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AGGRESSIVITY VERSUS CRASH TEST PARAMETERS OF LIGHT TRUCKS AND VANS

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16. Abstract

How the fatality risk for a car driver in collisions between cars and light trucks or vans depended on certain characteristics of light trucks was studied. The fatality risk was measured by the ratio of killed drivers to involved drivers. Information on killed drivers was taken from FARS (Fatality Analysis Reporting System), on involved drivers from GES (General Estimates System). Because of incomplete information, cases from the Northeast and California could not be used.

The fatality risk is influenced by vehicle weight, driver age, driver sex, speed limit, and other factors. Because they could confound the findings, mathematical models to adjust for their influence were developed. Without such adjustments, the fatality risk to a car driver in a collision with a SUV (sport utility vehicle) was 3.3 times as high as in a collision with a car; 2.6 times as high in a collision with a pickup truck; and 2.3 times as high in a collision with a van. After adjusting, these ratios were 1.6, 1.4, and 1.4.

How these ratios depend on a vehicle design characteristic, using the height of the center of gravity from the ground, and the forces the light truck exerted on the barrier in crash tests was examined. Specifically, the average height of the force, the peak force, and the static and dynamic stiffness were measured in the test. Overall, the risk increased with the average height of the force, but it could not be determined whether this was a continuous increase, or whether exceeding a threshold was necessary. Stiffness showed a weaker, increasing relation with the risk, whereas peak power showed conflicting patterns. If the front of a light truck struck the left side of the car, the driver fatality risk always increased with the average height of the force; there were no apparent relations with other factors. In front-front collisions, no consistent pattern relating risk and characteristics of the light truck appeared.

17. Key Words
Crash test, FARS, GES, aggressivity, SUV, LTV, sport utility vehicle, light truck, van, pickup truck, fatality risk, modelling, parameters, vehicle design, speed limit, model, stiffness, peak power

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ABBREVIATIONS AND CONVENTIONS

AHOF:	Average height of the center of force. Obtained from crash tests.
CGFG:	Height of the center of gravity from the ground
Comparable:	In the context of comparing car-LTV collisions with car-car collisions, they are called comparable if the other car in the car-car collisions has the same weight as the LTV in the car-LTV collision, its driver is of the same age and sex as the driver of the LTV, and the speed limit is the same in both collisions.
FARS:	Fatality Analysis Reporting System (previously the Fatal Accident Reporting System)
GES:	General Estimates System - a component of NASS
Graphs:	Size of the circles is approximately proportional to the number of deaths represented by the data point, not the number of cases. Sizes are not comparable between different graphs. The value of a number is the smaller of the number of FARS cases, and the actual GES cases from which the risk is calculated. The size of the character is approximately proportional to the number of deaths represented by the data points. Sizes are not comparable between graphs. Some graphs contain legends and text in the body of the graph. If they are not self-explanatory, or conflict with the caption, they should be ignored.
LTV:	Light trucks and vans. Sports utility vehicles, pickup trucks, and small and mid-size vans.
NASS:	National Automotive Sampling System (previously National Accident Sampling System)
Non-standard error:	These errors are calculated by the same formulas as standard errors. However, because extensive preliminary analyses were made to select variables and subsets of data, and some simplifications were made, they should not be interpreted like standard errors.

PJ:	Police Jurisdiction. The second level of clusters, within the PSUs, of the GES sampling plan. Also called secondary sampling units in the statistical literature.
PSU:	Primary Sampling Unit. The first level clusters in the GES sampling plan.
PSU stratum:	12 strata of the GES sampling plan, defined by cross-classification of Region and Type - Central City, Suburban, other.
Region:	Northeast, South, Central (or Midwest) and West
“Significant”:	This term is used if the t-tests, or the normal distribution were used to estimate significance levels, using “non-standard” errors. For the same reasons as calling the errors “non-standard”, they should be considered as illustrative only, and not be taken too seriously.
SUV:	Sport utility vehicle
Stratum:	Four strata of the GES sampling plan are defined by crash type.
Vehicle group:	Kahane has identified car and LTVs by two 4-digit codes. One code identifies make/model, the other a vehicle group consisting of make/models built on the same “platform”.
VIN:	Vehicle Identification Number
WxCA:	The Western NASS Region, excluding California

EXECUTIVE SUMMARY

Car driver fatality risks per collision involvement in collisions between cars, and between cars and LTVs (light trucks, including SUVs and vans) were studied. To estimate such risks, fatality data from FARS (the Fatality Accident Reporting System, in recent years the Fatal Analysis Reporting System) and data for collisions from GES (the General Estimates System) were combined. A statistical approach to combine these differing data bases had to be developed. Because some critical information was missing, data from the Northeastern states and California had to be omitted. Though this makes estimating national totals difficult, it is unlikely to affect the estimates between the fatality risk and the factors studied, which were derived from the data.

As a basis with which to compare car-LTV collisions, car-car collisions were studied. The fatality risk in a collision is influenced by many factors. The weights of the two vehicles play a major role, as do the ages and sexes of the drivers. Speed plays a very large role, but since it was unknown, the speed limit was used as a very rough proxy. Other factors are also known to influence the fatality risk, but because they were either not known or not reliably known, they could not be included in the analysis. To stay within the scope of the work, the fatality risk for one driver was modelled as a function of only the characteristics of the other vehicle and its driver. This allowed control, to some extent, for differences between cars and LTVs in terms of vehicle weight, driver, and speed environment.

The strongest factor was the speed limit. The fatality risk increased roughly by a factor of 50 from the lowest to the highest speed limits. The effect of the other vehicle's weight is second; an increase from about 2,000 lb to 4,000 lb increased fatality risk by a factor of about 5. The fatality risk increases with the declining age of the other driver, by a factor of about 1.5 from the highest to the lowest ages. (This contrasts strongly with the effect of the driver whose risk is studied, where it increases by a factor of about 15 from the lowest to the highest ages). If the other driver is a man, the risk is 1.5 times higher than if the other driver is a woman. Mathematical models were developed which expressed the fatality risk as functions of these factors. Table ES-1 shows in the first column the risk (per 1,000 involvements) to a car driver in collisions with a car, and with each of the three types of LTVs. The risk in car-car collisions just happens to be 1.02 and it is not standardized or normalized to be, or to approximate 1. The car driver's risks in collisions with pickup trucks and SUVs are 3.30 and 2.60 respectively. Considering their estimated errors, "about 3" is an adequate description. The risk in collisions with vans is 2.29. It is noticeably lower than in collisions with SUVs and pickup trucks.

The second column shows the risks to be expected (according to the mathematical model for car-car collisions) if the other vehicle had been a car of the same weight. One would expect 1.02 for car-car collisions, but it is 1.04 because not all cars could be used for developing the model as a result of missing information. For car-pickup truck collisions, it is 2.12. This means that because of the higher weight, and possibly also differences in driver and speed environment, the collisions of cars with pickup trucks would have been more risky for the car drivers, even if the pickup trucks had been replaced by cars of the same weight. The situation is similar for SUVs and vans.

Table ES-1 Fatality risks per 1,000 involvements for car drivers in collisions. Absolute risks are estimated as actual deaths per 1,000 involvements. "Expected" risks are calculated from the models, assuming that the LTV had been replaced by a car with the same weight. Excess risk factor shows the ratios between the numbers in the first and second columns. Error estimates are in parentheses, calculated in a similar way as standard errors, but not strictly comparable with them.

Other Vehicle	Absolute Risk	Expected Risk	Excess Risk Factor
Car	1.02 (.09)	1.04	.98 (.09)
Pickup truck	3.30 (.33)	2.12	1.55 (.17)
SUV	2.60 (.29)	1.79	1.45 (.17)
Van	2.29 (.20)	1.69	1.36 (.12)

The third column shows the ratios of the first and second columns. They show how much more risky, for the car driver, collisions with LTVs are, even after accounting for their greater weight, and possibly differences in driver and speed environment. These "excess risk" factors for pickup trucks and SUVs are practically equal (within their errors), 1.5. The "excess risk" factors for vans is also practically the same, considering its error. The factor 1.5 means that, in addition to the effect of their on-the-average greater weight, other characteristics of the LTVs increase the risk to the driver of a car with which they collide by about 50%.

To determine which characteristics of LTVs might increase the risk to car drivers by 50%, the following was done. LTV models for which barrier crash tests had been performed were selected. Of the crash test results, the average height of the center of force (AHOF), the peak power, and static and dynamic stiffness (which are fairly closely related) were used. Also used was the height of the center of gravity from the ground (CGFG), which is determined by pendulum tests. Absolute and excess risks for the selected models were studied in relation to the tested characteristics.

Table ES-2 shows the findings in qualitative terms. For all three types of LTVs, AHOF appears as a factor in all collisions, and in collisions where the front of a LTV strikes the driver's side of the car. Stiffness appears in all collisions with pickup trucks and vans, and in front-front collisions with pickup trucks. Peak power shows no consistent pattern. In two cases peak power appears with the expected positive sign, in two others with an unexpected negative sign. Especially surprising is that for vans it appears with a positive sign in all collisions, but with a negative sign in front-front collisions. Therefore, one should not conclude that peak power is related to an increase in risk.

Table ES-2 Vehicle characteristics found to be related to increased risk to car drivers in collisions with LTVs. AHOF is average height of force, CGFG is height of center of gravity from the ground, stiffness means both static and dynamic stiffness. A "+" indicates that the risk increases with the value of the characteristic, a "-" that it decreases, and a "?" indicates a weaker indication of a relation.

LTV Type	**Collision Type**		
	All	**Front-Left**	**Front-Front**
SUV	AHOF + CGFG +	AHOF +	peak power -
Pickup truck	stiffness + AHOF + ?	AHOF +	stiffness + peak power -
Van	AHOF + dynamic stiffness + peak power +	AHOF +	peak power -

That no clear pattern appears in front-front collisions should not be surprising. Their numbers are much smaller than those of front-left collisions, and even real effects can be hidden in the scatter of the data points.

Quantitative estimates of the relations are not very precise. For SUVs, the car driver fatality risk appears to increase by 38 to 47% per 10 cm increase in AHOF (and by 26 to 38% per 10 cm increase in CGFG), assuming a continuous increase with AHOF. However, the data are also compatible with a "threshold" at 60 cm. Below that the risk increases much more slowly, above it much faster with AHOF. The relation with CGFG, however, shows the opposite pattern. The relation with CGFG demonstrates risk increases faster below, slower above the threshold. Another way to look at the data shows a 23% per 10 cm increase for SUVs under 2,800 lb, but a 72% per 10 cm increase for heavier ones.

In front-left collisions, the risk increased by 7 to 40% per 10 cm change of AHOF. For AHOF under 55 cm, the increase appeared to be greater, 40% per 10 cm; for greater values of AHOF it appeared smaller,15% per 10 cm.

For vans, the increase of risk in all collisions appeared to be 15 to 55% per 10 cm difference in AHOF, in front-left collisions it was 50 to 60%. Quantitative estimates for pickup trucks are not shown because they are even more uncertain. The uncertainties of the relations found between risk and LTV characteristics is mainly due to two factors. First, because of the limitations of the test equipment, AHOF can be determined only with low precision. Second, crash tests were performed for only a limited number of LTV models. Also, the number of collisions involving many SUV models was small, resulting in great uncertainty of the corresponding risk estimates.

Overall, this work has shown that pickup trucks and SUVs in collisions with cars expose the car driver to 3 times the fatality risk than in collisions with other cars (for vans, the factor is 2.3). Their greater weight contributes most to these factors, but differences in driver and driving environment may also contribute. After controlling for these factors, there still remains a risk increase of 50%, which is presumably due to more subtle characteristics of LTVs than weight. One factor showing a consistent relation with the risk to the car driver is the average height of force, as determined by barrier crash tests of LTVs. Their stiffness, as measured in these tests, shows a much weaker relation.

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1 INTRODUCTION

1.1 Background and Objectives

The first objective of this work was to quantify the incompatibility between cars and light trucks and vans (LTVs) in collisions– also called “aggressivity” of LTVs. The second objective was to find quantitative relations between measures of incompatibility or aggressivity, and physical characteristics of LTVs. Incompatibility or aggressivity was measured in terms of the increase of the car driver fatality in collisions between cars and LTVs, compared with the risk in collisions between comparable cars.

Absolute fatality risks can be calculated from the number of driver deaths (or deaths of occupants of specific seating positions) in crashes, divided by the number of drivers (or any other specified occupants) in crashes. In principle, state accident data files contain most of the necessary information, but the number of fatal crashes in any single state’s file is small, and therefore the fatality risk estimates are not very precise. The only data base with sufficient numbers of fatal crashes is FARS. However, there is no corresponding nationwide file of non-fatal crashes. The closest to that is GES, which is a sample of about 50,000 mostly non-fatal, but also including some fatal crashes, each of which represents between 2 (two) and 3,000 actual crashes. This allows, in principle, to calculate fatality risks which are nationally representative, also less dependent on factors or conditions peculiar to individual states, and have greater statistical precision than can be obtained from a few states’ files. There are, however, a number of technical difficulties that make an analysis of the combined FARS and GES files less than straightforward.

1.2 The Data

The data bases were prepared by the Volpe National Transportation System Center from the original FARS and GES data files, adding information obtained by decoding the Vehicle Identification Number (VIN). Crash data for the years 1991-99 were used. Collisions involving two cars, or a car and a LTV were selected.

To determine the physical characteristics of a vehicle, the Vehicle Identification Number is needed. The FARS files contain the VIN for nearly all cars and LTVs. In GES files, many VINs are missing. Some are randomly missing, but there is a strong systematic pattern by geographical region as defined in the GES. With two exceptions, within a primary sampling unit (PSU) either nearly all, or nearly no VINs are given for cars. The following pattern appears:

Northeast: 1 PSU with all VINs, 2 with some, 11 with none

Central (also called Midwest): 12 with, 4 without VINs

South: 17 with, 1 without VINs

West: 7 with, 5 without VINs

Since for most GES cases in the Northeast VINs were not available, all GES cases from this region were omitted from the study. Correspondingly, all FARS cases from the states composing the Northeast were also omitted. This posed no problem of matching because the regions were defined by the states they were composed of.

In the Central and Southern regions, in most PSUs, the cars in GES cases had VINs. In these regions, all cases from the PSUs without VINs were omitted, and the expansion factors for the cases from the PSUs with VINs adjusted. This results in statistically valid estimates of police reported crashes in these regions, and allows to combine them with the fatal crashes from FARS in these regions.

The West posed an additional problem. Nearly half of the PSUs had no VINs, all in California. From a purely formal point of view, the same procedure as for the Central and Southern regions could be applied: the data from the 7 PSUs with VINs could be used with adjusted expansion factors, to estimate police reported crashes. However, these 7 PSUs are all outside of California which not only accounts for the vast majority of crashes in the Western region, but also differs in many respects from the other states. Therefore, the results would most likely be biased.

To avoid such a bias, the approach was modified. A new region, the West excluding California (WxCA) was defined. The data from the 7 useable PSUs were used to make estimates of police reported crashes for WxCA (in this case the adjustments of the expansion factors were more complicated). Correspondingly, the FARS cases from California were omitted. Again, this resulted in a statistically valid match of FARS and GES cases in the WxCA region.

For the analyses, the FARS and GES cases were combined. GES cases with a fatality were omitted, and FARS cases were assigned a expansion factor of 1. Adding a 0/1 variable indicating driver survival (GES cases) or death (FARS cases) as dependent variable, one can use statistical techniques to estimate fatality risks.

