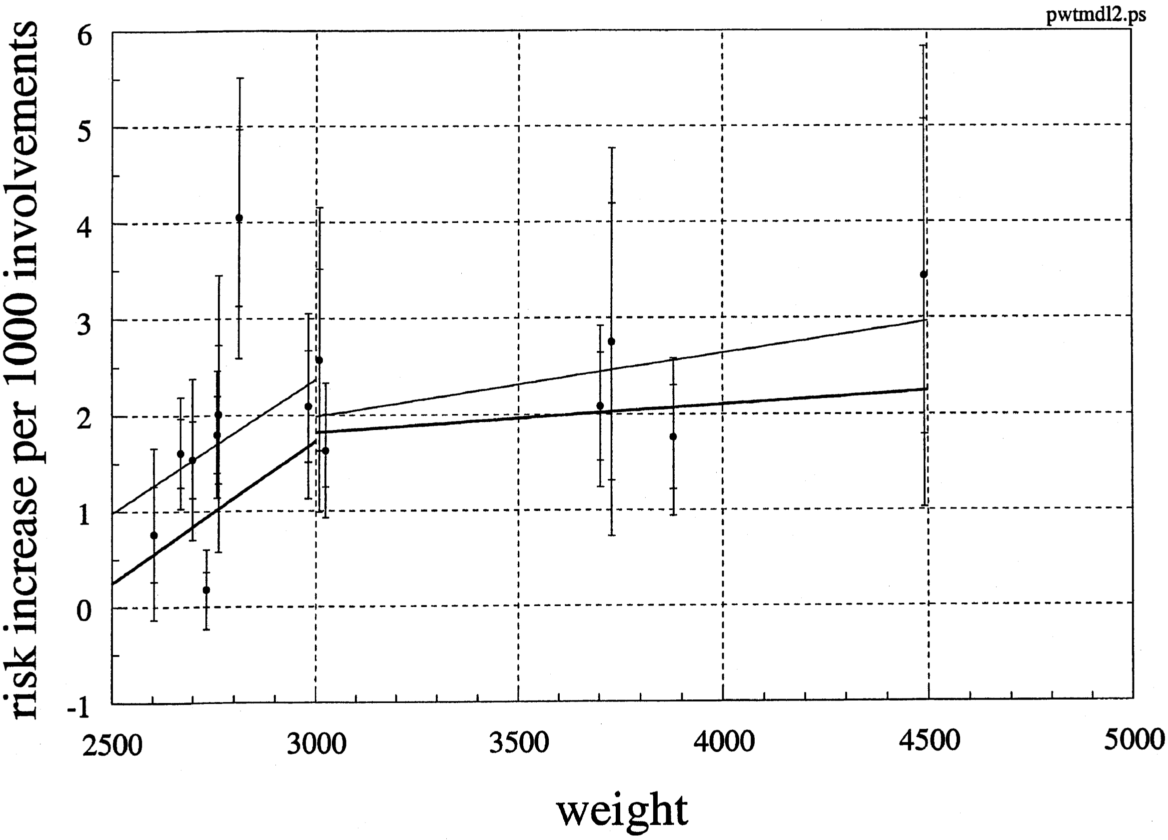

Figure 4.5.3-2 Risk increase in pickup-car collisions against car-car collisions versus pickup truck weight. The lines are linear regression lines fitted as described in the text. They are purely descriptive, not to be considered "significant".

That the lines based on weighted cases have similar slopes, but are below those based on unweighted cases is easily explained; lower risk increases tend to have smaller errors than higher ones at similar vehicle weights, therefore, they have higher regression weights and "pull down" the regression lines.

Figure 4.5.3-3 shows the risk increase versus the height of the center of force. No relation is apparent. The same holds for static stiffness (Figure 4.5.3-4) , and for dynamic-stiffness (Figure 4.5.3-5).

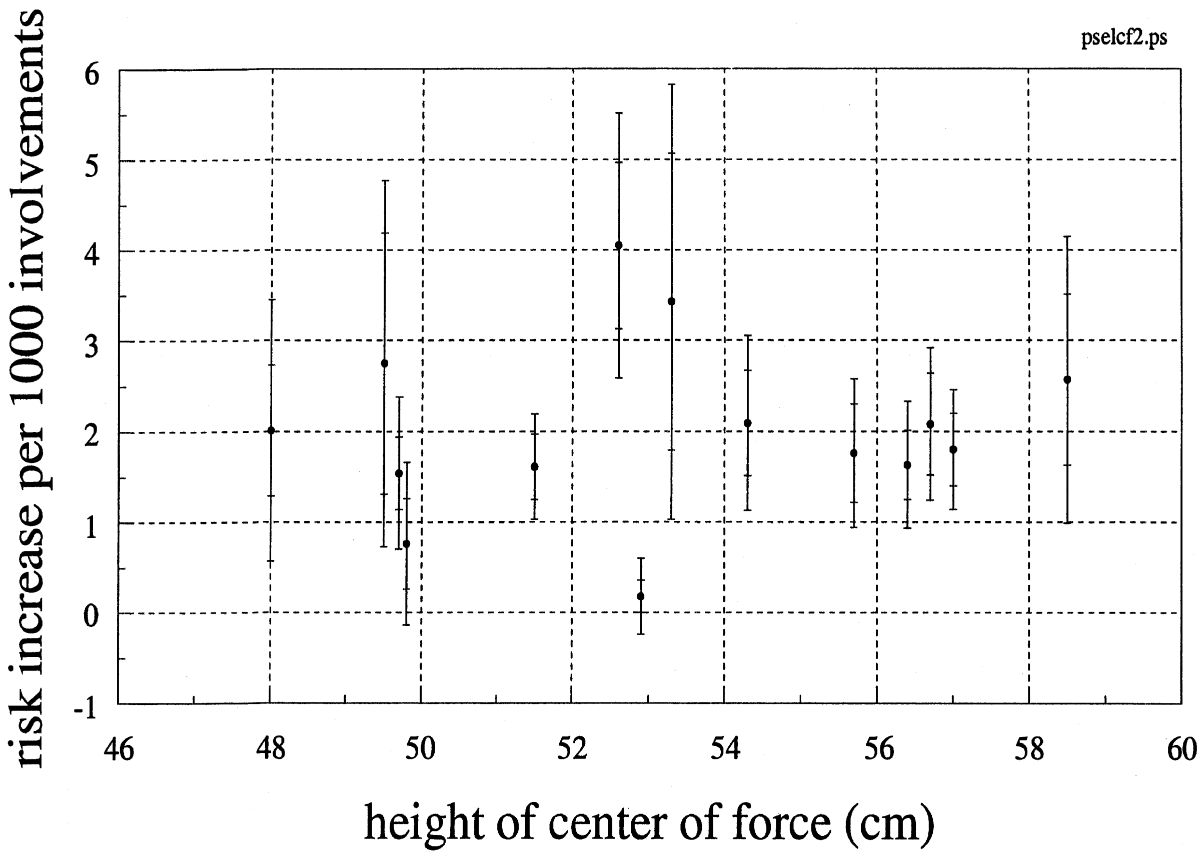

Figure 4.5.3-3 Risk increase in pickup-car collision against car-car collisions versus height of center of force of pickup truck.

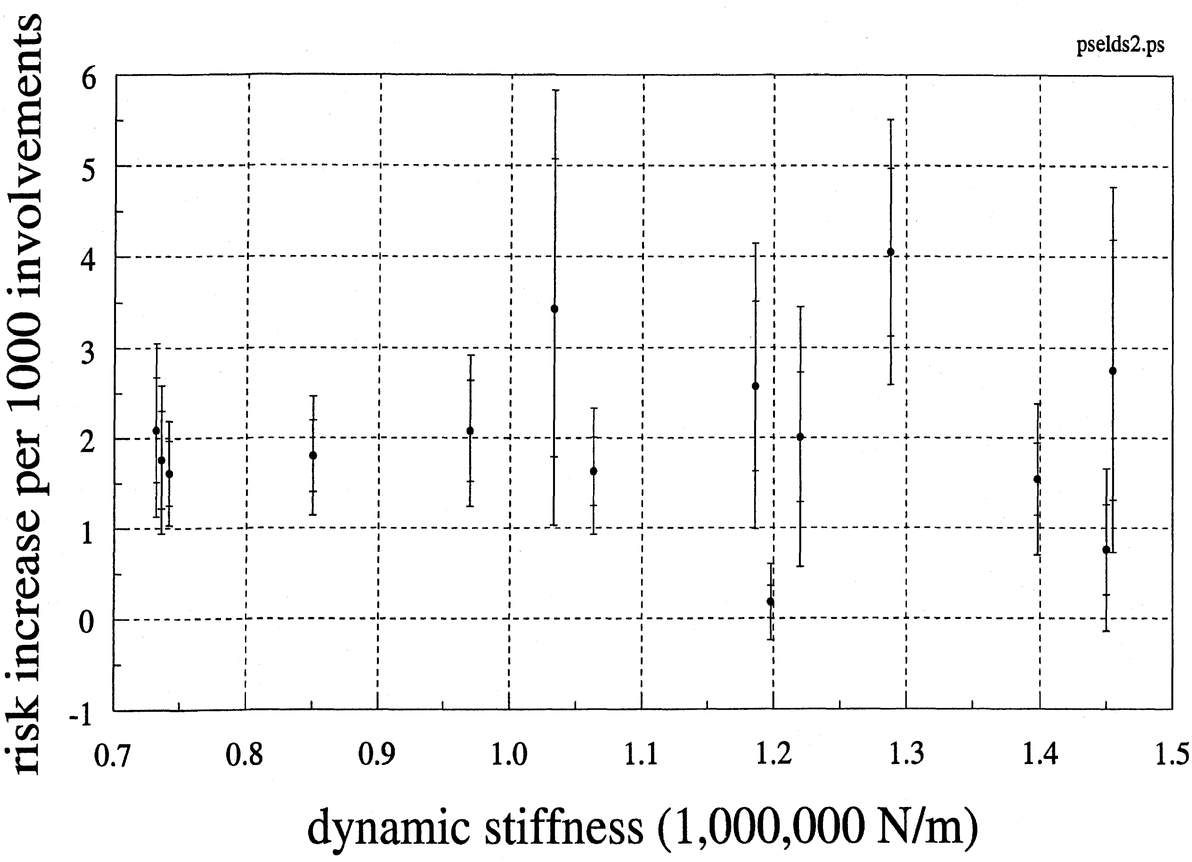

Figure 4.5.3-4 Risk increases in car-pickup collisions against car-car car collisions versus static stiffness of pickup trucks.

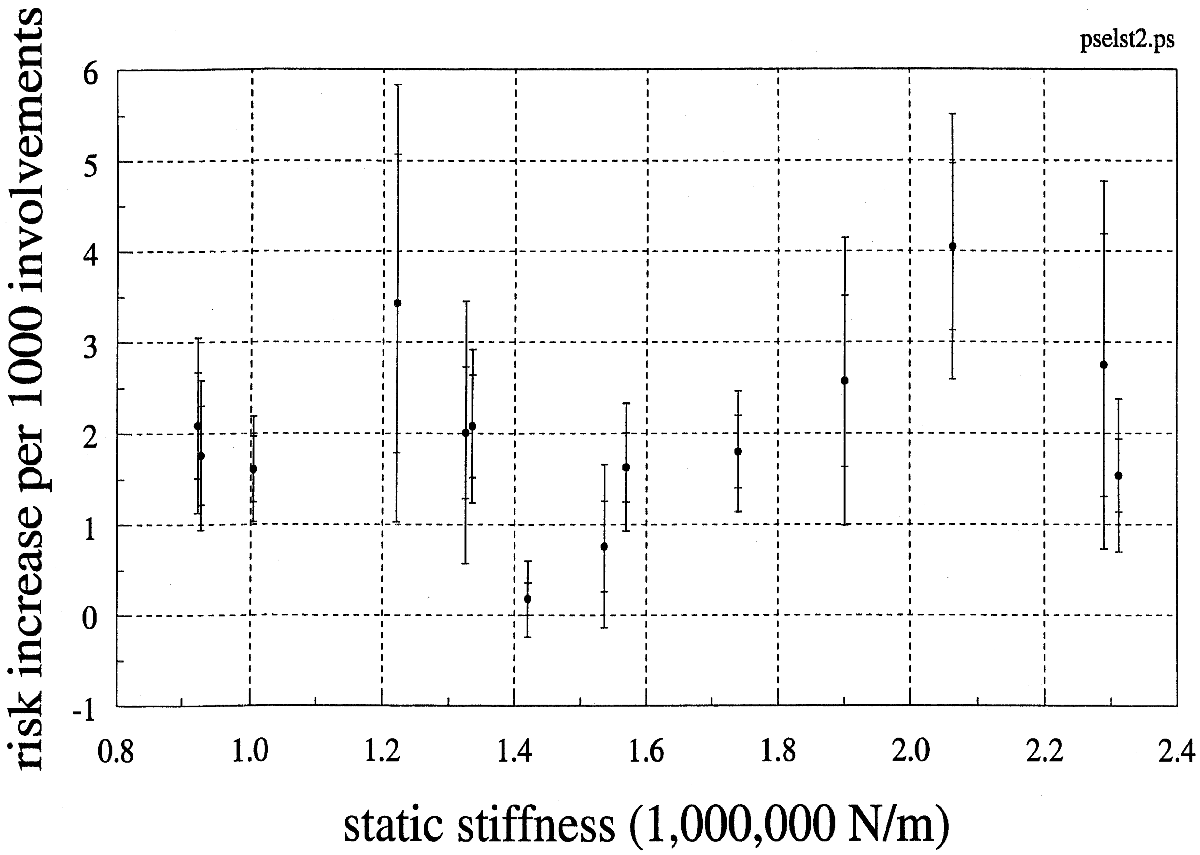

Figure 4.5.3-5 Risk increases in pickup-car collisions against car-car collisions versus dynamic stiffness of pickup truck.

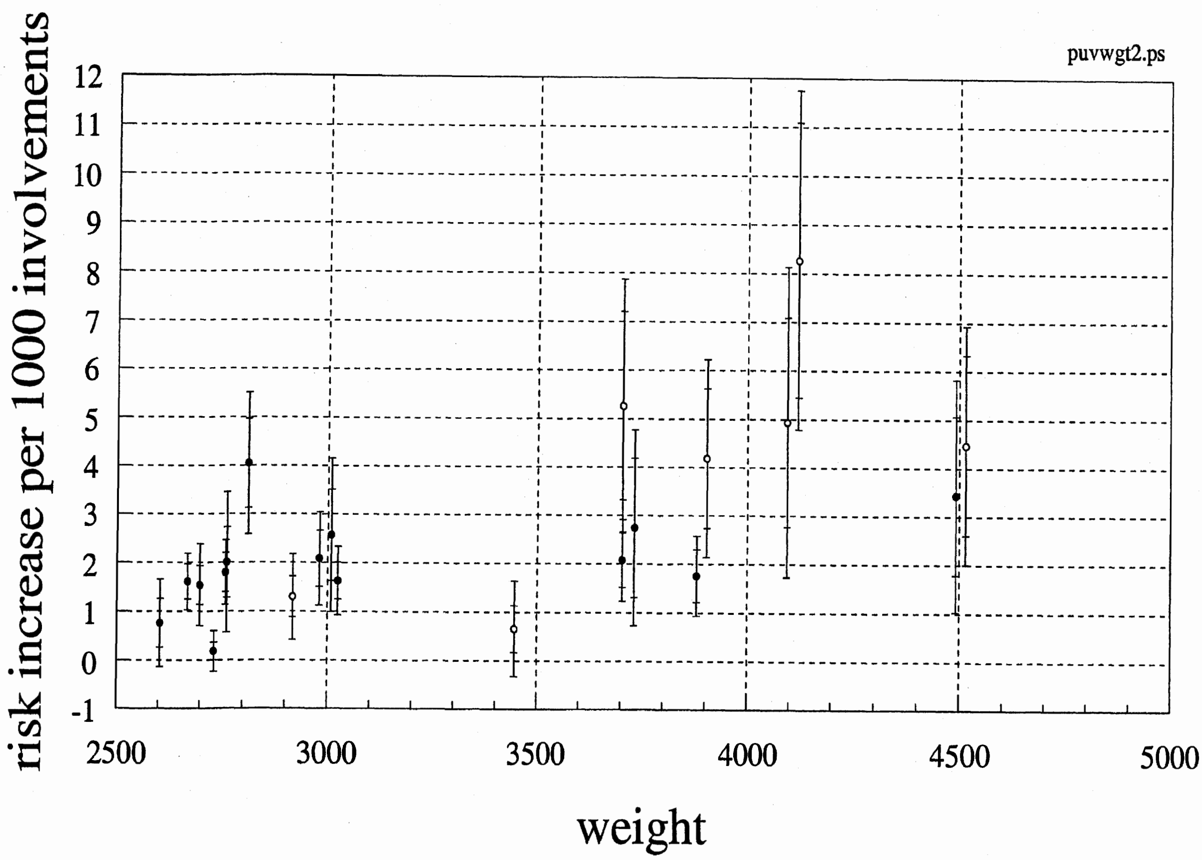

Figure 4.5.3-6 Risk increase in pickup-car (solid dots), and sport utility vehicle-car (open circles) collisions against car-car collisions versus weight of pickup truck or sport utility vehicle.