1.3 Modelling

Many factors besides vehicle characteristics influence the fatality risk in a crash. Some other factors have a much stronger effect. A very obvious factor is crash configuration. The risk depends on the impact direction and its point on the vehicle, and on the impacting part of the other vehicle in a collision. Such factors are best accounted for by studying different collision configurations separately. The effects of other factors can be captured by mathematical modelling. The following are very rough illustrations of the order of magnitude of the effects some factors have over their ranges from the lowest to the highest values found in crashes:

speed limit	1:50 (low to high)
age of the driver of the case car	1:15 (young to old)
age of the driver of the other car in a collision	1.5:1 (young to old)
sex of the driver of the case car	1.5:1 (man to woman)
sex of the driver of the other car in a collision	1.5:1 (man to woman)
weight of the case car	2:1 (2,000 to 4,000 lb)
weight of the other car in a collision	1:5 (2,000 to 4,000 lb)

Other important factors are the effect of alcohol (in this context not on the occurrence of a crash, but on its severity in terms of delta-V or a similar measure). It could not be considered, because even in FARS information on alcohol is far from complete, and in GES even more so.

There is some evidence that alcohol involvement might differ between vehicle types. This is shown by Table 1.3-1 which was produced outside of the scope of this contract, based on the 2000 FARS data.

Drivers of large and small (including convertibles which are not necessarily small) cars are distinctly different in terms of alcohol involvement, at 11-13% for the large cars, and 19-23% for the small car group. This may be related to driver age, younger drivers are more likely to drive after drinking (but possibly counteracted by relatively more women driving smaller cars), but can also be due to other socioeconomic factors.

The alcohol involvement of SUV station wagon drivers is about the same as that of drivers of large cars; that of other SUV drivers slightly higher, but still well below that of drivers of small cars. That of pickup truck drivers is higher, but below that of small car drivers, whereas van drivers have the lowest alcohol involvements (this may be due to many vans being used "on-the-job").

If alcohol results in higher speeds, vehicles whose drivers have higher alcohol involvement will appear more aggressive than is due to their physical characteristics. Air bags and seat belts, when used, have strong effects on the fatality risk, as do airbags, when they deploy. Information on belt use, however, is not considered reliable, especially in GES. Because of these problems, we did not use alcohol involvement, safety belt use, and air bag availability in modelling.

Table 1.3-1 Police reported alcohol involvement by percentage of all drivers involved in fatal crashes in 2000, by body style of vehicle.

body style	percentage alcohol involvement
convertible	23
2-door sedan/hardtop/coupe	22
3-door/2-door hardtop	19
4-door sedan/hardtop	11
5-door/4-door hatchback	13
station wagon	11
compact SUV	15
large SUV	17
SUV station wagon	12
compact pickup	18
large pickup	18
minivan	9
large van	11

Initially, we considered both vehicles' weights, both drivers' ages and sexes, and the speed limit. Speed limit is only an imperfect proxy for actual travel or impact speed. Actual travel speed may be much higher, and sometimes much lower (the difference may be correlated with driver age and sex). In a collision at an intersection, the speed limit is usually that of the higher order road, typically higher than that on the cross road. Nonetheless, its empirical effect is so strong that we did include it. The travel speeds will have a different effect (in terms of delta V) in a front-front collision than in a front-rear collision.

The second strongest effect is that of driver age. The fatality risk increases in a highly non-linear manner with age: up to about 40 years roughly linear, faster between 40 and 60, and rapidly increasing with higher ages. This is probably a combination of two effects: young drivers driving faster (relative to the speed limit) and thereby increasing their risk; and older drivers driving closer to the speed limit, but being more vulnerable and more likely to die in a crash. The first effect is suggested by the effect of the age of the "other" driver in a collision, the fatality risk declines with his or her increasing age. Women have a lower fatality risk, and also create a lower fatality risk for other drivers in a collision.

The effects of vehicle weight shown above are “pure” weight effects obtained from statistical models. Driver age and vehicle weight are correlated, older drivers tend to drive heavier cars. Therefore, without adjusting for this, heavier cars would appear less protective than they actually are. On the other hand, heavier cars appear less aggressive in a collision than they actually are, compared with lighter cars.

Driver sex has similar effects. Women tend to drive lighter cars than men. This makes heavier cars appear less protective than they are, but also less aggressive in a collision. More detailed analyses show that the effects of the factors are not always independent, but can interact.

In collisions, the characteristics of both drivers and vehicles play a role. Initially, both were used in the models. This, however, complicated the model development very much, and often some coefficients in the final model depended on only a few cases. Since there are only weak, if any correlations between the characteristics of the two vehicles and drivers in a collision, we decided to omit the case vehicles’ and drivers’ characteristics. This should not bias the results much, though it might increase their random errors.

There are basically two types of models, categorical and continuous. Categorical models collapse continuous data into relatively few “cells”, calculate risks for each cell, and relate the risks to the driver, vehicle, and speed values characterizing each cell. Their advantage is that one can identify interactions relatively easily. One great disadvantage is that defining the cells so that not too much information is lost (e.g. not creating cells where the fatality risk can not be calculated or cells within which the fatality risk varies widely) tends to be laborious. There are also other disadvantages.

Continuous models express the fatality risk as a mathematical function of the variables characterizing vehicles, drivers and speed. This requires assuming a mathematical form for this function, or experimenting to find one which fits the data well. This can also be laborious. However, we found that the same basic structure could be used for all models developed. For simple practical reasons, we used a logistic model, and the statistical package STATA offered very efficient routines for it.

We did not use it for the specific mathematical form of the logistic function which is not always most suitable for modelling fatality risks. In our case, however, the logistic model was practically equivalent to a multiplicative model of the form

$$risk=a\cdot \exp(b\cdot \mathbf{x})\cdot \exp(c\cdot \mathbf{y})\cdot \exp(d\cdot \mathbf{z})...$$

where the x,y,z,... can be the variables themselves or interactions of variables. To represent highly non-linear (or in this case, in effect, non-exponential) relations, we used “kinky” relations, e.g. by adding a new variable which was equal to the age if it was over 40, and 0 otherwise, etc. For vehicle weight, we found that a logarithmic transformation, x=log(weight) nearly always gave the best model fit. This amounted, in effect, to having a weight term of the form weight$\cdot$ $\mathbf{b}$ for the risk. This will be discussed in more detail later in the report.

The fit of the model was assessed, not only by overall comparisons of actual with predicted risks, but also by comparing them with respect to each of the variables used, and with respect to several of their interactions.

1.4 How to Quantify “Aggressivity”

In this work “aggressivity” refers to a characteristic of a vehicle, once a collision has happened. It does not reflect driver behavior, nor does it consider which characteristics might increase the risk of getting into a collision with another vehicle.

“Aggressivity” quantifies the injury or fatality risk for the driver of one vehicle in a collision as a function of characteristics of the other vehicle. This study considered the fatality risk of car drivers in collisions with LTVs. The objective was to estimate how this risk depended on LTV characteristics.

Since many factors influence the fatality risk in a collision, mathematical models were used to separate the effects of vehicle characteristics from those of other factors. For simple physical reasons, vehicle weight has a strong effect on the fatality risk. This effect is universal. Therefore, one wants to separate it from the effect of vehicle specific design characteristics. There are many design characteristics which may influence the fatality risk. To identify the important ones by analyzing fatality risks would be very complicated. Therefore, in addition to design characteristics, also crash test results which reflect the forces which a vehicle exerts on a barrier in a test, and which may be similar to those exerted on another vehicle in a collision were used.

One way to describe the aggressivity of a LTV is to develop a model for the car driver fatality risk in collision with a LTV, as a function of the LTV characteristics. Then, the coefficients of the LTV characteristics are direct measures of the aggressivity of each LTV characteristic. While this may be useful for a vehicle designer, it is difficult to interpret.

Another way to express aggressivity is to use car-car collision as a “baseline”, and first estimate car driver fatality risks in relation to those in car-car collision. For each car-LTV collision, one calculates what the car driver fatality risk would have been if the collision had been with a car, but with all other variables being the same. Comparing the actual deaths in car-LTV collisions with the weighted sum of the probabilities calculated for car-car collisions allows to calculate relative risks which are an overall measure of the aggressivity of a LTV group. We used the ratio of the actual deaths to the predicted deaths. We also experimented with the differences between actual deaths and predicted deaths, but found that the relations were less clear.

2 MODELLING DRIVER FATALITY RISK IN CAR-CAR COLLISIONS

As a baseline with which to compare car driver fatality risks in car-LTV collisions, we studied and modelled collisions between two cars. The fatality risk of a car driver per involvement (actually, 1,000 involvements were used which resulted in an overall risk of the order of magnitude 1) in a collision with another car was modelled as a function of vehicle, driver, and collision factors.

Initially, we used vehicle and driver factors of both vehicles, since both strongly affect the fatality risk. Readily available factors are the vehicles' weights, the drivers' ages and sexes, and the speed limit. The actual travel or impact speed is not available, but the speed limit is a very rough proxy for travel speed, and its empirical relation to the risk was so strong that its use seemed justified. Air bags also have a strong influence on the fatality risk, if they deploy. That information is only in FARS, and is available there only for relatively few crashes, but not in GES. However, the availability of the air bag, irrespective of deployment information is related to the fatality risk; therefore we considered it initially. When we later dropped the characteristics of the case vehicle (the vehicle of the driver for whom the fatality risk was modelled), air bag availability was also dropped. Safety belts also have a strong effect on the fatality risk, if used. Usage information for killed drivers in FARS may be fairly reliable, but in GES it is questionable. Therefore, it was not considered, and would in any case have been dropped when later the characteristics of the case vehicle and its driver were omitted. Alcohol plays a double role, it increases the probability of a crash, presumably also its severity; and it also increases the fatality risk, given an injury of a certain severity. Regarding the fatality risk of the driver of the case vehicle, only the second aspect is relevant, as far as the probability that a crash occurred, part of the first aspect is irrelevant since we deal only with crashes once they have occurred, but if alcohol influences the severity of a crash, we should deal with it. However, information on alcohol involvement even in FARS is incomplete (though imputed alcohol information is available), and in GES even more so and of questionable reliability. Therefore, we did not attempt to use alcohol involvement as a variable in the models.

Initially, we used both vehicles' weights, both drivers' ages, both drivers' sexes, and the speed limit as variables. The crash configuration was considered by studying in addition to all planar collisions also separately collisions where the left side was struck by the front of the other vehicle, and front-front collisions. One such detailed model, developed later and outside the scope of this contract, is presented in Appendix C. However, when we tried to develop such models, we found that the effort was beyond the scope of the contract, that it was too easy to overfit the data, and that different combinations of some higher order terms gave models fitting the data equally well.

Therefore, we decided to omit the variables relating to the case vehicle, and use only those of the "other" vehicle whose aggressivity we wanted to quantify. Since there were practically no correlations between the characteristics of the two vehicles, and between those of their drivers, this should bias the risk estimates only little. However, it probably increased the variance of the estimates.

Collisions were selected as follows. They had to be "planar", which means FARS impact codes 1-12, or GES impact codes 1-4, or 7-14 applied. As a case vehicle, for which the driver's fatality risk was studied, any car for which the VIN had been decoded and the weight obtained was allowed.

As the "other" car, only cars of model years 1985 or later, with decoded VIN and their weight available were allowed. The purpose of this selection was to make the collisions comparable with car-LTV collisions. For LTVs, Kahane codes were available only for model years 1985 and later. Cases for which the variables needed in the models were missing were omitted.

When all of the selected collisions were studied, often both cars were eligible as "other" cars. In these cases, the collision yielded two observations for the analysis: one with car A as the case car, and B as the "other" car; and one with B as the case car and A as the "other" car. The same applied to front-front collisions. Using such collisions twice uses the available information completely. However, it introduces subtle problems by destroying independence of the observations. We did not pursue this question further. In front-side collisions, where the case car always had the side impact, the roles of the two cars are different and can not be exchanged. Thus, the problem does not arise here.

The modelling approach is briefly described in section 1.3. It involved extensive work, sometimes requiring a few dozen regression runs to find the best functional form of the functional relation of two variables and their interaction, with the driver fatality risk. In all cases, the model was tested not only by graphing actual versus modelled risk for the entire data set, but also by plotting actual and modelled risks versus each of the variables used in the model, for the entire data set as well as for subsets which reflected interactions between two of the variables.

The model for the probability of death has the form

$$p=\exp(f)/(1+\exp(f))$$

It was selected not because the mathematical form is especially appropriate to represent the fatality risk, but because good computer programs are available. In the context of this study, the model is practically equivalent to

$$p=\exp(f)$$

f is a function of the values of the other vehicle's weight, its driver's age and sex, and the speed limit. Additive functions of terms in these variables were used. Table 2-1 shows the coefficients of the variables. Expressions such as (splimit<30) represent a categorical variable with the value 1 if the speed limit is less than 30 mph. "Female" has the value 1 for a female, 0 for a male driver.

There is no constant term, because the categorical variables for the speed limit add to 1; with a constant term in the model, one of them would have to be dropped. The difference of the speed limit terms of -8.48 for speed limits under 30 mph, and -4.67 for speed limits over 50 means that, all factors being equal, the fatality risk at the highest speed limits was 45 times higher than at the lowest. The relatively low number of cases for speed limits above 50 mph did not allow reliable estimates for different speed limits in this range.

The term -0.50 for female means that the fatality risk is 40% lower if the other driver is a female, than if it is a man. The term 1.84• log(weight/2,800) means that the fatality risk is approximately proportional to weight • 1.84. The next term

0.38• log(weight/2,800)• (splimit>50)

means that the effect of weight is reduced to

weight • (1.84-0.38) = weight • 1.46

for speed limits higher than 50 mph.

There is a third interaction term of weight

0.70• log(weight/3,200)• (weight<3,200)• (age>50).

It changes the effect of weight for drivers over 50 years old to

weight • (1,84-0.70)=weight • 1.14

for weight under 3,200 lbs and speed limits under 55 mph, and to

weight • (1.84-0.38-0.70)=weight • (0.76)

for speed limits over 50 mph.

We have not found a plausible interpretation for these terms, but they did definitely improve the fit of the data by the model. Findings were surprising for calendar year-1990. They indicate that, all other factors being equal, the fatality risk in car-car collisions declined annually by 5.5%. Part of this might be due to the phasing out of very old cars and phasing in of cars equipped with air bags. Increased safety belt use due to seat belt laws and their enforcement may also have contributed. Many other factors, perhaps some subtle ones which are not easily recognizable may have contributed to it. We note that reporting changes at the state level might also explain some of the effect captured by the calendar-year variable in the models. For instance, one may speculate that more aggressive drivers may have shifted to SUVs, thus making car-car collisions relatively safer, but car-SUV collisions more dangerous than they would be on the basis of the physical differences of the vehicles only. Of course, this is a purely speculative hypothesis, and it would be very difficult, if possible at all, to prove or disprove it. Table 2-2 shows the model coefficients for the driver fatality risk if his car was struck at the left side by another car. Here, fewer terms appear than in the case of "all" collisions. This may be partially due to the much lower number of case vehicles (10,152 versus 69,197), but possibly also to other vehicle characteristics, which were not included in the model, but might play a major role in this type of collision. One aspect is noteworthy. For women drivers over 65 years of age, the fatality risk for the driver of the other vehicle appears to be independent of her car's weight: the coefficient -2.01 of the corresponding interaction term is exactly the negative of the coefficient 2.01 of the general weight term.

Table 2.3 shows the model coefficients for front-front collisions. Though the number of case cars (7,467) is even lower than for front-left collisions, the model is more complicated. The coefficient for the general weight term is very large. However, it is modified by several other terms. The term for weights over 2,800 lb reduces it dramatically– though this term is not very reliable. The interaction with the speed limit, which was validated by very detailed and thorough analyses, increases it strongly for lower speed limits. A weight term for older drivers, not very reliably quantified, increases the weight effect for older drivers. Similarly, there are complicated interactions of driver age and sex.

These models were used to predict "baseline" risks for the actual car-LTV collisions, against which relative risk were calculated.

Table 2.1 Coefficients of model for car driver fatality risk (per 1,000 involvements) in collisions with another car. The driver and vehicle characteristics are for "the other" car. 69,197 case vehicles.

variable	coefficient	non-standard error
(splimit<30)	-8.48	.18
(splimit=30/35)	-7.43	.15
(splimit=40)	-7.04	.19
(splimit=45)	-6.52	.23
(splimit=50)	-6.12	.38
(splimit>50)	-4.67	.15
log(weight/2,800)	1.84	.14
log(weight/2,800)• (splimit>50)	-.38	.19
female	-.50	.05
(age-30)• (1-female)/100	-.91	.18
(age-30)• female/100	-.33	.20
log(weight/3,200)• (weight<3,200)• (age>50)	-.70	.32
(calyear-1990)/10	-.55	.14

Table 2.2 Coefficients of model for car driver fatality risk (per 1,000 involvements) in collisions with another car, when struck on the left side by the other car. The driver and vehicle characteristics are for "the other" car. 10,152 case vehicles.

variable	coefficient	non-standard error
(splimit<30)	-7.68	.19
(splimit=30-35)	-6.94	.12
(splimit=40)	-6.41	.18
(splimit=45)	-5.92	.17
(splimit=50)	-5.44	.36
(splimit=55)	-4.27	.16
(splimit>55)	-3.47	.28
log(weight/2,800)	2.01	.22
female	-.39	.07
(age-30)/10	-.13	.02
log(weight/3,400)• female• (age>65)	-2.01	.66

Table 2.3 Coefficients of model for car driver fatality risk (per1,000 involvements) in front-front collisions with another car. The driver and vehicle characteristics are for "the other" car. 7,467 case vehicles.

variable	coefficient	non-standard error
(splimit<30)	-7.01	.20
(splimit=30-35)	-5.57	.18
(splimit=40)	-5.33	.24
(splimit=45)	-4.25	.26
(splimit=50)	-3.72	.30
(splimit=55)	-2.18	.27
(splimit>55)	-1.30	.34
log(weight/2,800)	3.04	.60
log(weight/2,800)•(splimit-40)•(splimit<55)/10	-.83	.23
log(weight/2,800)•(age>60)	1.08	.54
log(weight/2,800)•(weight>2,800)	-2.55	1.07
female	-.46	.09
(age-30)•female/10	.21	.06
(age-55)•(age>55)•female/10	-.55	.14
(age-70)•(age>70)•(1-female)/10	-.42	.23
(age-50)•(weight<2,400)•(1-female)/10	-.16	.08
(calyear-1990)/10	-.71	.35

3 RISKS IN COLLISIONS BETWEEN CAR AND LTVs

3.1 Comparison by Vehicle Type

For these comparisons, all types of LTVs were used, with comparisons made between the different types of LTVs. Distinguished were pickup trucks and SUVs, and within them, “compact” and “large” or “standard,” and vans, distinguishing “minivans” and “large vans”. The classifications by make and model were provided by the National Highway Traffic Safety Administration (NHTSA). To allow more specific comparisons between cars and LTVs, cars were also classified by weight under 3,000 lb; between 3,000 and 4,200 lb; and heavier.

For each of the vehicle classes, the actual weights of the vehicles used in this analysis were used to calculate the averages shown in Table 3.1.1-1. The actual numbers of FARS and GES cases are also shown. The numbers of FARS cases are not the total numbers of car driver deaths in such collisions during the years 1991-99. First, the states in the Northeast region and California are not included; second, some cases had to be omitted because of missing information. The number of GES cases is the actual number of cases on which the calculations are based; it is not the expanded number which was used to calculate the risks. The column “absolute risk” shows the car driver fatality risk in such collisions, per 1,000 involvements. By chance, this value is 1.02 for car-car collisions– this is not a standardized value which should be 1. If “the other” car weighs less than 3,000 lb, the risk is only 0.83, if it is heavier, it is 1.35. For the heaviest cars, over 4,200 lb, it is practically the same,1.37. This is not really surprising, since these are raw, unadjusted risks. If the heaviest cars are driven by older drivers whose driving is less aggressive, this counteracts the effect of the higher weight.

Such effects are controlled for in the column “expected risk”. Here, for each collision the risk is calculated which the car driver would have faced if he had collided with a car of the same weight, with a driver of the same age and sex, and on a highway with the same speed limit. The actual number of car driver deaths, divided by the sum of risks, gives the relative risk: the factor by which the car driver’s fatality risk would have been different, if the collision had been with another car, not a LTV.

The relative risk for collisions between cars is 0.98, whereas 1.00 would be expected. The very small discrepancy is due to slight differences in the vehicle populations studied, due to missing data. For cars under 3,000 lb, and for those between 3,000 and 4,200 lb, the relative risks are 0.98 and 0.99. This is what one would expect. For cars over 4,200 lb, however, the relative risk is only 0.65. This suggests that our model over predicts the probability of driver death in collisions with a very heavy car. This is not too surprising because there are very few cases in that weight range so that there the modelled values become imprecise.

Comparing the fatality risks a car driver faces when colliding with a LTV shows that they are roughly three times as high in collisions with pickup trucks and SUVs as in collisions with cars; in collisions with vans, they are only about twice as high. The relative risks in collisions with pickup trucks and SUVs, however, are only about 50% higher than in car-car collisions. That shows that differences in vehicle weight, driver, and speed environment roughly double the absolute risks. For vans, the effect is smaller.

An interesting pattern appears if one disaggregates pickup trucks and SUVs into compact and large sizes. The absolute risks for the large sizes are much higher than for the compact sizes, but the relative risks are lower. One potential explanation is that the risk model for car-car collisions overestimates the risk for collisions with cars above 4,200 lb, which is supported by the observation that the relative risk for cars of 4,200 or more lb is only 0.65 instead of 1, which one would expect. For vans, the situation is not as extreme, the absolute risk in collisions with large vans is much higher than in those with minivans, but the relative risks are nearly equal. These observations suggest caution when using relative risk for large pickup trucks, large SUVs, and large vans.

We must conclude that any apparent effects of vehicle weight on the relative risk may not reflect physical effects of vehicle weight, but might be confounded by other factors, including the extrapolation of the basic models beyond the range within which they were "calibrated".

Table 3.1-1 Comparisons of absolute and relative car driver fatality risk in collisions, by type of the other vehicle. The average weight (lb) is for the vehicles used in the calculation. The absolute risk is the car driver fatality risk per 1,000 involvements. The relative risk is the number of actual car driver deaths in collisions with vehicles of each class, divided by the number which would have occurred if the "other" vehicle had been a car of the same weight, with a driver of the same age and sex, as the "other" vehicle, and the speed limit had been the same, shown in the column "expected" risk. Non-standard errors are in parentheses.

"Other" vehicle type	average weight (lb)	FARS cases	GES cases	absolute risk	"expected" risk	relative risk
car	2,800	11,422	66,750	1.02 (.09)	1.04	.98 (.09)
<3,000 lb	2,550	5,781	42,046	.83 (.08)	.85	.98 (.09)
3,000 to < 4,200 lb	3,420	5,594	24,513	1.35 (.11)	1.36	.99 (.08)
>= 4,200 lb	4,320	47	191	1.37 (.23)	2.12	.65 (.13)
pickup truck	3,510	5,653	9,990	3.30 (.33)	2.12	1.55 (.17)
compact	2,960	2,474	5,220	2.78 (.32)	1.57	1.77 (.23)
standard	4,100	3,179	4,770	3.85 (.43)	2.71	1.42 (.17)
SUV	3,710	2,088	4,724	2.60 (.29)	1.79	1.45 (.16)
compact	3,480	1,617	3,812	2.48 (.30)	1.58	1.57 (.20)
standard	4,720	471	912	3.16 (.61)	2.72	1.16 (.19)
van	3,710	2,139	5,299	2.29 (.20)	1.69	1.36 (.12)
minivan	3,500	1,314	3,893	1.94 (.18)	1.46	1.33 (.13)
large van	4,270	825	1,406	3.21 (.33)	2.28	1.41 (.13)

3.2 Comparisons by Weight

Cars and LTVs differ greatly in their average weights and their individual weights vary greatly, resulting in a vehicle overlap of their weight ranges. Therefore, it is to some extent possible separate the contributions of weight, and of more subtle physical differences to the aggressivity of LTVs. To control for the effects of weight in a simple manner, the overall weight range from less than 2,000 to more than 5,000 lb was divided into shorter intervals. Within each of these weight intervals, similar comparisons as in section 3.1 were made.

Figure 3.2-1 shows the results for pickup trucks. As “baseline”, the actual risks in car-car collisions are shown by circles, their representation by the model by the solid line. With the exception of the heaviest cars, above 4,500 lb, of which there are only very few, actual risks and the model agree well. The triangles represent the actual car driver fatality risks in collisions between cars and compact pickup trucks, the squares those in collisions between cars and standard pickup trucks. The broken lines (short for compact, long for standard pickup trucks) show the risks the car driver would have faced, if the pickup truck would have been replaced by a car with the same weight. With one exception, these risks are higher than in actual car-car collisions. This means that for a given vehicle weight, the differences in driver age and sex, and in speed limit make collisions with pickup trucks more dangerous for car drivers, even if the truck had been replaced by a car. In addition, however, the actual risks in collisions with pickup trucks are even higher than those predicted for corresponding car-car collisions. This means that either physical characteristics of pickup trucks, or more subtle driver and environmental factors than those used in the model, increase the fatality risk.

We also notice that the assessment of the aggressivity of heavy pickup trucks, above 4,500 lb, depends on the validity of the extrapolation of the model for car-car collisions. While the model fits the data in the range up to 4,500 lb quite well, it fits the few cases between 4,500 and 5,000 lb badly; there are no cases to validate its extrapolation beyond 5,000 lb.

Figure 3.2-2 shows the corresponding information for collisions between cars and SUVs. One difference is that the broken lines tend to be closer to the solid line than in Figure 3.2-1. This means that the differences in drivers and driving conditions in collisions between SUVs and cars are not as great as in collisions between cars and pickup trucks. This agrees with the general observation that SUVs are widely used as substitutes for cars.

Figure 3.2-3 shows the corresponding information for collisions between cars and vans. For minivans, the broken line, and the solid line are even closer than for SUVs and cars. This means that drivers and driving conditions of minivans are similar to those of cars.

To quantify how “aggressive” LTVs are in comparison with cars, we calculated, for each weight range, the ratio of the actual car driver fatality risk to that modelled for corresponding car-car collisions.

Figure 3.2-4 shows the ratios for car-car collisions. As to be expected, for weights up to 4,500 lb, the risk and the model agree well within much less than one non-standard error of the risk. Only for the very few cars above 4,500 lb does the model not represent the actual risks, where it overestimates them by more than a factor of two.

Figure 3.2-5 shows the ratios for car-pickup truck collisions. They tend to be greater than one, sometimes by not much more than one non-standard error. A closer look shows a declining trend with weight, which is confirmed by a regression analysis.

Figure 3.2-6 shows the ratios for car-SUV collisions. The pattern is grossly similar to that in collisions between cars and pickup trucks. However, the declining trend with weight is more easily recognizable.

Figure 3.2-7 for vans shows a very different pattern. The ratios for minivans and large vans are very different, and the declining trends with weight are more clearly recognizable.

These findings strongly suggest a separate– additional to its inertial effect in collisions between two vehicles– effect of LTV weight, or a factor correlated with weight; on the car driver fatality risk, it reduces the risk. Whether this effect is real for weights above 4,500 lb is questionable; in this weight range it depends completely on the unverifiable extrapolation of the car-car collision model. However, even at lower weights such an effect appears indicated. This is surprising and deserves further study.

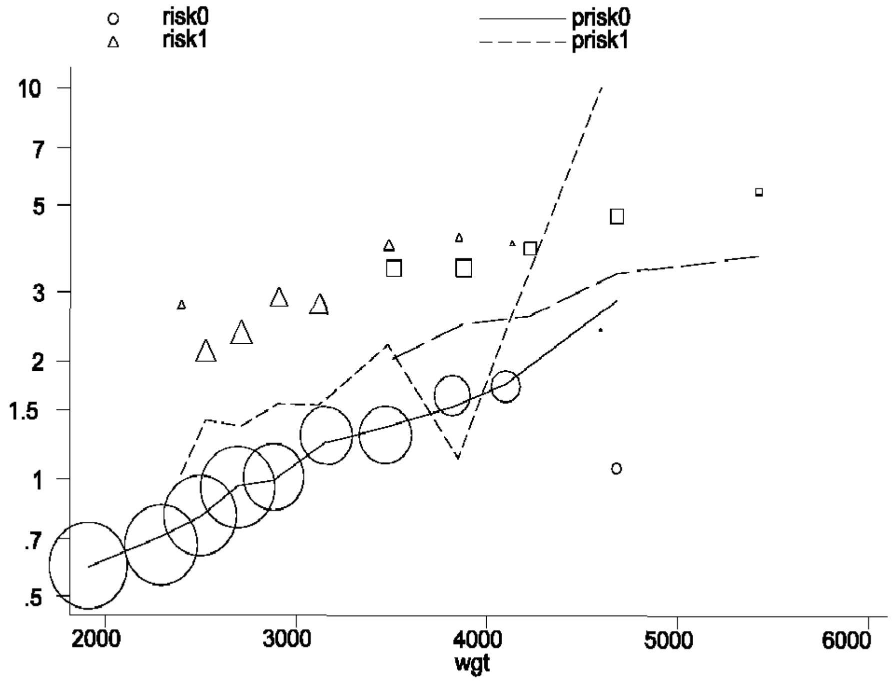

Figure 3.2-1 Actual and predicted risks (per 1,000 involvements) of car driver death in car-pickup truck collisions, versus weight of pickup truck. Circles show the risks in car-car collisions, the solid line the modelled risks. Triangles show the actual risks in collisions between cars and compact pickup trucks, the short broken line shows what the risk in these collisions would have been, had the pickup truck been replaced by a car of the same weight. Squares show the actual risks in collisions between cars and standard pickup trucks. The long broken line shows what the risk would have been, had the pickup truck been replaced by a car of the same weight. Logarithmic scale for risk. The sizes of the symbols are proportional to their statistical weights.