It is conceivable that the selected pickup models have combinations of these parameters which hide their effects in univariate plots. Therefore, regressions using some interactions, and also powers of the parameters were run. No "significant" and not even suggestive relations were found.

Finally, the relation with weight, the only suggestive one was compared with that found for sport utility vehicles. Figure 4.5.3-6 shows the risk increases for pickup trucks and sport utility vehicles versus weight. Overall, the pseudo-confidence ranges overlap widely, so that one would not consider them different. A closer look shows that for weights below 3500 lbs, sport utility vehicles are in the low range of the risk increases. For weights above 3500 lbs, all 5 points for sport utility vehicles are above the 4 points for pickup trucks. This seems to invite a non-parametric test which would show a probability of only 0.016 for the observed pattern of two runs. That, however, is not valid since the estimated risk increases are not independent because they result from the complex NASS sampling plan.

In sum, there is no indication that the aggressivity of pickup trucks is related to one of the available parameters. There is a very weak suggestion that it might increase with vehicle weight up to about 3000 lbs, and very little, if at all, beyond that.

5. Findings and recommendations

5.1 Findings

5.1.1 Combining FARS and NASS GES data.

To estimate fatality risks, data from FARS for drivers killed, and from NASS GES for drivers involved in collisions were combined. FARS provides a census of fatal crashes in the U.S., NASS GES estimates for all police reported crashes. They have many data elements in common, and for most the codes are comparable. However, the data could not be simply combined.

In the present study it was important to identify the impact points on the vehicles. FARS and NASS GES codes differ, and there is no unambiguous translation between them. Therefore, we are not certain to what extent frontal impacts in FARS cases, and in NASS GES cases describe the same situation. This could have biased some of our estimates. However, the biases are likely to be similar among the vehicle types studied, and therefore affect comparisons between vehicle types less than absolute estimates.

FARS and NASS GES use the same body style codes, but in FARS usually specific codes are used, for instance "compact sport utility vehicle", while in NASS GES they are very often less specific, such as "sport utility unknown body". Therefore, the body style codes could be used only for comparing broad vehicle classes, such as cars, sport utility vehicles, vans, and pickup trucks. Studies of more specific vehicle classes had to rely on decoding the VIN. It was also found that, in few cases, the body style and the decoded make/model did not agree.

In FARS the VIN is nearly always given, in NASS GES it is often missing. The missing VINs are not randomly distributed, but systematically: in certain PSUs the VIN is shown for all or nearly all cars and LTVs, in others not at all, or only for very few cases. Ignoring the pattern could have caused biases. An approach was developed to reduce such biases.

Most PSUs in the South and Central NASS regions provide the VINs. Therefore, FARS data and NASS GES data from these regions were used, adjusting the NASS GES expansion weights to account for the PSUs with missing VINs. In the West, PSUs outside of California provide VINs, most in California don't. Therefore, FARS and NASS GES data from the West excluding California were used, this time adjusting the NASS GES expansion weights for the exclusion of California.

This was done, and tested with fatality rates in collisions between cars and the three types of LTVs. The rates obtained from the FARS and NASS GES data for the South, Central, and West excluding California combined (which is the same as the U.S. less the Northeast and California) were very close to for the entire U.S. However, some small systematic differences remained. It might be possible to reduce them by refining the approach.

To assess differences between rates for different vehicle classes, or for analyzing how they depend on vehicle parameters, one needs estimates of standard errors. This is not straightforward. NASS is a complex sample, and calculating exact sampling errors is complex. The standard errors one obtains reflect differences between the estimates from the sample, and the actual national values. Calculating exact errors and correlations between estimates - which are important if one wants to make comparisons -, or the common approximations would have been beyond the scope of this study. Therefore, approximations published by NHTSA were used.

Another complication is that one is rarely interested only in the sampling error of the ratio of an exact numerator from FARS, and a denominator estimated from NASS GES. Statistical analyses imply that FARS counts are random variables following a Poisson distribution, and that nationwide counts of police reported crashes are also random variables following this distribution.

This random variation has to be combined with the sampling error to assess whether differences of rates should be considered to be due to chance or "real" - "significant" is the term commonly used, but misleading those without a statistical background and even some with one.

An exact, and even a satisfactory approximate solution of this problem was found to be beyond the scope of this study. However, a heuristic combination of NHTSA's simplified error estimates for NASS GES with the assumed Poisson variability of collision counts and fatality counts, gave error estimates which are probably at least of the right order of magnitude.

In sum, we believe that we have found a valid way to combine FARS and NASS GES data to study problems where the use of the VIN is critical. It is probably possible to improve this approach further.

While we have made rough error estimates for fatality rates, we do not believe that the approach used is satisfactory, and that a very thorough analysis is needed to develop satisfactory estimates.

5.1.2 Controlling for confounding factors.

Many factors influence the fatality risk in a collision. Such factors may bias the results or merely increase their random errors. "Internal" and "external" confounding factors were distinguished. Internal factors used were the studied driver's age and sex, the availability of an air bag, and the vehicle's weight. Others were considered but not studied. External factors studied were the speed limit of the highway and the ratio of the two vehicles' weights (the weight of the striking vehicle was also studied separately, as an external factor, and as a potential parameter of aggressivity).

The effects of the victim's age and of the speed limit were very strong and highly nonlinear. They also interacted, and there were interactions with sex and air bag availability. It was not possible, within the scope of the work, to develop a sufficiently realistic model encompassing all the factors which showed relations with the fatality risk.

Therefore, a simple model including only the speed limit and the weight ratio was developed. This model was used to "control" for the effects of these two factors.

5.1.3 Differences between the aggressivity of vehicle classes.

The first analyses distinguished only cars, sport utility vehicles, vans, and pickup trucks. In some, the vehicle weight ratio, and the speed limit at the collisions were controlled for. Table 5.1.3-1 shows the car driver fatality risks in collisions with the three types of LTVs, relative to those in car-car collisions. The "raw" risks, not controlled for any differences in the vehicles nor collision environments range from 4 to 6 times as high as in car-car collisions. Controlling for the weight differences between cars and LTVs, and the speed environment reduces the discrepancies to a range of 2 to 3. (Very little, if any of the difference is due to the difference in geographical coverage - the South, Central, and truncated West include over 80% of all collisions). Very roughly, the controlled relative risks are between 1/3 and 2/3 of the uncontrolled risks.

Table 5.1.3-1 Car driver fatality risks in collisions with other vehicles, relative to car-car collisions.

data	adjustment	other vehicle		
		sport utility vehicle	van	pickup
Nationwide	none	5.8	6.1	4.3
South, Central, and truncated West	weight ratio, speed limit	3.4	1.9	2.3

Table 5.1.3-2 compares the weight-ratio-adjusted and speed-adjusted car driver fatality risks relative to car-car collisions with those from a previous study[3], which are not adjusted for weight, but controlled for driver age. Front-front, front-left, and front-right collisions are distinguished. For vans, the estimates from the two studies differ widely, for pickups, they agree better. However, the good agreement of the estimates for sport utility vehicles is striking, especially since the estimates are controlled for different factors. For vans and pickups, differences between collision configuration are not clear, but sport utility vehicles are clearly most aggressive in front-front collisions, followed by front-left, and finally front-right.