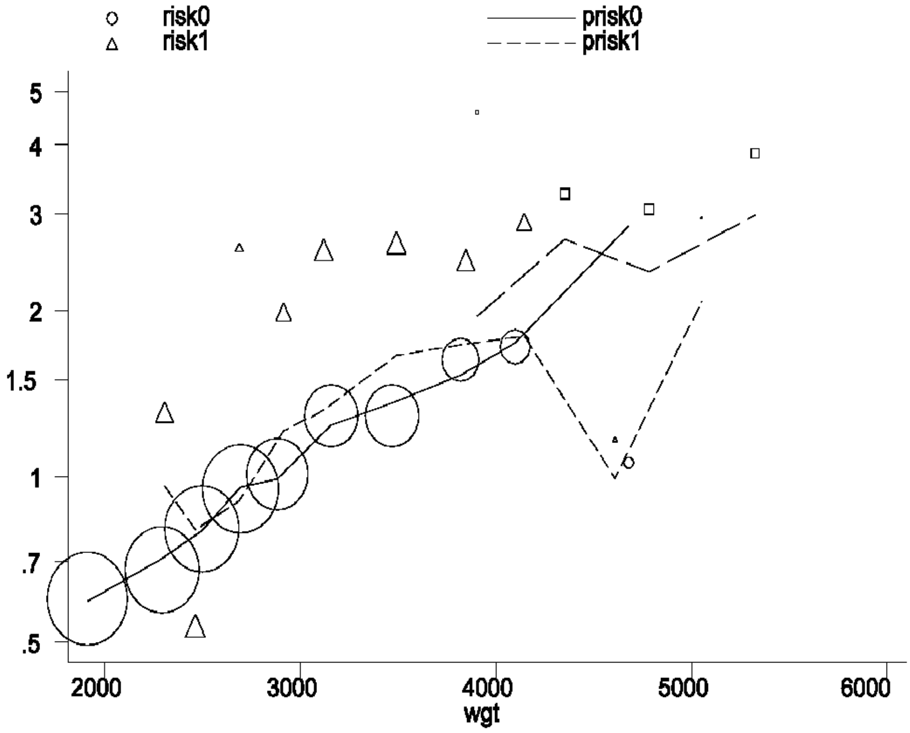

Figure 3.2-2 Actual and predicted risks (per 1,000 involvements) of car driver death in car-SUV collisions, versus weight of SUV. Circles show the risks in car-car collisions, the solid line the modelled risks. Triangles show the actual risks in collisions between cars and SUVs, the short broken line shows what the risk in these collisions would have been, had the SUV been replaced by a car of the same weight. Squares show the actual risks in collisions between cars and standard SUVs. The long broken line shows what the risk would have been, had the SUV been replaced by a car of the same weight. Logarithmic scale for risk. The sizes of the symbols are proportional to their statistical weights.

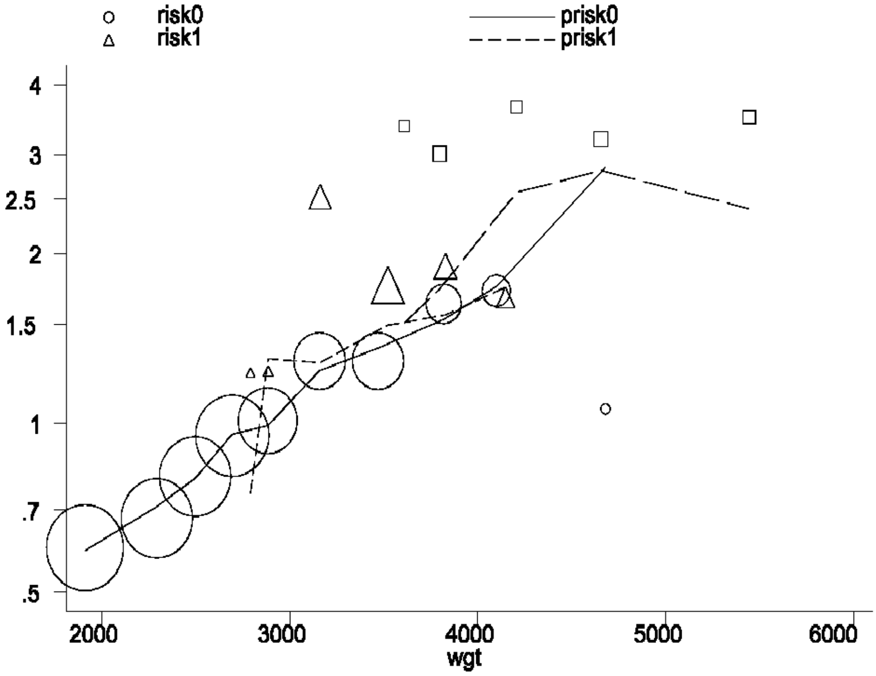

Figure 3.2-3 Actual and predicted risks (per 1,000 involvements) of car driver death in car-van collisions, versus weight of van. Circles show the risks in car-car collisions, the solid line the modelled risks. Triangles show the actual risks in collisions between cars and minivans, the short broken line shows what the risk in these collisions would have been, had the minivans been replaced by a car of the same weight. Squares show the actual risks in collisions between cars and large vans. The long broken line shows what the risk would have been, had the van been replaced by a car of the same weight. Logarithmic scale for risk. The sizes of the symbols are proportional to their statistical weights.

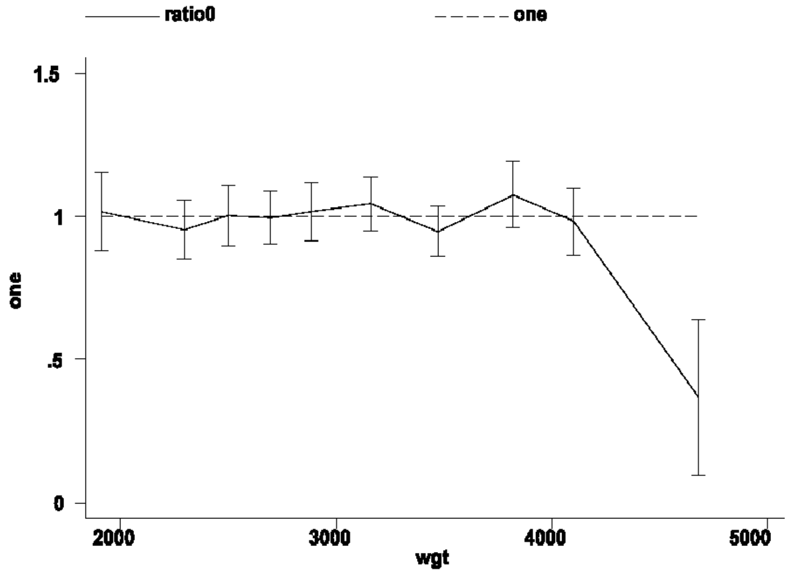

Figure 3.2-4 Ratio of the actual car driver fatality risk in car-car collisions, to that resulting from the model, versus car weight. The vertical bars show the modelled risk +/- one non-standard error; the broken line shows a ratio of one.

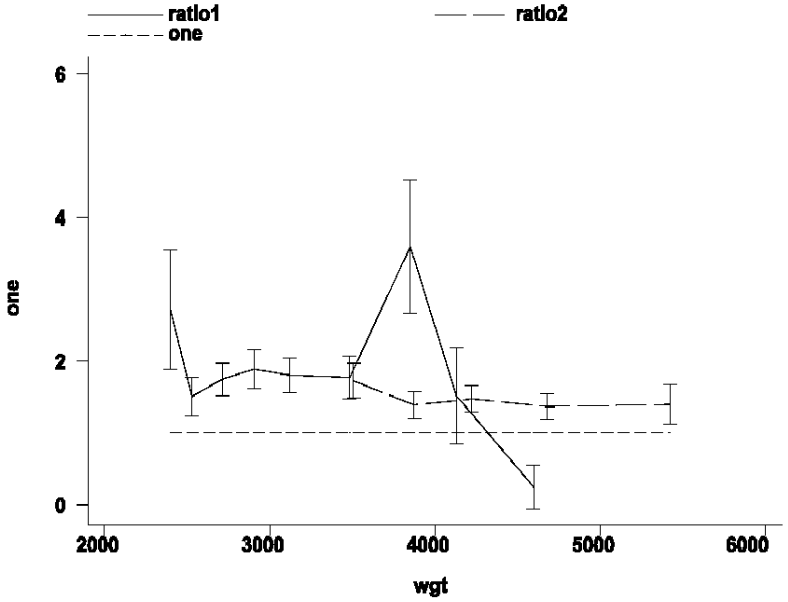

Figure 3.2-5 Ratio of the actual car driver fatality risk in collisions between cars and pickup trucks, to the probability of car driver death if the pickup truck had been replaced by a car of the same weight. The vertical bars show the modelled risk +/- one non-standard error; the broken line shows a ratio of one.

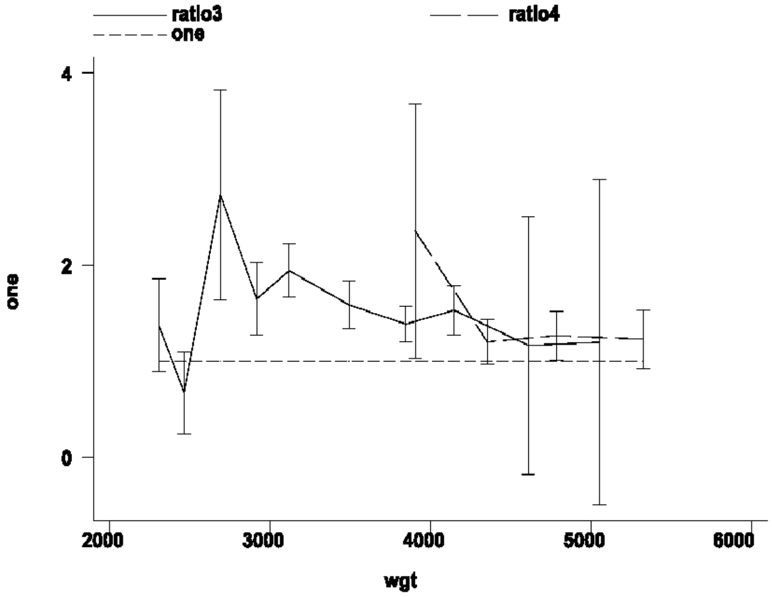

Figure 3.2-6 Ratio of the actual car driver fatality risk in collisions between cars and SUVs, to the probability of car driver death if the SUV had been replaced by a car of the same weight. The vertical bars show the modelled risk +/- one non-standard error; the broken line shows a ratio of one.

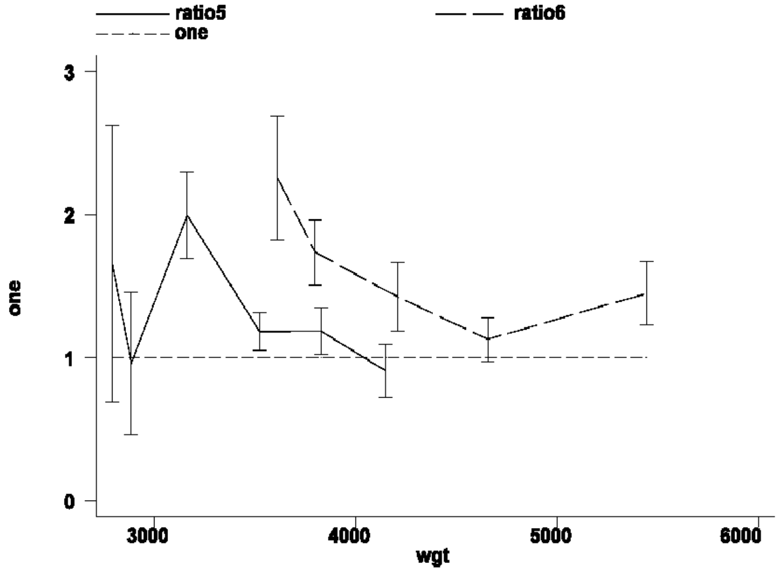

Figure 3.2-7 Ratio of the actual car driver fatality risk in collisions between cars and vans, to the probability of car driver death if the van had been replaced by a car of the same weight. The vertical bars show the modelled risk +/- one non-standard error; the broken line shows a ratio of one.

4 RISKS BY LTV GROUP IN RELATION TO VEHICLE PARAMETERS

4.1 Sport Utility Vehicles

4.1.1 Characteristics of Sport Utility Vehicles

The available characteristics of the studied SUVs are not all statistically independent. This can make the separation of any effects they might have imprecise if not impossible.

Figure 4.1.1-1 shows the average height of the center of force in crash tests versus vehicle weight (average weight in the actual crashes studied, not weights of the tested vehicles). There is an increasing trend, but the correlation is not very close, which makes separation of the two effects by statistical modelling easier. However, because the average height of force is calculated from readings on sensors at only four different heights, the precision of the AHOF value is limited. This makes it impossible to recognize small differences in the actual heights of centers of force, and could make it impossible to separate their effects from those of other factors.

The height of the center of gravity from the ground (CGFG) versus vehicle weight (Figure 4.1.1-2) shows also an increasing trend. The correlation is much closer than for the AHOF, which makes separation of any effects more difficult. Also, the CGFG is available only for few SUV groups heavier than 4,000 lb. Therefore, the usefulness of the CGFG is limited.

There is a positive correlation between AHOF and CGFG (Figure 4.1.1-3). However, it is the result of the vehicle groups forming two clusters. Within these clusters, the trends appear to be very different from the overall trend.

Figure 4.1.1-4 shows all relations between AHOF and the impulses on the four rows of the crash sensors. AHOF is clearly negatively related with the impulse on row 2, and positively with the impulses on row 3 and row 4. Correspondingly there are clear negative relationships between row 2 and row 3, and a positive relationship between row 3 and row 4. This is a consistent picture. The relationship appears even stronger if one does not use the actual values of the impulses, but the percentages of the total impulse which falls onto each row. The negative relationship between row 2 and row 3 suggests that design variations tend to shift impulses from the height of row 2 to row 3, even if the total impulse is not changed.

The relationship between the impulse on row 1 and the other variables is a clear, but very unusual pattern. Some vehicles have roughly the same, very low impulse on row 1, another group of vehicles has low (in the case of row 2, high) values of the other variable, but widely varying values for the impact on row 1. There is no obvious explanation for this phenomenon.

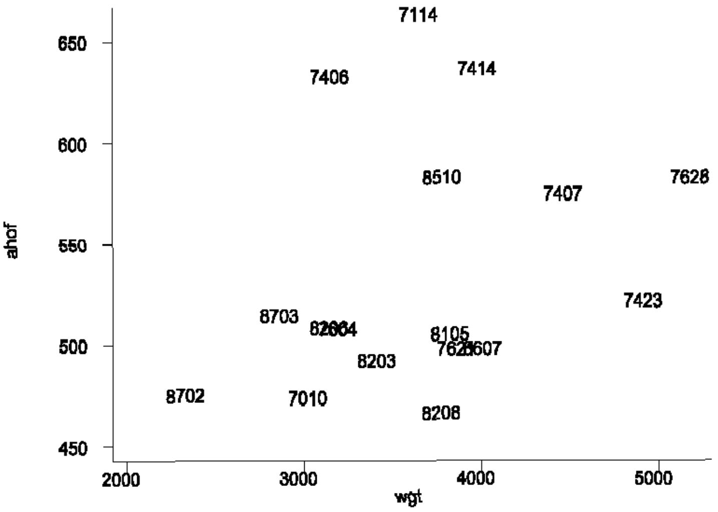

Figure 4.1.1-1 Average height of force versus vehicle weight. Sport utility vehicles. The numbers are Kahane’s group codes.

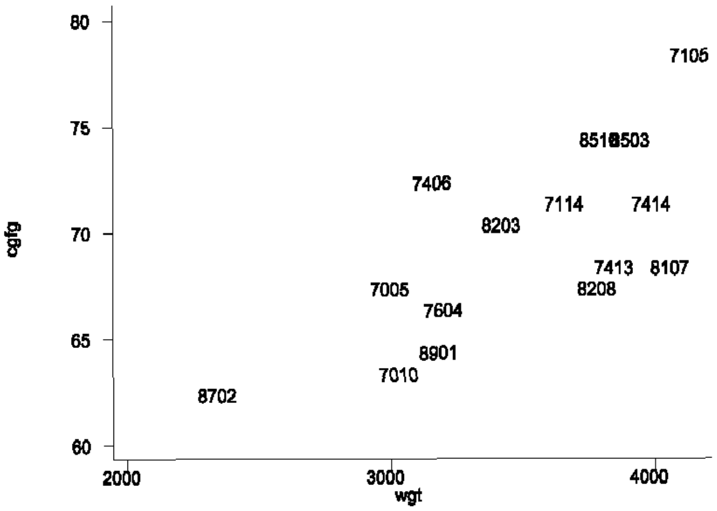

Figure 4.1.1-2 Height of the center of gravity from the ground versus vehicle weight. Sport utility vehicles. The numbers are Kahane’s group codes.

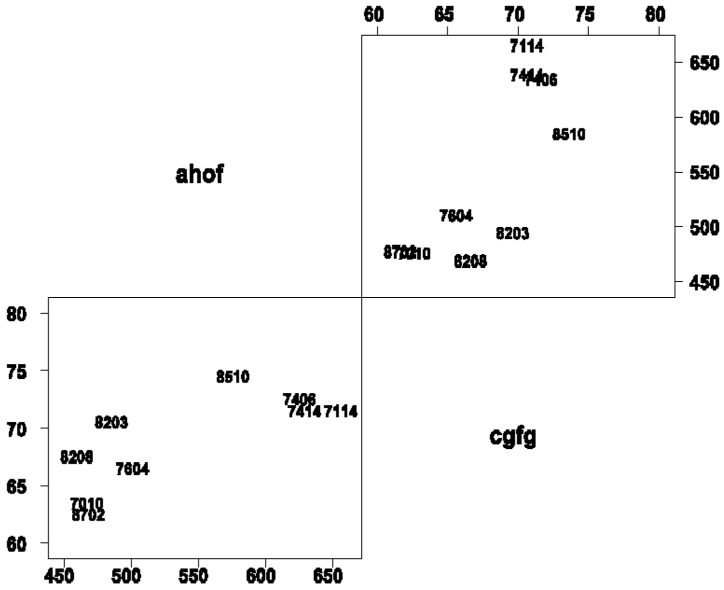

Figure 4.1.1-3 Average height of force versus height of the center of gravity from the ground versus vehicle weight. Sport utility vehicles. The numbers are Kahane’s group codes.

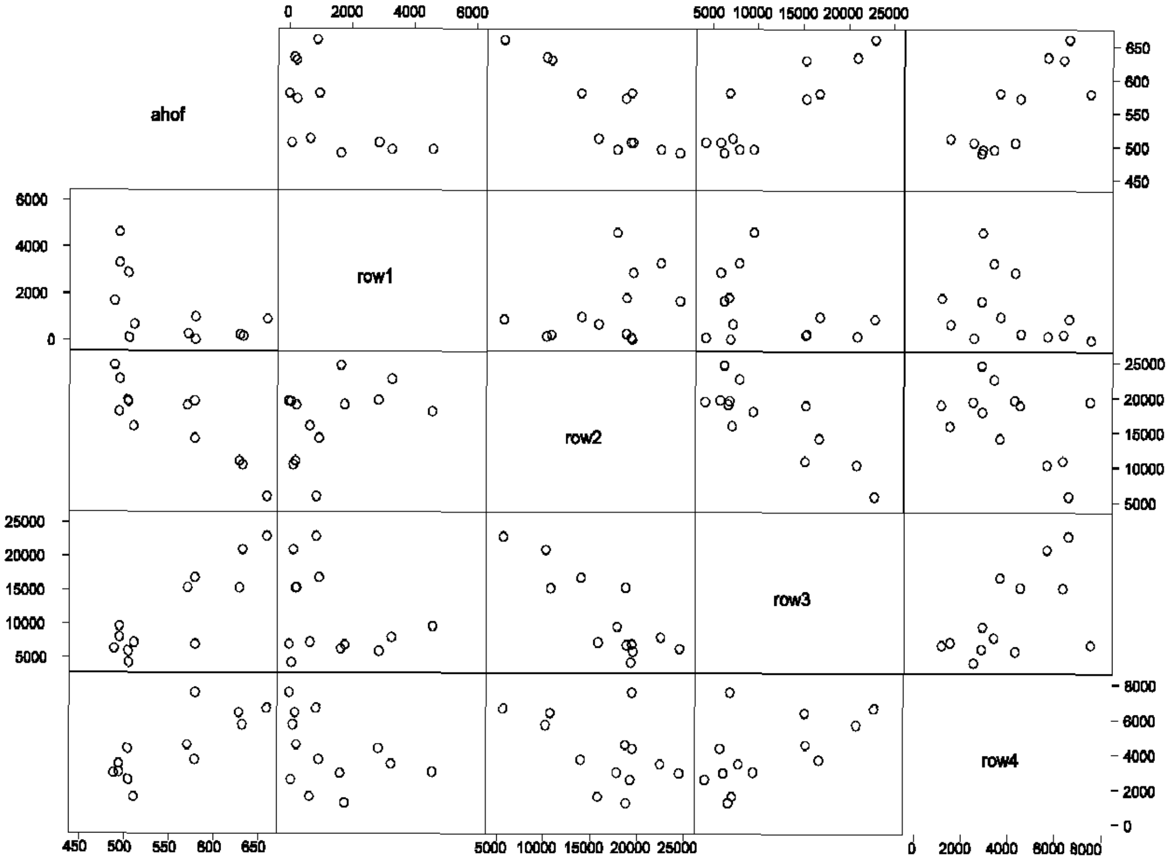

Figure 4.1.1-4 Matrix plot of all pairs of average height of the center of force, and impulses on row 1, row 2, row 3, and row 4 of the crash sensors. Sport utility vehicles.

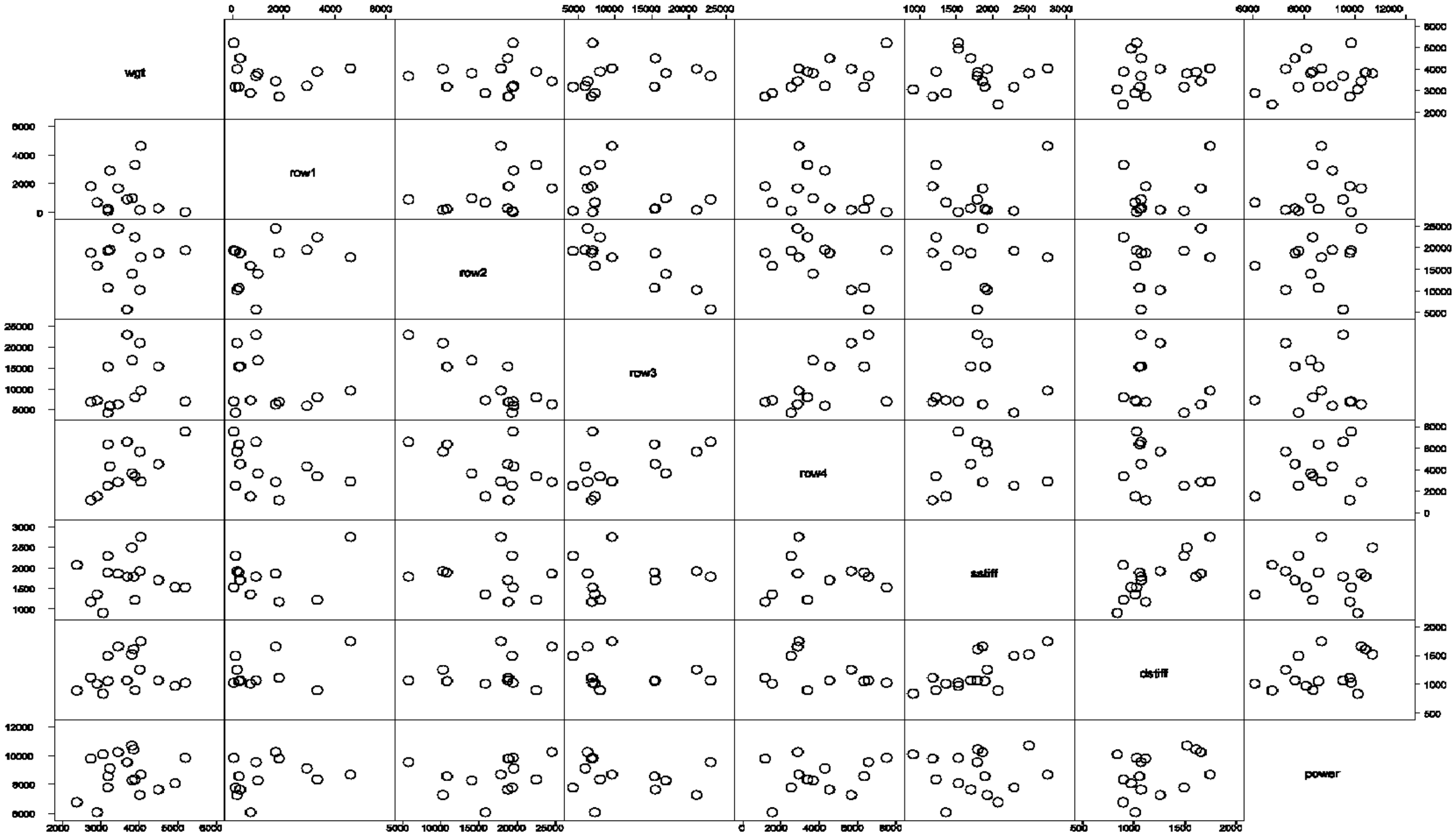

Figure 4.1.1-5 Matrix plot of all pairs of vehicle weight, impulses on row 1, row 2, row 3, and row 4 of the sensors, static stiffness, dynamic stiffness, and peak power. Sport utility vehicles.

Figure 4.1.1-5 contains much of Figure 4.1.1-4 (AHOF is excluded); added are vehicle weight, static stiffness, dynamic stiffness, and peak power. Static stiffness and dynamic stiffness show a fairly close positive relationship, and dynamic stiffness shows a weak positive relations with peak power. Vehicle weight shows a fairly close positive relationship with the impulse on row 4, and a weak positive relation with peak power.

Such correlations between the independent variables make it difficult to separate the effect of the various factors by statistical modelling. Usually, a weak correlation is more favorable for separating such effects than a tight correlation. However, in our situation with sometimes very few data points, even a weak correlation is not sufficient to successfully separate any effects.

4.1.2 Risk Estimates

4.1.2.1 Absolute and Relative Risks

Our original plan was to develop models for the driver fatality risk in car-car collisions, and use these models to estimate what the car driver fatality risk in a car-LTV collision would have been, if the LTV had been replaced by a car of the same weight, with a driver of the same age and sex that of as the LTV, and the speed limit had been the same. The ratio of the actual deaths to the weighted sum of the modelled probabilities estimates the relative risk in car-LTV and comparable car-car collisions. Relating this relative risk to parameters of LTVs should provide insight which factors influence the aggressivity of LTVs.

The initial analysis for SUVs had a surprising result: the car driver fatality risk relative to collisions with a car appeared to decrease with SUV weight (Figure 4.1.2.1-1). A simple regression line through the points showed a clear, “significant,” decreasing trend. A closer examination showed a much more complicated pattern. Up to a weight of about 3,800 lb, the relative risk increased with SUV weight, for higher weights, the relative risk appeared to be level or to decline. More extensive analyses showed that the data could not be fitted by a single function of SUV weight alone. Different functions were needed for the lower weight range, and for the higher weight range, with a “step” between them at about 3,900 lb, where the risk dropped.

There are two potential explanations for this complicated pattern. First, the risk is calculated relative to that in car-car collisions. The car population for which this model was developed contains few cars weighing more than 3,500 lb, and extremely few more than 4,000 lb. Thus, the application of the model to vehicles over 3,900 lb requires extrapolation beyond the basis of the model. Such extrapolations are notoriously unreliable. This could severely bias the estimates of the relative risks above 3,900 lb.

Another possibility why the relation between the relative risk and SUV weight analysis changes abruptly at 3,900 lb weight is that other SUV characteristics might differ between the lighter and the heavier SUVs. If that were the case, it should be recognized by the analysis of the other SUV characteristics together with weight.

Therefore, we also performed additional analyses with the absolute car driver fatality risks (per 1,000 involvements) in collisions with SUVs. In principle, models similar to those for car-car collisions with vehicle, driver, and environmental factors could have been developed. However, because the numbers of car-SUV collisions are much smaller than those for car-car collisions, the models would be much less precise. Also, when the counter-intuitive pattern was noticed, the work had progressed too far to do this. In additional analyses the actual car driver fatality risks were used, and their relation to only LTV vehicle characteristics studied (section 4.1.2.3).

Figure 4.1.2.1-2 shows the absolute car driver fatality risk (per 1,000 involvements) versus SUV weight. Again, the pattern is not simple. Up to a SUV weight of about 3,700 lb, there is a clearly increasing trend. For higher weights, it seems to level off.

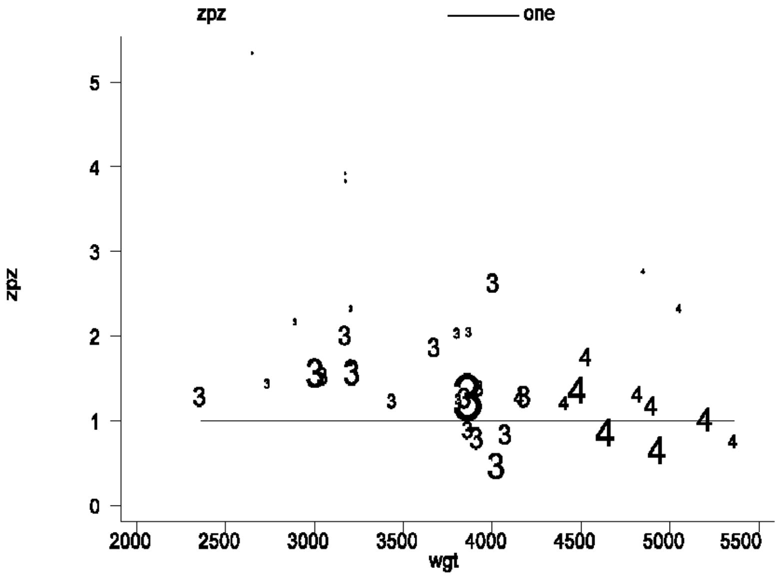

Figure 4.1.2.1-1 Relative (to collisions with another car) car driver fatality risk in collisions with a SUV, versus weight of SUV. Each "point" represents a SUV group. "3" represents compact SUVs, "4", larger SUVs. The sizes are proportional to the statistical weights of the risks. The straight line represents the value 1.