Table 5.1.3-2 Car driver fatality risks relative to car-car collisions, adjusted for the vehicle weight ratio and speed limit (upper number) with such risks from a previous study, controlled only for the victim's age, (lower number) by collision configuration.

collision configuration	other vehicle		
	sport utility vehicle	van	pickup
front-front	6.4 5.6	1.4 5.4	2.0 3.0
front-left	4.2 4.5	1.7 2.0	2.8 3.8
front-right	3.6 3.7	2.4 6.0	1.5 2.3

[3]Joksch, H, Massie,D, Pichler,R, Vehicle Aggressivity: Fleet Characteristics Using Traffic Collision Data. DOT-HS-808-679, February 1998

If one separates low and high (55 mph or more) speed environments, the aggressivity of vans and pickups seems to be lower in the higher speed environment. For sport utility vehicles, there seems to be no difference.

Table 5.1.3-3 compares the estimates from this study, the same as in Table 5.1.3-2 with those from another previous study[4], which were controlled for vehicle weight alone, and for vehicle weight and driver age. These controls were very strict: the differences between the weights of the two colliding vehicle, and those between the ages of their drivers had to be below certain limits.

Table 5.1.3-3 Car driver fatality risks relative to car-car collisions, adjusted for vehicle weight ratio and speed limit from this study (upper number), with such risks from a previous study, controlled for vehicle weight (lower left number), and controlled for vehicle weight and victim's age (lower right number).

collision configuration	other vehicle		
	sport utility vehicle	van	pickup
front-front	6.4 1.6/1.9	1.4 1.7/2.0	2.0 1.7/1.8
front-left	4.2 2.5/3.1	1.7 1.3/1.5	2.8 1.8/4.3

[4]Joksch, H, Fatality Risk in Collision Between Car and Light Trucks, DOT-HS-808-802, October 1998

The aggressivities of vans and pickups, are comparable, but not close. For sport utility vehicles, the risks from the two studies differ very much, though both are controlled for weight or weight-ratio, important factors.

That the adjusted risks for collisions with sport utility vehicles in Table 5.1.3-3 differ greatly, whereas the adjusted and the unadjusted risks in Table 5.1.3-2 agree fairly well, is puzzling. However, Table 4.3-4 suggests an explanation: the average weight of sport utility vehicles is much higher than that of cars and even pickups, and still higher than that of vans. The adjustment model for weight-ratio and speed limit was developed for car-car collisions, and it did fit well in the weight-ratio range covering most cars. It may fit less well at higher weight ratios where there are relatively few cars but more LTVs. If the model there underestimates the effect of the weight ratio, the adjustment for the weight ratio in car-utility vehicle collisions is insufficient, and the risk increases are closer to the actual risks.

In sum, even after controlling for two important factors, LTVs face a car driver with a 2 to 3 times as high fatality risk as another car in a collision. Utility vehicles are the most aggressive of the LTVs. In front-front collisions with a sport utility vehicle, car occupants are exposed to an even higher risk: about 6 times as high as in car-car collisions. In front-front collisions with other LTVs, the risk is only about 2 times as high as in car-car collisions.

5.1.4 Aggressivity and vehicle parameters.

5.1.4.1 Considering only vehicle parameters.

Relating vehicle parameters to aggressivity by plotting the adjusted fatality risk in one vehicle versus the values of a selected parameter for the striking vehicle without distinguishing vehicle classes showed that the risk increased with weight, height of the center of force, and stiffness of the striking vehicle. A closer look, however, showed that this was not a valid approach. The values of the selected parameters for LTVs are higher than for cars, though their ranges overlap. Together with the higher aggressivity of LTVs, this created the appearance of smooth relations.

If the apparent overall relation between aggressivity and a parameter reflected a physical effect, the same relation should appear within each vehicle class (at least after accounting for the other parameters). Treating the vehicle classes separately showed a much less clear picture. One surprising observation was that dynamic stiffness showed often a negative relation with aggressivity, though static stiffness with which it is correlated showed a positive relation. Multivariate statistical models did not show stable and consistent quantitative relations.

However, a few qualitative relations appeared. For sport utility vehicles and pickup trucks, weight, the height of the center of force, static stiffness, and dynamic stiffness showed all positive relations with aggressivity. For sport utility vehicles, the effect of weight appeared strongest, for pickup trucks that of static stiffness. Within the class of vans, no large effect appeared, and many relations had a negative slope.

For cars, the height of the center of force had the strongest effect; weight had also a strong effect, beyond that via the weight ratio which was controlled for. Effects of static and of dynamic stiffness were inconsistent.

The only relations which were clear and stable were differences between cars, and vans and pickup trucks - between which there was no consistent difference -, and between these vehicle classes and sport utility vehicles.

5.1.4.2 Distinguishing make/models.

Vehicles of the same make/model have the basic parameters in common, and there might be other important differences between the make models beyond those captured by the basic parameter. Therefore, cases involving the most common makes/models of LTVs were selected, and average adjusted risks for each make/model used for analyses.

This showed a clear pattern for sport utility vehicles. An additive linear model including weight and the height of the center of force represents the points for seven sport utility vehicles fairly well. Static stability alone represents the data even better - if one excludes the Isuzu Trooper which is a far outlier.

Models including weight, height of the center of force, and static stability are practically underdetermined because of correlations between these three factors. Retaining or excluding the Trooper changes the model coefficients dramatically. On the other hand, models containing only weight and height of the center of force are changed much less by excluding the Trooper.

Differences between van models were so small that no modeling was attempted.

For pickup trucks, some relation between aggressivity and weight appeared: it increased up to about 3000 lbs, but remained essentially constant for higher weights. A comparison with sport utility vehicles showed that at lower weights pickups and sport utility vehicles had about the same aggressivity. At higher weights, that of sport utility vehicles was always higher, but the approximate confidence ranges overlapped.

No relation between aggressivity and height of the center of force, nor with stiffness was apparent for pickup trucks.

5.2 Recommendations.

5.2.1 Combining FARS and NASS GES.

For studying fatality rates based on numerators from FARS and denominators from NASS GES, the highest priority has the development of practical, perhaps approximate, methods to estimate the "errors" for differences and ratios of fatality rates. These errors must combine the effects of the sampling error, and of the random variability of the actual crash counts. Also studied should be which effects the historical changes in the NASS GES sample over time have on the errors of combined data from several years. Of generally lower - but important for studies which rely of precise identification of vehicle make/models - priority is to refine the approach used in this study to combine parts of the FARS data with parts of the NASS GES sample, to obtain less biased national rates. Approaches similar to ratio estimators seem to be promising.

The definitions of impact points in FARS and NASS GES, and the actual coding practices should be examined. The current codes are not completely compatible. Also, the original codes in the state crash report forms are not fully compatible. However, a trained NASS GES coder, and even more a FARS analyst might be able to obtain more precise information by using the sketches and narratives in the crash report, and not only the impact codes in them. By providing additional information on the impact codes, the value of NASS GES and FARS for crashworthiness studies could be greatly enhanced. However, care must be taken to maintain some compatibility between historical and new data.

The distinction of urban and rural environments in FARS is crude, but has been successfully used to control in a very simple manner for crash severity. NASS GES does not have such a simple code, and therefore this simple, but useful approach can not be used in work combining FARS and NASS GES. A code for rural/urban, exactly matching the definitions of FARS, should be added to NASS GES.

5.2.2 Extending the data base.

More calendar years should be added to the data base used in future studies. Kahane's codes should be extended to the most recent model years and incorporated in the data base. It should be determined whether broader classes of sufficiently similar vehicles can be developed on the basis of Kahane's codes, to increase the case numbers and reduce the random variability of "data points". It should also be determined to which vehicle classes the results of NCAP and compliance tests could be realistically extended, at least for exploratory work.

5.2.3 Adding more aggressivity parameters.

Since the parameters used in this study did not adequately predict aggressivity, additional parameters should be used. The first step would be to refine the information contained in the available data bases. For instance, stiffness at various levels of deformation could be used, instead of the overall measure used in this study. Instead of the single value of the height of the center of force, one might consider values such as the highest point exceeding a certain value, the vertical extent where the force exceeds a certain level, or other characteristics based on engineering considerations.