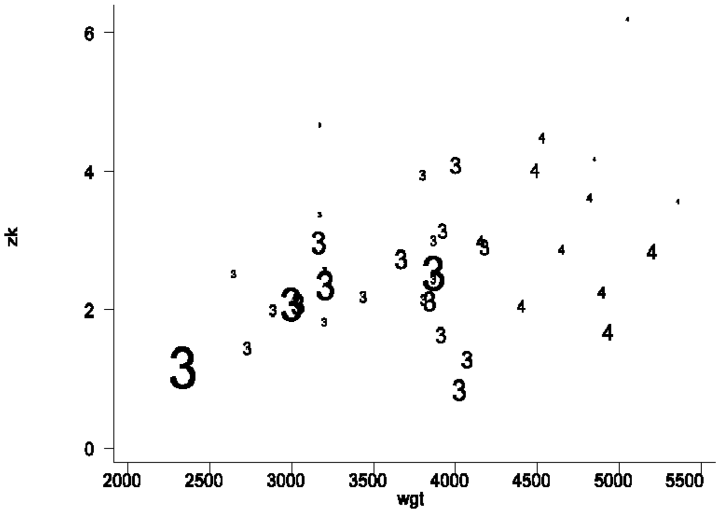

Figure 4.1.2.1-2 Car driver fatality risk (per 1,000 vehicle involvements) in collisions with a SUV, versus weight of the SUV. Each "point" represents a SUV group. "3" represents compact SUVs, "4", larger SUVs. The sizes are proportional to the statistical weights of the risks.

The patterns in Figure 4.1.2.1-1 and Figure 4.1.2.1-2 have one factor in common, which is a rapid change in the trend at weights just below 4,000 lb. This makes it less likely that the break in Figure 4.1.2.1-1 is due to the risk model for car-car collisions being invalid for weights above 4,000 lb, and more likely that it is due to differences in other SUV characteristics.

There is another interesting difference between the two figures. The size of the numbers "3" and "4" represent the statistical weight = 1/(non-standard error)• 2 with which the points are used in the analysis; it reflects the statistical "precision" with which the absolute and the relative risks are known. In Figure 4.1.2.1-1 most symbols "3" and "4" between 4,500 and 5,300 lb are fairly large, indicating that the errors of the relative risk estimates for these SUV groups are very low. In Figure 4.1.2.1-2, the corresponding symbols are, relatively, much smaller. The reverse holds for the "3" near 2,500 lb. In Figure 4.1.2.1-2 it is the largest symbol, in Figure 4.1.2.1-1 it is of about average size. Such differences in statistical weights between different measures of risk can have very subtle effects on the results of analyses.

4.1.2.2 Relative Risks

Relative risk is the actual deaths of car drivers in collisions with SUVs, divided by the expected number of deaths which would have occurred in collisions with cars, all other factors being equal. Using relative risk should eliminate or at least reduce effects of potential differences in vehicle weight, driver characteristics, and driving environment, leaving only differences due to specific characteristics of LTVs. As discussed in the preceding section, it is doubtful whether this approach succeeded with respect to vehicle weight.

Therefore, in this section we are treating vehicle weight as a confounding factor only, the influence of which should be eliminated as far as possible; any relations found with respect to weight should not be interpreted as physical effects of weight.

Figure 4.1.2.2-1 presents the same data points as 4.1.2.1-1, but using Kahane's SUV group codes as symbols. This allows the reader to search for more subtle patterns.

To explore potential relations between relative risk and SUV weight, the following was done. First, a regression line through all points was fitted. The coefficients are shown in Table 4.1.2.2-1, and the regression line as solid line in Figure 4.1.2.2-2.

Table 4.1.2.2-1 Regression coefficients for the relative risk of car driver death in car-SUV collisions, as function of the SUV weight.

variable	coefficient	non-standard error
SUV weight (1,000 lb)	-0.277	(.107)
constant	2.37	(.44)

Next, the weight range was split into a lower and an upper part. For each a separate regression line was calculated. This was done for several "breakpoints", from 3,000 to 4,200 lb. The result was that in all cases the line for the higher weight was practically identical with the line for all weights. The regression line for the lower weights, however, showed up to a breakpoint of 3,850 lb always a positive, though not "significant" slope. Figure 4.1.2.2-2 shows this regression line as a broken line (there is also a broken line representing the regression line for the higher weights, but it is barely distinguishable from the overall line). If the breakpoint is higher than 3,850 lb, both regression lines for the lower and the higher weights are practically indistinguishable from that for all points.

A closer inspection of the improvements achieved by using two rather than one regression line, compared with the +/- one non-standard error range shows that it is minimal and practically negligible. That means that to eliminate any confounding effect of weight, including one linear weight term should suffice.

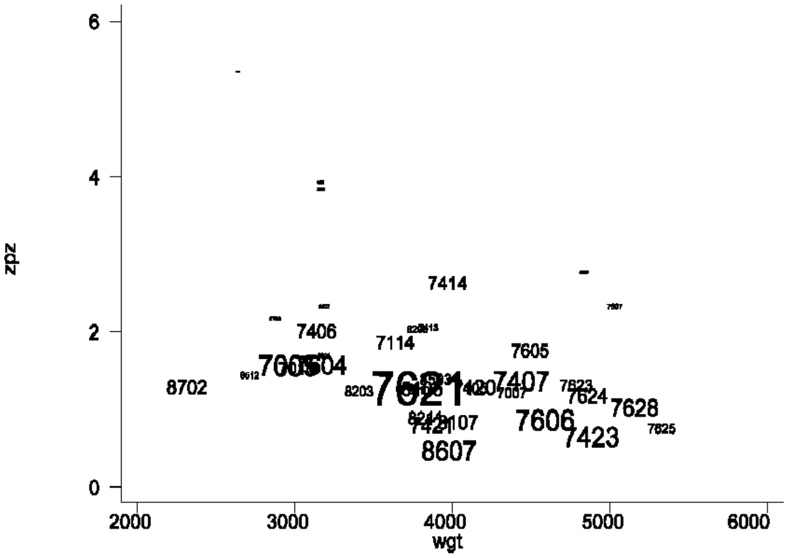

Figure 4.1.2.2-1 Car driver fatality risk in car-SUV collisions relative to that in car-car collisions, by weight of the other vehicle. The numbers are the Kahane codes for SUV groups. Their sizes are proportional to the statistical weights of the relative risks.

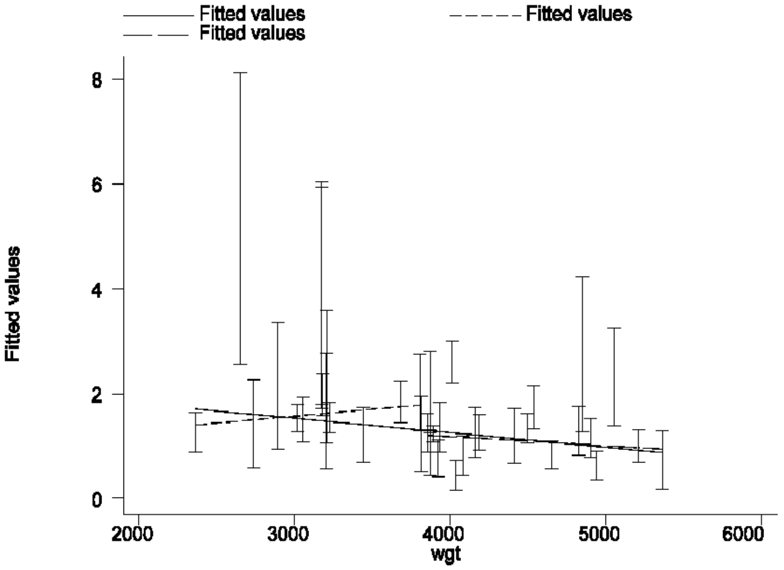

Figure 4.1.2.2-2 Car driver fatality risk in car-SUV collision relative to that in car-car collisions, by weight of the other vehicle. The vertical bars are the +/- one non-standard error ranges for each SUV group. The solid line is the regression line based on all points, the long broken line (barely distinguishable from the solid line) that for SUVs with weights of 3,850 lb or higher, the short broken line that for SUVs with lower weights.

However, considering that our risk models for car-car collisions represented the actual risks in the weight range through about 3,500 lb very well, and even up to 4,000 lb fairly well, it appears plausible to consider the possibility that there is no weight effect (a horizontal regression line) up to 3,850 lb, and a linearly declining trend above that. To consider that in an informal way, we will use bivariate graphs for a first assessment, where weight and the parameter under study are the coordinates, and the relative risk is used as a symbol to represent the data point.

Figure 4.1.2.2-3 shows the relation of the relative risk to SUV weight and the average height of the force (AHOF). The following pattern appears: the highest risks appear for the three points at the middle weights, and AHOF above 60 cm. For the lower weights, there seems to be little variation in risk. With regard to weight, there is perhaps a slight decrease of the relative risk with weight, except for the points with the highest AHOF. A number of statistical models were explored, but no satisfactory model was found, as they all depended critically on one or two points. The simplest models are shown in Table 4.1.2.2-2.

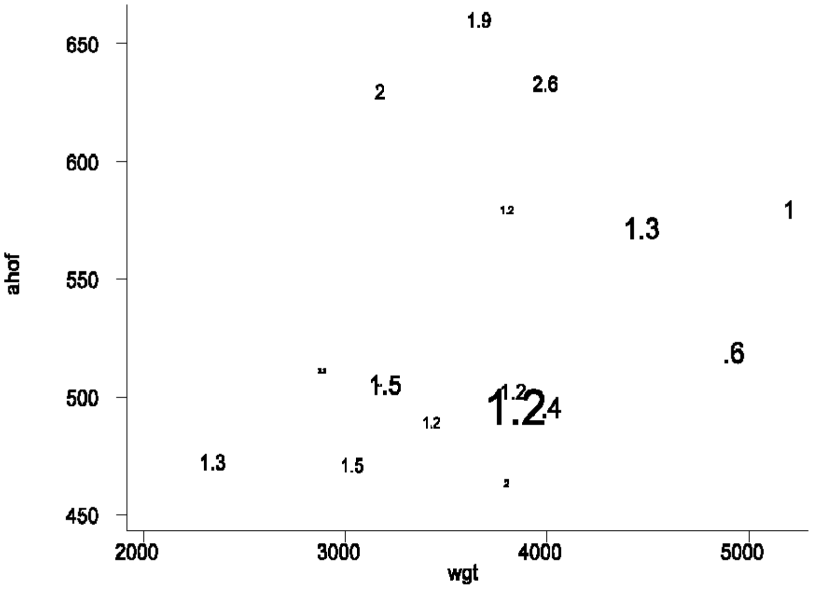

Figure 4.1.2.2-3 Relative (to car-car collisions) car driver fatality risk in car-SUV collisions versus average height of force (mm) and SUV weight. The numbers representing the points are the relative risks, their sizes are proportional to the statistical weights of the relative risks.

Table 4.1.2.2-2 Regression models for the relative (to car-car collisions) car driver fatality risk in car-SUV collisions.

	Model 1		Model 2	
variable	coefficient	non-standard error	coefficient	non-standard error
AHOF (cm)	.046	(.021)	.061	(.017)
weight (1,000 lb)			.438	(.132)
constant	-1.16	(1.10)	-.21	(.90)

Figure 4.1.2.2-4 shows the actual relative risks versus those resulting from model 1, Figure 4.1.2.2-5 those resulting from model 2. A closer look suggests that model 1 does not fit the points very well; up to modelled relative risks of about 1.5, the actual risks seem to be constant. The regression depends critically on the three points with high predicted risks. These points correspond to the SUVs with high values of AHOF. In Figure 4.1.2.2-5, a relation between actual and predicted risks appears to exist even for the points with lower predicted risks, and the three points with high predicted risks are better presented than in Figure 4.1.2.2-4. Thus, model 2 is better. Figure 4.1.2.2-6 shows the same points as Figure 4.1.2.2-5, but with the Kahane codes as symbols, and the +/- one non-standard error bars. Only 3 of the 17 points are more that one non-standard error from the lines indicating equality of the actual and modelled risks. That is a very good fit.

A closer look at Figure 4.1.2.2-3 suggests a very crude way of "controlling" for effects of SUV weight, whether actual or resulting from imperfections of the base model. The data can be quite naturally be split into three sets: those with weights under 3,800 lb; between 3,800 and 4,200 lb; and above 4,200 lb. For each of these sets a regression of the relative risk on AHOF was run, and also one on AHOF and SUV weight.

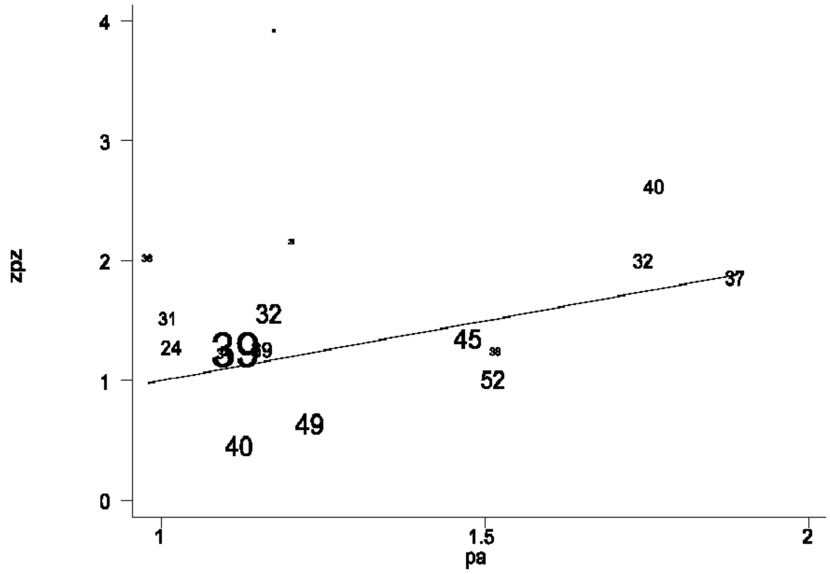

Figure 4.1.2.2-4 Actual versus modelled relative car driver fatality risks in car-SUV collisions. Model 1 from Table 4.1.2.2-2. The numbers representing the points are the average weights of the SUVs in each group (in 100 lb). The sizes of the numbers are proportional to the statistical weights of the relative risks. The line represents equality of actual and modelled risks.

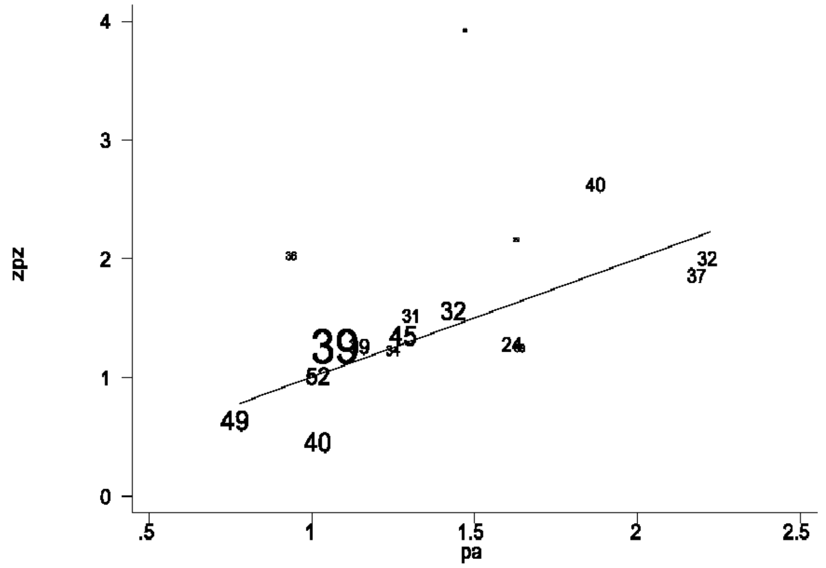

Figure 4.1.2.2-5 Actual versus modelled relative car driver fatality risk in car-SUV collisions. Model 2 from Table 4.1.2.2-2. The numbers representing the points are the average weights of the SUVs in each group (in 100 lb). The sizes of the numbers are proportional to the statistical weights of the relative risks. The line represents equality of actual and modelled risks.