One should also consider additional measures, such as ride height, the height of the bumper supports, or other direct measurements of vehicle characteristics.

5.2.4 Developing a realistic model for confounding factors.

Ignoring confounding factors adds random variability to the findings, and may even bias them. Therefore it is desirable to control for them, e.g. by using a model estimating their influence. Some very strong confounding factors, however, seem to have mathematically complex effects, and their interactions are even more complex. Too simple approximations may not achieve the desired effects and some experiments suggested that they might add worse biases. Therefore, a realistic model for the effects of the major confounding factors which are available in FARS and NASS GES should be developed. This would also benefit other studies based on these data bases.

Appendix 1. Illustrations of confounding factors

As described in section 4.2, the effects of several confounding factors was studied, and a model to control for two of them was developed. In this appendix, some simple graphs are presented to give an idea of the magnitude of the effects of some confounding factors. These graphs are based on preliminary data files which differ somewhat from those finally used. Thus, they should not be compared with those shown in the body of the report.

Figure A.1-1 shows how the driver fatality risk varies with the weight ratio of the two cars in the car-car collisions. Other things being equal, the velocity change experienced by the car is proportional to the weight ratio. Since the fatality risk is approximately proportional to the a-th power of the velocity change, where a is approximately 3.5-4, one would expect a clearly curved relation. Actually the relation is practically a straight line (the extreme points are based on few cases and therefore not reliable). Thus, it appears likely that other factors confound the true relation.

Impact speeds also influence the velocity change. They are not known. However, the speed limit is a very gross indicator of travel and thereby impact speeds. Figure A.1-2 shows the relation between the fatality risk in car-car collision and the speed limit. It is tempting to draw a smooth, highly non-linear curve through the points. However, then the points at 55, 60, 65, and 70 deviate very much from the curve. Since the point for 55 mph contains a very large portion of the cases, this is undesirable. Weighting the points according to the number of cases they are based on does not eliminate the problem: it just shifts the discrepancies to other speed ranges. One has to realize that speed limits and actual speeds can differ in a systematic manner, and that a model represented by a continuous function of the speed limit is probably unrealistic. Using categories for the speed limit appears more realistic.

There seem to be interactions between weight ratio and speed limit, but they can not be presented in a simple and clear graph. An approximate model is described in section 4.2. Fatality risks by speed limit are lower for women than for men. Figure A.1-3 shows the ratio of these fatality risks. There is a weak suggestion of a trend: at lower speed limits, the risk for women is much lower than, at higher speed limits it is closer to that of men. Again, the extreme points based on very few cases should be discounted.

Figure A.1-4 shows driver fatality risks in car-car collisions by the driver's age, separate for men and women. This risk does not include the risk of getting into a collision, which is higher for younger than for older drivers. It is the risk to die, once a collision has occurred. The relation between this risk in highly non-linear and extends over a range of about 1:20, therefore, a logarithmic scale for the risk is used. Even in this scale the relation is not even approximately linear, that means the risk increases faster than exponential. It would require a fairly complex mathematical function to represent it.

The risk for women is nearly always lower than for men. The percentage difference is greater at younger ages than at higher ages.

Finally, Figure A.1-5 shows relations between the driver fatality risk in car-car collisions and vehicle age, the driver's vehicle's as well as the other vehicle's. There should be no direct relation between these ages and fatality risk, but there are indirect ones. One is that older vehicles, especially very old ones, are usually of earlier model years and therefore not satisfying some of the convert Federal Motor Vehicles Safety Standards, or weaker ones. The other is that vehicle age is related to socio-economic factors which can be related to driver and driving environment. For instance, if older vehicles are more often used in remote areas, medical care will be delayed with a consequently higher fatality risk.

A closer look at the curves seems to confirm the hypothesis: among non-air bag cars, no trend appears until the age of 5 years, presumably as long as the first owners have the car. Beyond that, a small consistent, but not negligible trend appears until the age of 15 years. Beyond that, the risk increases more strongly with age. The large fluctuations are not surprising, considering the very small numbers of cars that survive that long. Concerning the age of the striking ("other") vehicle, no trend is apparent, and there are great fluctuations beyond the age of 5 years.

Striking vehicles go only up to an age of 13, because only vehicles for which Kahane's codes are available were selected as striking vehicles.

Surprising is that the risk in air bag cars is roughly 40% lower than in non-air bag cars, whereas studies of air bag effectiveness have found much lower values. This may be due to the fact that air bags were initially installed only in heavier vehicles, and later in the lighter ones. Thus, air bag vehicles would have had lower fatality risks even without the air bag. This effect confounded the comparison in this study.

A closer study of these suggested several potentially important interactions. This together with the mathematically difficult slope of even univariate relations shows that controlling for these factors in a realistic manner will require a very thorough study.

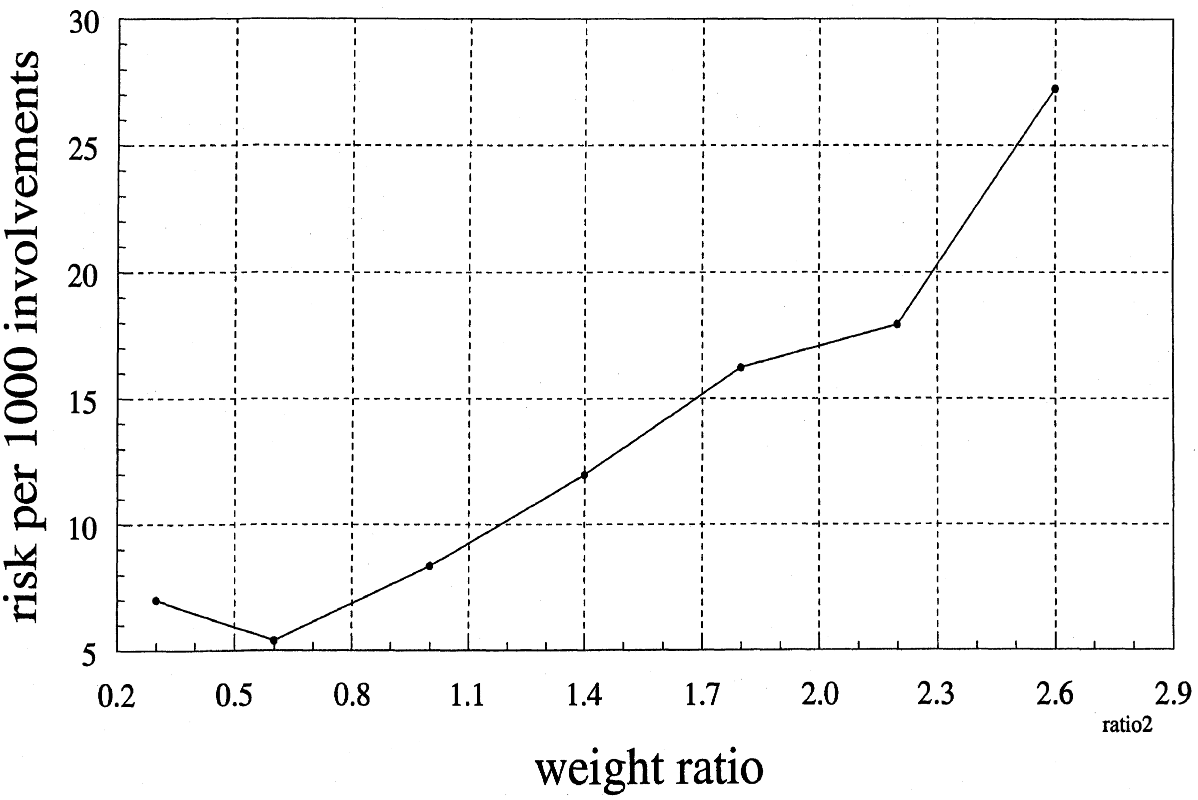

Figure A.1-1. Driver fatality risk in car-car collisions by ratio of the car weight.