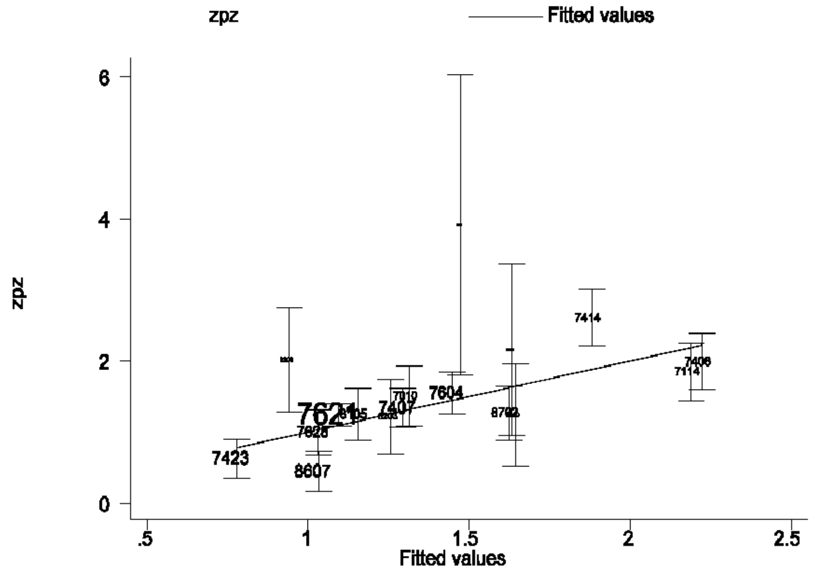

Figure 4.1.2.2-6 Actual versus modelled relative car driver fatality risk in car-SUV collisions. The numbers representing the points are the Kahane codes of the SUV groups. Their sizes are proportional to the statistical weights of the relative risks. The vertical bars represent the +/- one non-standard error ranges for the relative risks. The line represents equality of actual and modelled risks.

It is not surprising that the coefficients of SUV weight in these models for narrower weight ranges are either negligible, or non-“significant”; they are not shown. Also, the coefficients of AHOF for models with and without weight were practically identical or equal within one non-standard error. Table 4.1.2.2-3 shows the coefficients of AHOF. Striking is that those for the two higher weight ranges are practically equal. Those for the lowest weight range are much smaller, about one third of the others.

Table 4.1.2.2-3 Regression coefficients of AHOF (cm) in models for the relative car driver fatality risk in car-SUV collisions. Non-standard errors are in parentheses, (x) means that no degree of freedom is left to calculate the non-standard error.

weight of SUV	model without weight	model including weight
<3,800 lb	.030 (.013)	.029 (.018)
3,800...4,200 lb	.095 (.048)	.116 (.041)
>4,200 lb	.093 (.060)	.087 (x)

Another look at Figure 4.1.2.2-3 shows that for AHOF values up to about 600 mm, no trend of the relative risk with AHOF is apparent. A regression analysis confirms this. For the three SUV groups with higher AHOF values, the relative risks are much higher. The average relative risk for the first group of SUVs is 1.15, that for the other 2.15, that is 87% higher. The average SUV weight for the first group is 4,000 lb, that for the second 3,600 lb, the average AHOF values 51 and 64 cm. Thus, a weight difference can not explain the risk difference between the two groups, except if the relations between risk and weight were very complex.

Clearly the higher AHOF values are associated with higher relative risks. The details of this relation are much less clear. The best overall model (2 in Table 4.1.2.2-2) shows that an increase of AHOF by 10 cm would increase the relative risk by 0.61, that is nearly half of the average relative risk of 1.3. The models distinguishing SUVs by weight in Table 4.1.2.2-3 indicates that the increase for SUVs under 3,800 lb is only half that much, whereas that for the heavier ones with an average coefficient of (.116 + .087)/2 =.10 is about two thirds higher. These estimates, however, assume a linear relation between relative risk and AHOF. The comparisons made in the previous paragraph indicated that there may be a threshold. There seems to be little, if any, variation of the relative risk with AHOF as long as it remains below about 60 cm, but it increases with higher values– in which form can not be determined from the limited data available.

Figure 4.1.2.2-7 shows the relative risks versus SUV weight and the height of the center of gravity from the ground. Weight and CGFG are fairly closely correlated, therefore, it is nearly impossible to separate any effects of weight and of CGFG. An additional limitation is that CGFG values were available only for SUVs with weights under 4,200 lb. Exploratory regression analyses showed no “significant” effects.

AHOF is essentially a weighted average of the forces acting on the four rows of sensors during a crash test. Using these forces (measured by the impulses impacted on the sensors) separately might provide better insights as to how an increase in AHOF is related to an increasing fatality risk. Figures 4.1.2.2-8 through 11 show the fatality risk versus SUV weight and impulse on each of the four rows of sensors. Figure 4.1.2.2-8 shows a surprising pattern. In the low to middle weight range (up to about 3,500 lb), the relative risk declines with an increasing impulse on row 1. The same holds for the higher range (from about 3,500 to 4,200 lb). In the highest weight range, there are only two cases; they do not allow recognition of a trend. For the second row (Figure 4.1.2-9) the same pattern holds. For the third row (figure 4.1.2.2-10), the pattern is reversed; within each weight range, the relative risk increases with the impulse. For the fourth row (Figure 4.1.2.2-11) the same holds, except for the heaviest SUVs. To explore this further, regressions were run, the results of which are shown in Table 4.1.2.2-4. The coefficients show about the same pattern as the graphs. Overall, model 1, using only the impulse on the lowest row 1 represents the data somewhat better than models 2, 3, or 4. If all four rows are included in the model, the representation of the data is slightly better. It is noteworthy that in the models with one row only, and that with all four rows, a similar pattern appears, where the coefficient for row 2 and row 3 are practically equal, but with opposite signs, as are the coefficients for row 1 and row 4. This suggests that the coefficients are more likely reflecting an effect of shifting the force between the low and the higher rows than separate effects of the forces on each row.

Therefore, further experiments were made. Instead of the absolute impulse one each row of sensors, the proportions of the impulse impartial on each row were used:

prow*i*=row*i*/(row1 + row2 + row3 + row4)

Models using these proportions allowed a slightly better representation of the data than those using the actual impulses. Table 4.1.2.2-5 shows one such model, including all 4 proportions (and omitting the constant term, to avoid the collinearity which would have been introduced by using all 4 proportions which sum to 1). Here, the pattern is different from that of model 5; only the coefficient for the proportion on row 1 is negative, the other coefficients are positive. Even more surprising is that the absolute values of the coefficients for all four rows are practically equal. This suggests introducing a new variable:

prow2 + prow3 + prow4 - prow1.

A model with only this variable and weight (model 7 in Table 4.1.2.2-5 and Figure 4.1.2.2-13) represents the data not less well, but minimally better than (6) which includes four row variables. Even the latter model represents the data barely better than one which is using only the impulse on row 1 and weight (Figure 4.1.2.2-12). However, model 7 implies a potential physical effect; a shift of impulse from the first row to a higher row has a detrimental effect on the relative fatality risk, but a shift within the upper three rows has none.

Figures 4.1.2.2-14 through 16 show the bivariate graphs of the relative risk versus SUV weight and static stiffness, dynamic stiffness, and peak power. No pattern is apparent. Various regression analyses were performed, but the coefficients of these variables were far from “significant,” and negative, contrary to what one would expect. Only in one case, when combining weight, AHOF, and static stiffness did the coefficient of the latter approach very weak “significance”, but again with the “wrong” sign. This depended completely on one single data point: that for the SUV group 8607, the 4 door Mitsubishi Montero from model years after 1991. Of course, this does not mean that these factors may not have physical effects. The shortcomings of our basic model may not have allowed us to identify them.

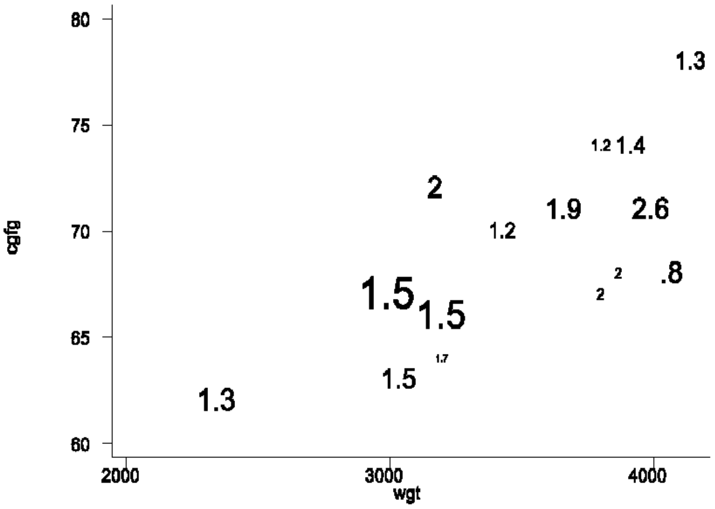

Figure 4.1.2.2-7 Relative (to car-car collisions) car driver fatality risk in car-SUV collisions versus height of the center of gravity of the SUV from the ground and SUV weight. The numbers representing the points are the relative risks, their sizes are proportional to the statistical weights of the relative risks.

Table 4.1.2.2-4 Regression coefficients of models relating the relative (to car-car collisions) car driver fatality risk in car-SUV collisions to SUV weight and impulse (mN• s) on four rows of sensors in SUV crashes tests. Models 1-4 use only one row of sensors, model 5 all four. Non-standard errors are in parentheses.

			Model		
variable	1	2	3	4	5
row 1	-.25 (.06)				-.14 (.11)
row 2		-.05 (.03)			-.06 (.06)
row 3			.06 (.02)		.06 (.05)
row 4				.22 (.08)	.15 (.16)
weight (1,000 lb)	-.56 (.18)	-.26 (.23)	-.34 (.22)	-.58 (.23)	-.72 (.27)
constant	4.08 (.75)	3.36 (.98)	2.09 (.89)	2.69 (.85)	2.00 (1.83)

Table 4.1.2.2-5 Regression coefficients of models relating the relative (to car-car collisions) car driver fatality risk in car-SUV collisions to SUV weight and proportions of impulse imparted on the four rows of sensors in SUV crash tests. In Model 7, the four coefficients were specified to be -1, 1, 1, 1 times a common coefficient. Non-standard errors are in parentheses.

	Model	
variable	6	7
prow 1	-3.97 (2.88)	-1
prow 2	3.79 (1.08)	1
prow 3	4.37 (0.94)	1
prow 4	4.01 (2.84)	1
combined		4.54 (1.05)
weight (1,000 lb)	-0.55 (0.20)	-0.59 (0.17)
constant		-0.32 (.094)

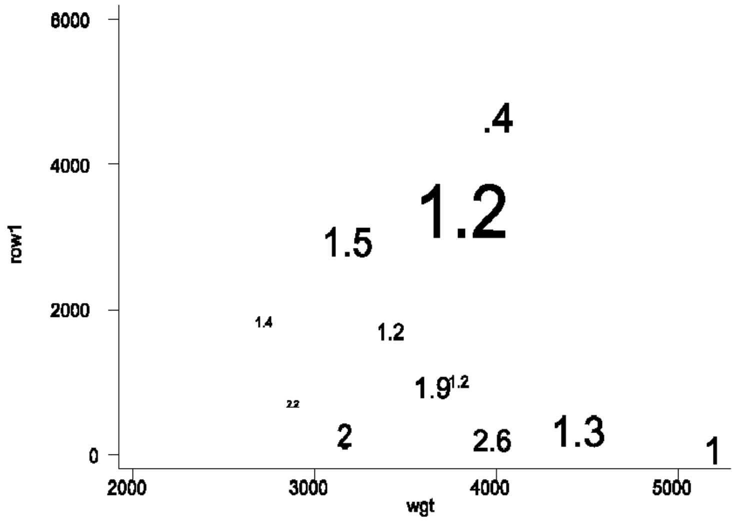

Figure 4.2.2-8 Relative (to car-car collisions) car driver fatality risk in car-SUV collisions versus SUV weight and impulse on row 1 of sensors. The numbers representing the points are the relative risks, their sizes are proportional to the statistical weights of the relative risks.

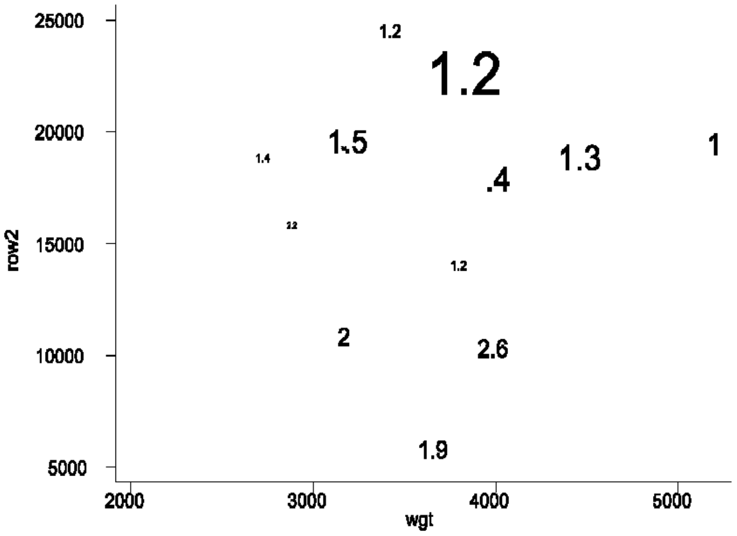

Figure 4.1.2.2-9 Relative (to car-car collisions) car driver fatality risk in car-SUV collisions versus SUV weight and impulse on row 2 of sensors. The numbers representing the points are the relative risks, their sizes are proportional to the statistical weights of the relative risks.

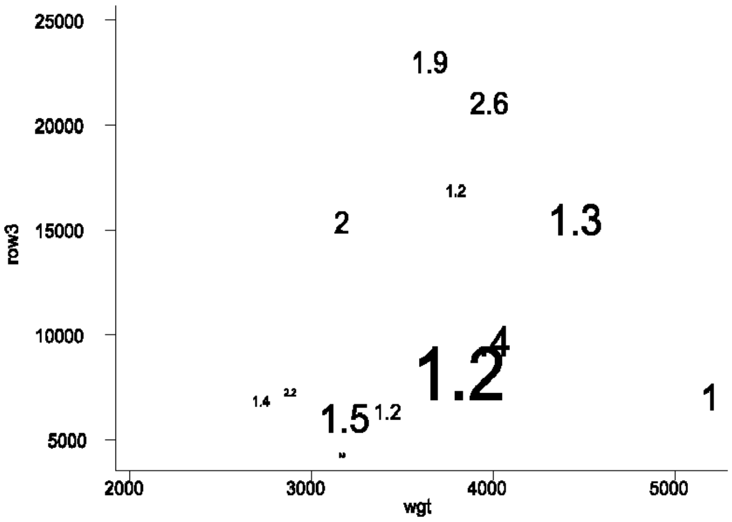

Figure 4.1.2.2-10 Relative (to car-car collisions) car driver fatality risk in car-SUV collisions versus SUV weight and impulse on row 3 of sensors. The numbers representing the points are the relative risks, their sizes are proportional to the statistical weights of the relative risks.