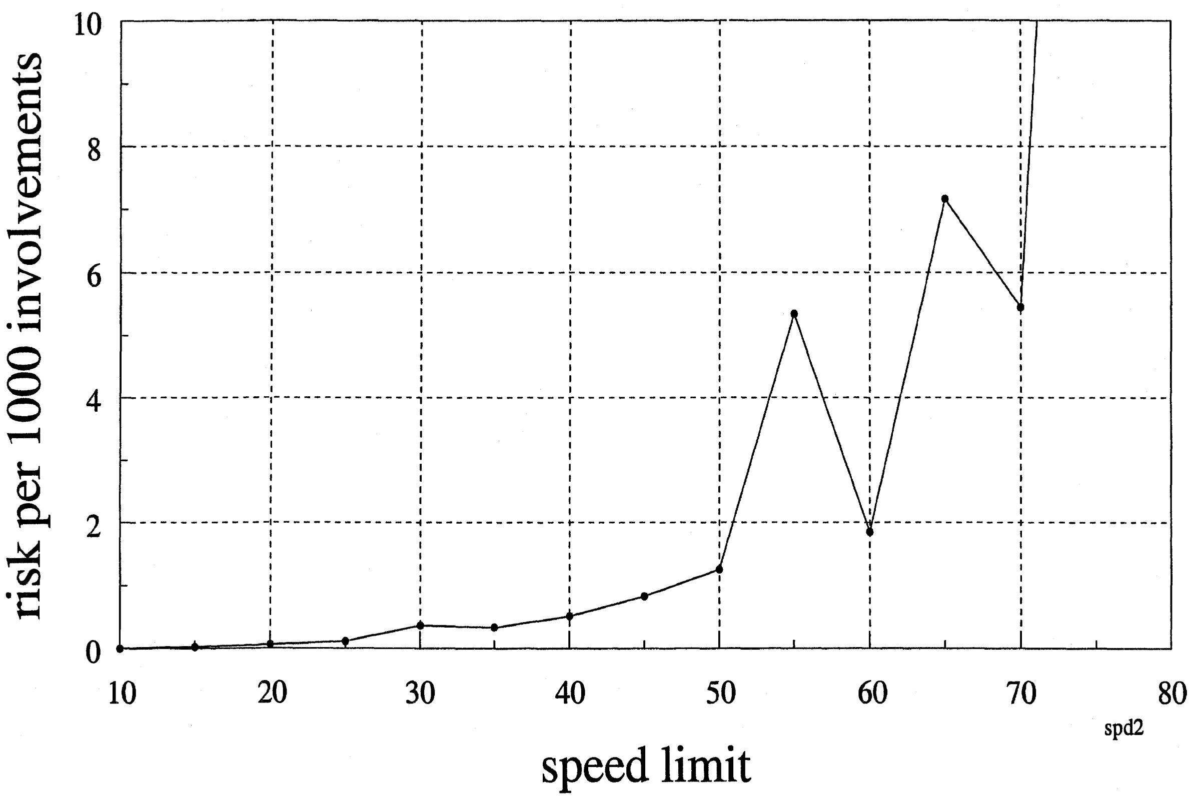

Figure A.1-2. Driver fatality risk in car-car collision by speed limit.

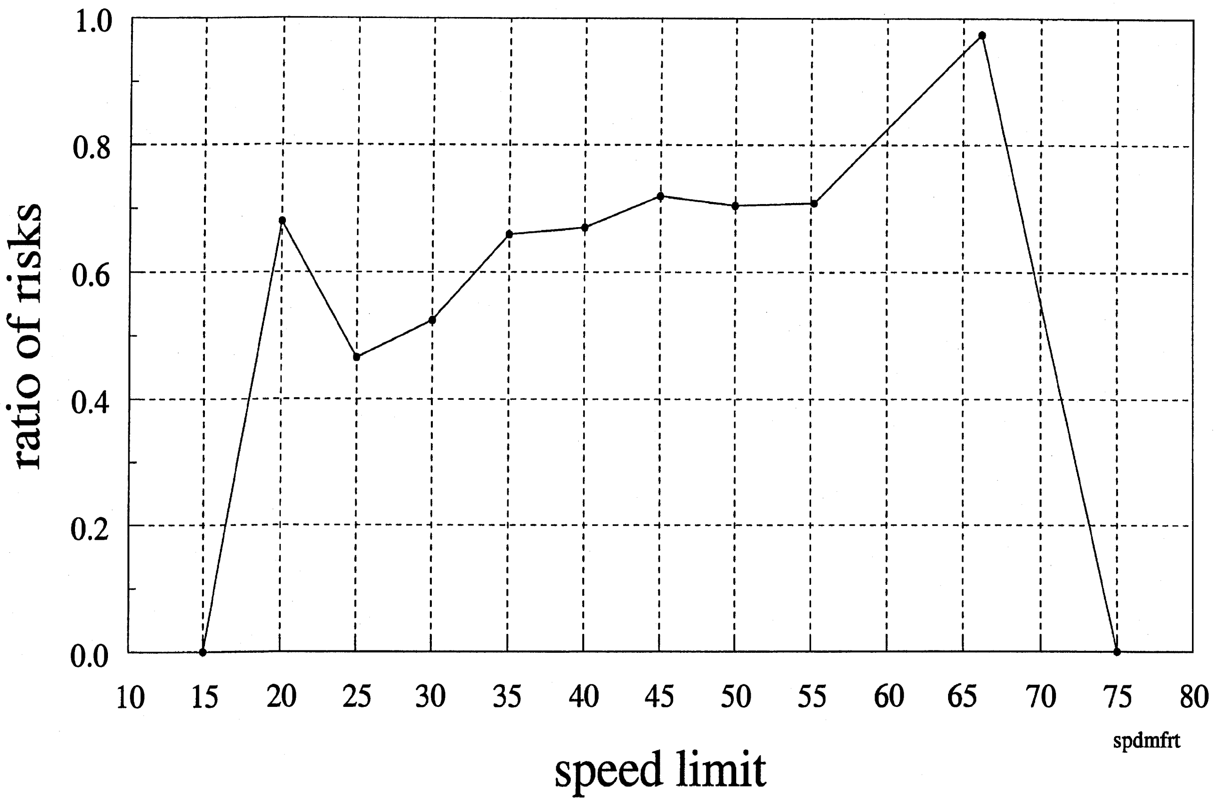

Figure A.1-3. Ratio of fatality risks in car-car collisions for female and male drivers by speed limit.

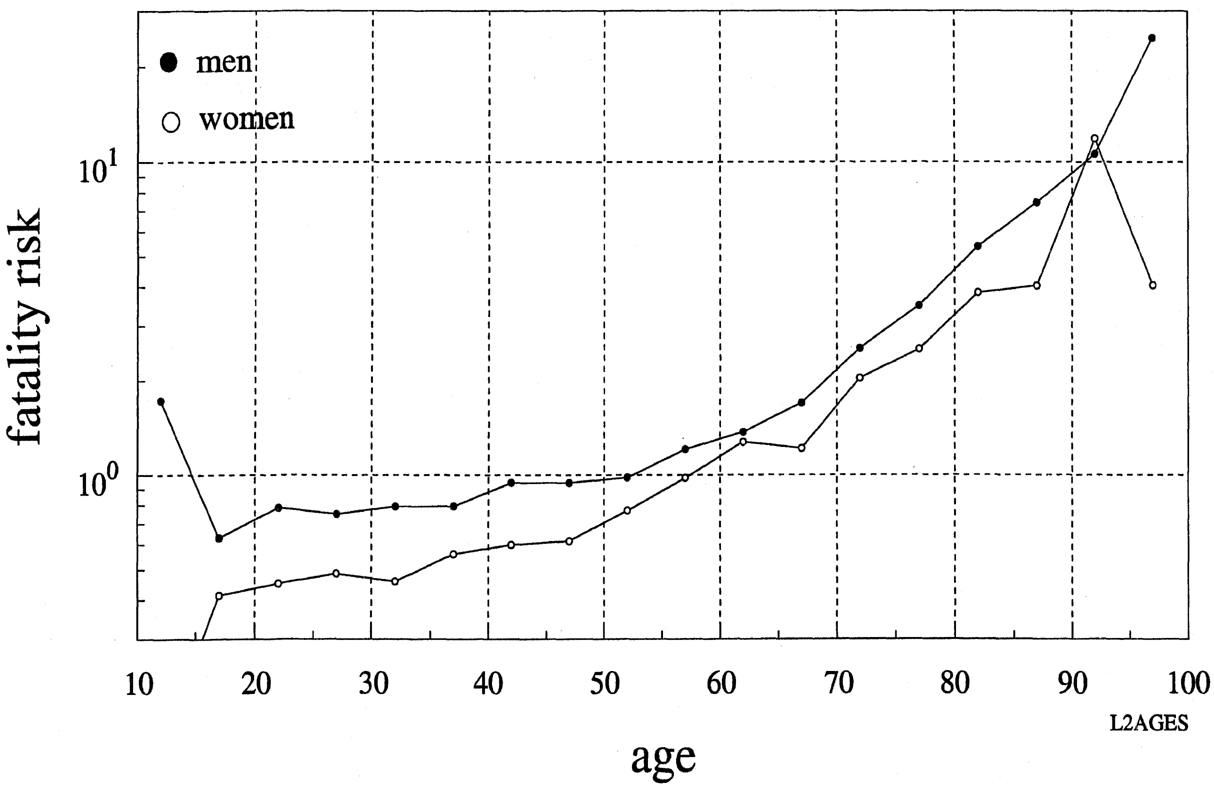

Figure A.1-4. Driver fatality risk in car-car collisions for male and female drivers by driver age.

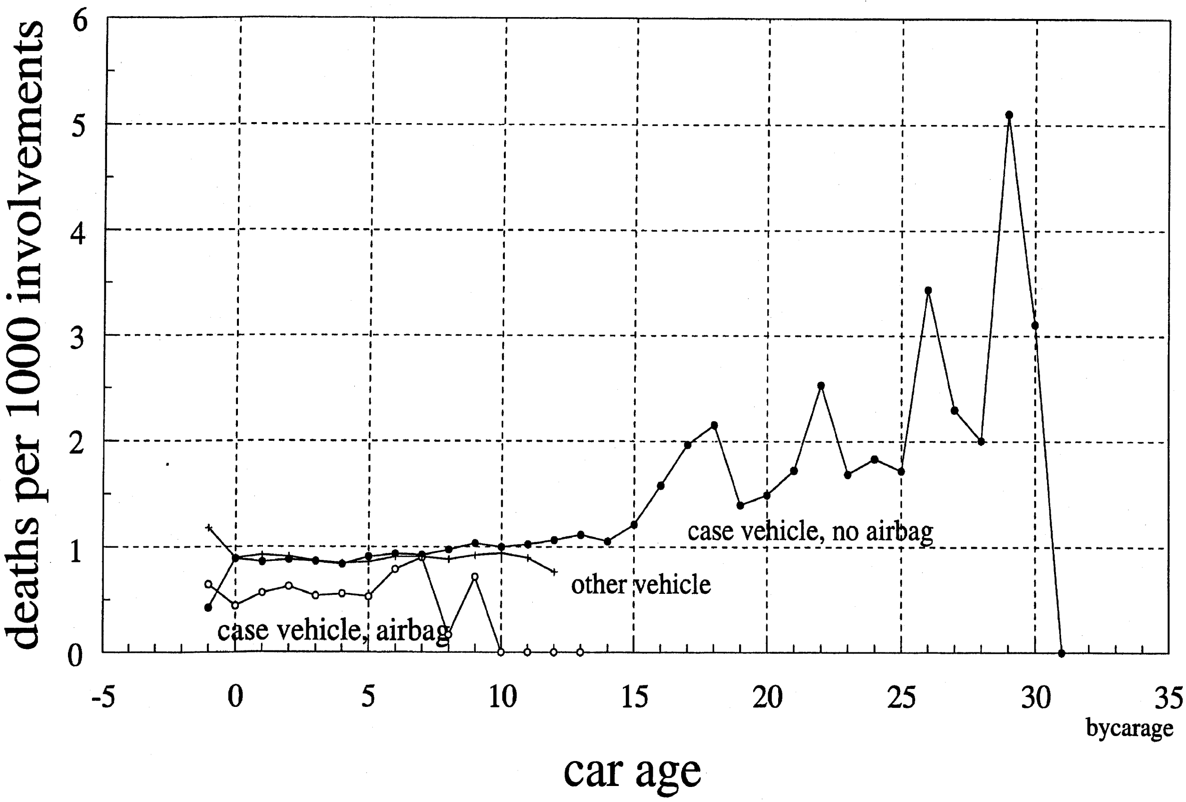

Figure A.1-5. Driver fatality risk in car-car collisions by car age: 1) by the driver's car's age, no air bag, 2) by the driver's car's age, with air bag, 3) by the other car's age.

Appendix 2. Error Estimates

A.2.1. Errors of ratios and risks.

The objects of this study are risks: the ratios of driver fatalities to driver involvements in collisions. They are calculated for groups of collisions which have certain characteristics in common, such as one vehicle being of a certain body type, the collision having a certain configuration, etc. Numerator and denominator are obtained from different sources: The numerator from FARS, which is a census as far as practicable, the denominator from NASS GES, which is a three level sample from all police reported crashes in the United States: The first level being a stratified cluster sample, the second a cluster sample and the third being a stratified systematic random sample.

Let *x* be the number of fatalities, *y* the number of involvements. The variance of the ratio *r=x/y* is given by

$$var(r)=r^2*(var(x)/x^2-2*cov(x,y)/(x*y)+var(y)/y^2) \quad (A.2.1\text{-}1)$$

if one uses the standard linear approximation assumption. There are two basically different ways of interpreting the ratio *r*. One treats it as purely descriptive: the ratio of the actual number *x* of deaths occurring during the study period, to the actual number *y* of involvements during the same period. *x* is known, *y* is estimated from a sample, thus it is subject to a sampling error. Therefore, *var(x)=0*, *cov(x,y)=0*, and one has

$$var(r)=r^2*var(y)/y \quad (A.2.1\text{-}2)$$

The other interpretation considers the actual count *x* as the result of a random process generating collisions and deaths, and the actual number *y* of involvements also as the result of the random process generating collisions. Therefore, both are subject to random variations, and consequently the ratio *x/y* is also. From this point of view, one is not interested in the observed "*r*", but in the ratio of the means of the underlying random processes. In addition, the actual number y is not known but estimated from a sample; thus, the estimate y is subject to the additional sampling variance.

For the number of deaths, it is common to assume that it follows a poisson distribution and that therefore its variance equal its means; thus *x* is an estimate of *var(x)*. This assumption may not be realistic; more complex models lead to a negative binomial distribution which has a variance greater than its mean. However, to determine this excess empirically requires extensive data bases, additional assumptions and complex analyses and is therefore rarely done.

The variance of *y* has two components: the sampling variance *v'(y)*, and the Poisson variance of the individual cases, which results in a variance contribution *v"(y)* for the estimate of *y*,
thus

$$var(y)=v'(y)+v''(y) \qquad (A.2.1\text{-}3)$$

For death to occur, a collision must have occurred. Therefore, counts of collisions and counts of deaths are not independent. Lack of independence is expressed by the correlation coefficient between the two random variables. With simple assumptions, one can derive correlation coefficients which are much smaller than what one finds in real data. Using fatality and collision data for certain classes of collisions over several years (adjusting for time trends, if necessary) one can estimate correlation coefficients, or one can use one year's data and compare fatality and collision data across different classes of collisions. One finds a wide range of correlation coefficients, sometimes exceeding 0.9. Thus, one can not substitute a simple, general expression for *cov(x,y)*. Combining all these factors, one gets

$$var(r)=r^2*(1/x-2*\rho*\sqrt{x*(v'(y)+v''(y))}/(x*y)+(v'(y)+v''(y))/y^2))$$

$$(A.2.1\text{-}4)$$

Compared with (A.2.1-2) the parenthesis contains the additional terms

$$1/x-2*\rho*\sqrt{x*(v'(y)+v''(y))}/(x*y) \qquad (A.2.1\text{-}5)$$

If *x* and *y* are uncorrelated, only the first term is present, and the variance of the ratio r, treating *x* and *y* as random variables is greater than if treating them as fixed quantities. However, if *x* and *y* are positively correlated, that may not be the case, if the covariance is large enough.

The variances and corresponding standard errors (A.2.1-2) and (A.2.1-4) hold for individual ratios, and they can give an idea of the statistical precision of the estimates. However, usually one wants to compare estimates for two or more classes of collisions, perhaps also to test their differences for significance, or to determine how the ratios depend on parameters which characterize the classes, such as vehicle parameters or collision condition. In this case, an additional complication arises because NASS GES involves cluster sampling without replacement.

For the difference between two ratios x_1/y_1, and x_2/y_2,, the analogon to (A.2.1-1) is

$$\begin{aligned} var(r_1-r_2)=r_1^2*(var(x_1)/x_1^2-2*cov(x_1,y_1)/(x_1*y_1)+var(y_1)/y_1^2) \\ +r_2^2*(var(x_2)/x_2^2-2*cov(x_2,y_2)/(x_2*y_2)+var(2_2)/y_2^2) \\ -2*r_1*r_2*(cov(x_1,x_2)/(x_1*x_2)-cov(x_1,y_2)/(x_1*y_2) \\ -cov(y_1,x_2)/(y_1*x_2)+cov(y_1,y_2)/(y_1*y_2)) \end{aligned} \tag{A.2.1-6}$$

The first two expressions are the variances of r_1 and r_2. The third term contains covariances among numerator, and/or denominators of different ratios. x_1 and x_2 being fatality counts for different classes of collisions, one has no reason to expect a correlation (except if the two groups exhaust the population). Also, one would not expect a correlation between fatalities in one class, and involvements in the other class. This leaves only one term

$$-2*r_1*r_2*cov(y_1,y_2)/(y_1*y_2) \tag{A.2.1-7}$$

If the y are counts of actual involvements, one would not expect a correlation between them. However, they are obtained from a sample including two levels of cluster sampling. This can create a correlation. To estimate such a correlation from the sampling place, seems to be very complex. There seems to be no way to calculate empirical values across collision classes with one year's data. However, over the years 1992-98, NASS GES estimates of collision between two cars, a car and a LTV, and between two LTVs show correlations from 0.5 to 0.82, after eliminating opposing time trends.

A.2.2 Using published error estimates for NASS GES.

NHTSA publishes approximate error estimates for NASS GES estimates[5]. They are expressed by

$$e = F(x) = \exp(a + b * (\ln(x))^2) \qquad (A.2.2\text{-}1)$$

where x is the estimated number, and "a" and "b" constants. Slightly different values of "b" and "a" are shown for estimates of crashes, of vehicles, and of people. Since this study deals with collisions, and considers only one driver per collision (in car-car collisions, two drivers are considered, but one collision is replaced by two involvements), the coefficients for collisions are used. These coefficients vary slightly over the period 1992-97, round averages of a=4.4, and b=0.035 were used. (A.2.2-1) holds for annual estimates of national totals. In this study, totals over a period of seven years for only part of the United States were used. Therefore, $F(x)$ can not directly be used.

The time aspect can be easily accounted for. Of the three sampling stages: 1)stratified cluster sampling of PSUs, 2) cluster sampling of police jurisdictions, and 3)stratified systematic random sampling of cases, the first two were performed once, and the selection retained over several years. The third changed the selection probabilities somewhat from year to year, and even within years. If one ignores the changes in the third level sampling, the sampling plan applies to aggregate data over several years as well as to data from a single year, especially since the estimated totals in the present study do not exceed the range for which NHTSA uses the approximate formula.

The spatial aspect is more complex, and we have to rely on heuristic arguments. NASS GES uses 12 strata: four geographic-regions combined with three land use types. We ignore the land use types and consider only the four geographic regions. Let $G_i(x_i)$ be an estimate of the standard error for an estimate of x_i in region i. Then, for the national total $x=x_1+x_2+x_3+x_4$,

$$F^2(x_1+x_2+x_3+x_4) = G_1^2(x_1)+G_2^2(x_2)+G_3^2(x_3)+G_4^2(x_4) \qquad (A.2.2\text{-}2)$$

[5]Appendix C in "Traffic Safety Facts", published annually since 1992.

To proceed further, one needs to make some fairly strong assumptions. First, that the sampling patterns in the regions are so similar that $G_1(x) \approx G_1(x) \approx G_3(x) \approx G_4(x)$, and second that the estimates for the regions are at least approximately equal $x_1 \approx x_2 \approx x_3 \approx x_4$. Then

$$F^2(x) \approx 4 * G^2(x/4) \qquad (A.2.2\text{-}3)$$

or

$$F(x) = 2 * G(x/4),$$

from which one obtains

$$G(x) \approx F(4 * x)/2 \qquad (A.2.2\text{-}4)$$

This study deals only with three instead of 4 regions, therefor, the error estimate for a total of x would be

$$f(x) \approx \sqrt{(3/4)} * F(4 * x/3) \qquad (A.2.2\text{-}5)$$

In reality, there are differences in the sampling patterns between the regions, and the crash totals differ. In addition, this study used *d* only 17 out of the 18 PSUs in the South, and 12 out of 16 in the Mid West. In the West, California was excluded, and all remaining PSUs was used as a basis for estimates for the "truncated" West. An estimate based on 17 PSUs has 18/17 times the variance of one based on 18, one based on 12 has 16/12 times that of one based on 16. Therefore, (A.2.2-5) has to be replaced by

$$f(x) = \sqrt{(18/17 + 16/12 + 1)} * F(4 * x/3) \qquad (A.2.2\text{-}6)$$

The difference between (A.2.2-5) and (A.2.2-4) is negligible considering the strong assumptions which had to be made:

$$\sqrt{(3/4)} = 0.87 \qquad \textit{and} \qquad \sqrt{(18/17 + 16/12 + 1)} = 0.92$$

A.2.4 The sampling error of fatality rates.

Equation (A.2.1-2) shows the variance of a driver fatality risk per involvement, interpreting it as the ratio of actual fatalities to actual involvements. Since the latter is estimated from a sample, it is subject to sampling error for which an approximation (A.2.2-5) was derived. Substituting this gives

$$var(r) = r^2 * (173/51) * F^2(4 * y/3)/y^2 \qquad (A.2.4\text{-}1)$$

for the sampling variance of the actual "descriptive" fatality rate.

A.2.5 Random variability and sampling error of fatality rates.

The other way to look at the fatality rates is to consider them as the result of a random process which creates collisions, and deaths in collisions.

In this case, one still calculates the ratio of actual deaths to estimated collision involvements, but it is interpreted as an estimate of the means of the ratio.

In this case, (A.2.1-4) applies. For $v'(y)$ one has to substitute $f^2(y)$ from (A.2.3-5). For $v''(y)$ we use the following argument. If y had been estimated from a count of z, applying a weight w, $y=w*z$, one would consider z a Poisson distributed variable for which estimated mean and variance are both z. Then, the variance of y would be w^2*z. In reality, different weights w_i apply to different classes of collisions. If z_i is the number of collisions in class i in the sample, then $\sum w_i*z_i$ is the estimate of y, and its Poisson variance is $\sum w_i^2*z_i$. This equals the sum of the squared weights for all cases in the sample, which will be denoted by S.

Substituting these expressions for $v'(y)$ and $v''(y)$, one obtains

$$v(r)=r^2*(1/x-2*\rho*\sqrt{(x*(f(y)+S))}+(f(y)+S)/y^2) \qquad (A.2.5-1)$$

This expression still contains the unknown correlation coefficient between the actual count of fatalities, and the estimated count of involvements. We see no way to make a prior estimate of it based on plausible assumptions. It has to be empirically determined, and we see no unique and fully convincing way of doing it. One approach e.g. is to study the values of x and y over several years, and calculate the correlation coefficient. Often variables show time trends which create correlations between otherwise unrelated factors. Therefore, time trends should be eliminated before calculating the correlation coefficient (or equivalently) partial correlation coefficient should be calculated. Another approach is to use several different classes of accidents and calculate the correlation coefficent between the x and the y. One difficulty is to select classes of collisions which are sufficiently "similar" for those studied.

A danger is that one includes one class which is much larger than the others and which just because of it's size has many more deaths, and many more involvement than the others. Then, one obtains a very high correlation coefficient, even if the other classes show only a low one.