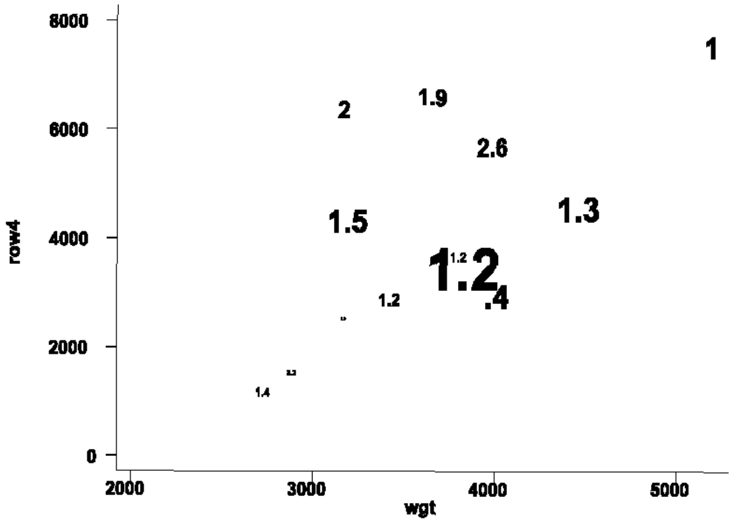

Figure 4.1.2.2-11 Relative (to car-car collisions) car driver fatality risk in car-SUV collisions versus SUV weight and impulse on row 4 of sensors. The numbers representing the points are the relative risks, their sizes are proportional to the statistical weights of the relative risks.

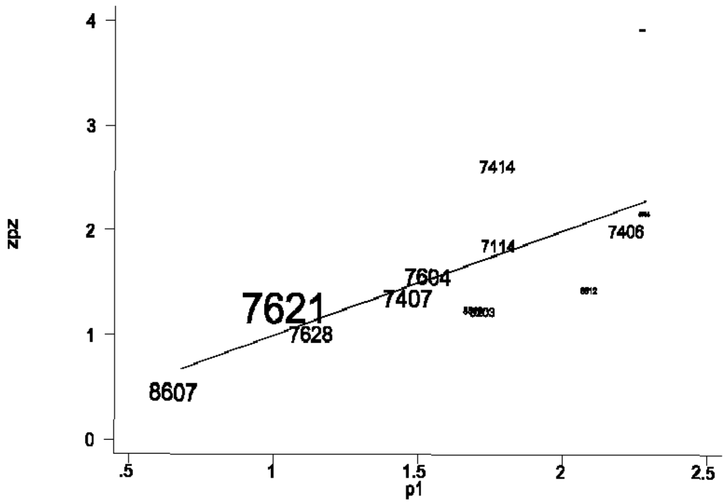

Figure 4.1.2.2-12 Actual versus modelled (model 1 in Table 4.1.2.2-4) relative (to car-car collisions) car driver fatality risk in car-SUV collisions. The numbers representing the points are the SUV group codes. The sizes of the numbers are proportional to the statistical weights of the relative risks.

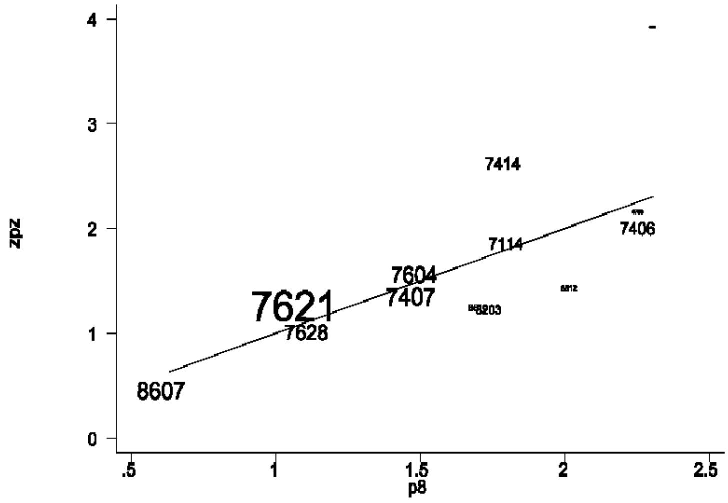

Figure 4.1.2.2-13 Actual versus modelled (model 7 in Table 4.1.2.2-5) relative (to car-car collisions) car driver fatality risk in car-SUV collisions. The numbers representing the points are the SUV group codes. The sizes of the numbers are proportional to the statistical weights of the relative risks.

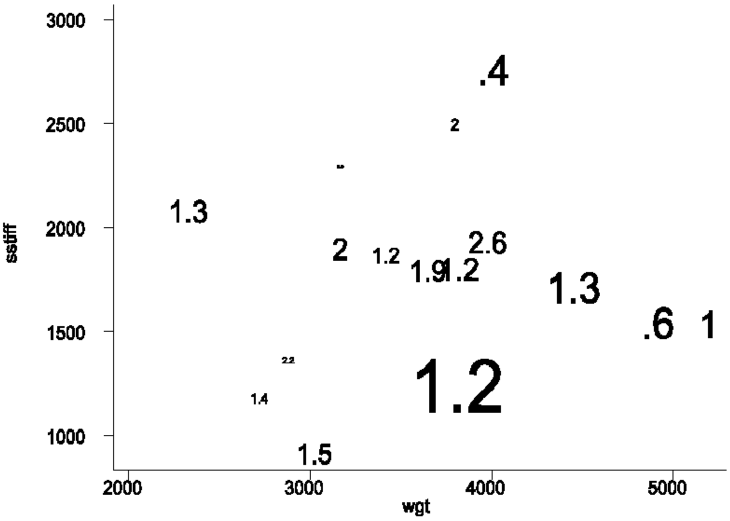

Figure 4.1.2.2-14 Relative (to car-car collisions) car driver fatality risk in car-SUV collisions versus SUV weight and static stiffness. The numbers representing the points are the relative risks, their sizes are proportional to the statistical weights of the relative risks.

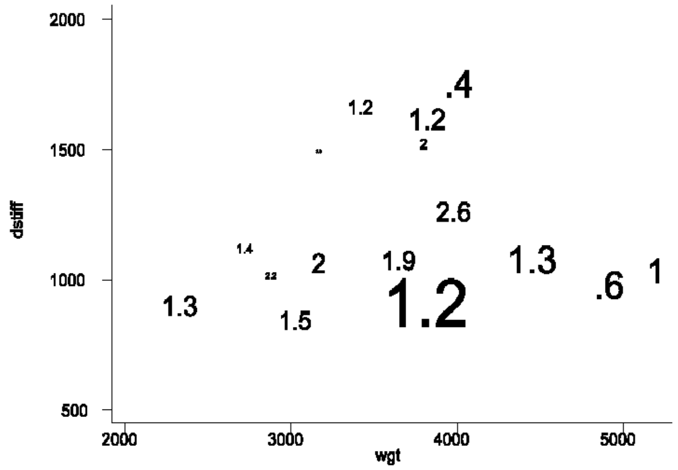

Figure 4.1.2.2-15 Relative (to car-car collisions) car driver fatality risk in car-SUV collisions versus SUV weight and dynamic stiffness. The numbers representing the points are the relative risks, their sizes are proportional to the statistical weights of the relative risks.

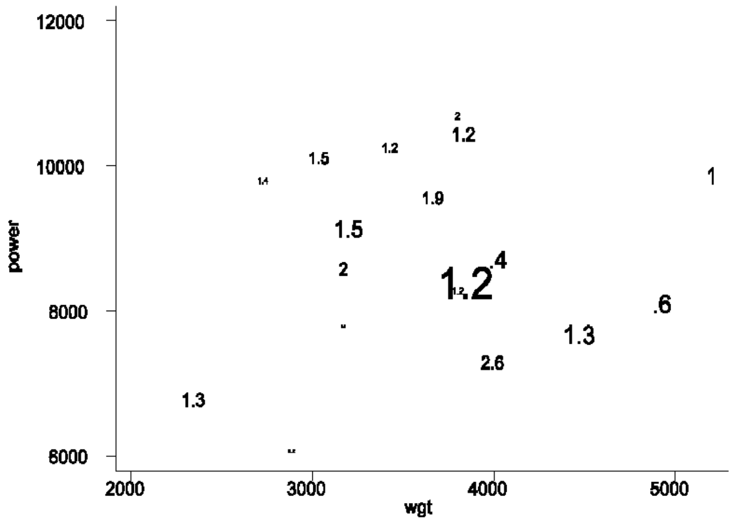

Figure 4.1.2.2-16 Relative (to car-car collisions) car driver fatality risk in car-SUV collisions versus SUV weight and peak power. The numbers representing the points are the relative risks, their sizes are proportional to the statistical weights of the relative risks.

4.1.2.3 Absolute Risks

In this section we describe how the car driver fatality risk (per 1,000 involvements) in collisions with a SUV relates to characteristics of the SUV. Figures 4.1.2.3-1 through 10 show the risks versus these characteristics. In addition to the circles, representing the SUV groups, regression lines through the circles are shown to make trends more easily recognizable. For the relationship with SUV weight, a broken line with a “kink” at 3,500 lb is shown, and the data strongly suggests a non-linear relationship which changes rapidly between about 3,200 and 3,700 lb.

“Significant” by conventional standards are the relationships with weight (Figure 4.1.2.3-1), with AHOF (Figure 4.1.2.3-2), with the height of the center of gravity (CGFG) (Figure 4.1.2.3-3), with the impulses on row 1 of the sensors (Figure 4.1.2.3-4) with a counterintuitive negative sign, and the impulse on row 4 (Figure 4.1.2.3-7). The impulse on row 3 (Figure 4.1.2.3-3) and the peak power (Figure 4.1.2.3-10) show positive though not “significant” relationships, whereas the impulse on row 2 (Figure 4.1.2.3-5) and the static stiffness (Figure 4.1.2.3-8) show negative, not “significant” relationships.

The strongest relationship is that with the height of the center of gravity (Figure 4.1.2.3-3 and Table 4.1.2.3-1). This does not mean that it has a better formal or a more likely physical relationship with the risk than AHOF, because the relations are based on different vehicle groups. CGFG is known for more vehicle groups, but their weights range only to a little beyond 4,000 lb, whereas the weight range for SUVs with known AHOF is much wider. Both were known for only 9 SUV groups.

Table 4.1.2.3-1 Regression coefficients for models of the car driver fatality risk in collisions with SUVs. CGFC is the height of the center of gravity from the ground (in cm). Non-standard errors are in parentheses.

	All SUVs		3,000<weight<3,500		3,500<weight	
variable	coefficient	non-standard error	coefficient	non-standard error	coefficient	non-standard error
CGFG	.15	(.04)	0.096	(.038)	.065	(.12)
constant	-8.00	(2.39)	-4.15	(2.53)	-1.82	(8.71)

The CGFG and the AHOF are both correlated with vehicle weight. Therefore, it could be that the apparent relationship between the risk and these characteristics are, in fact, an indirect effect of a relation with weight. This was more closely studied.

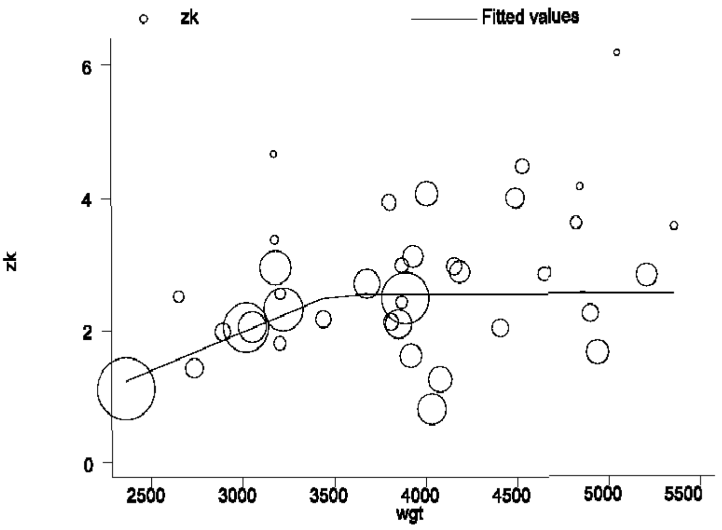

Figure 4.1.2.3-1 Car driver fatality risk in collisions with SUVs, versus weight (lb) of SUV. Each circle represents a SUV vehicle group. The sizes of the circles are proportional to the statistical precision of the risk estimates.

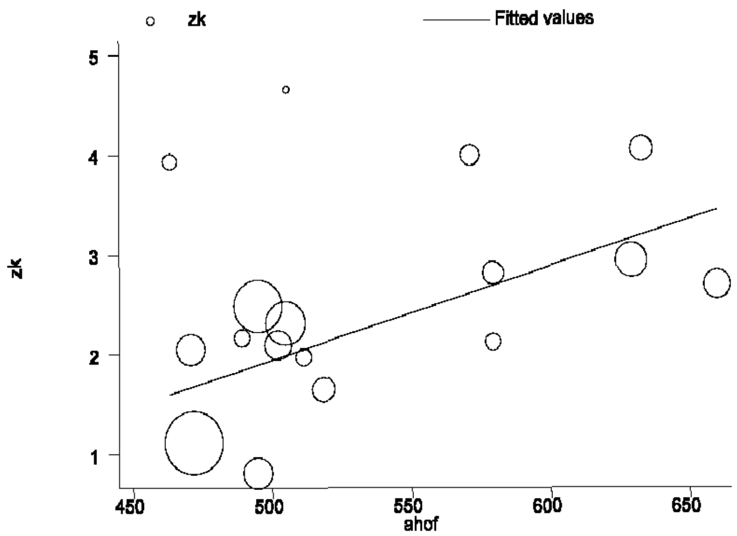

Figure 4.1.2.3-2 Car driver fatality risk in collisions with SUVs, versus average height of force (mm) of SUV. Each circle represents a SUV vehicle group. The sizes of the circles are proportional to the statistical precision of the risk estimates.

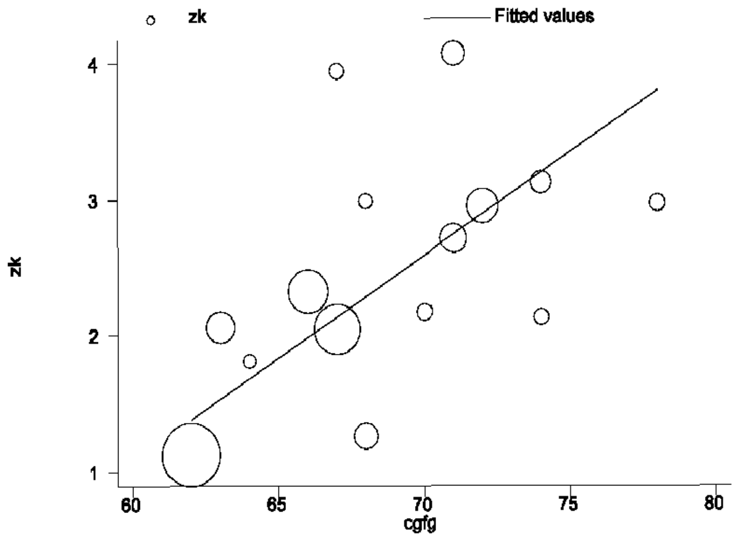

Figure 4.1.2.3-3 Car driver fatality risk in collisions with SUVs, versus height of the center of gravity from the ground (cm) of SUV. Each circle represents a SUV vehicle group. The sizes of the circles are proportional to the statistical precision of the risk estimates.

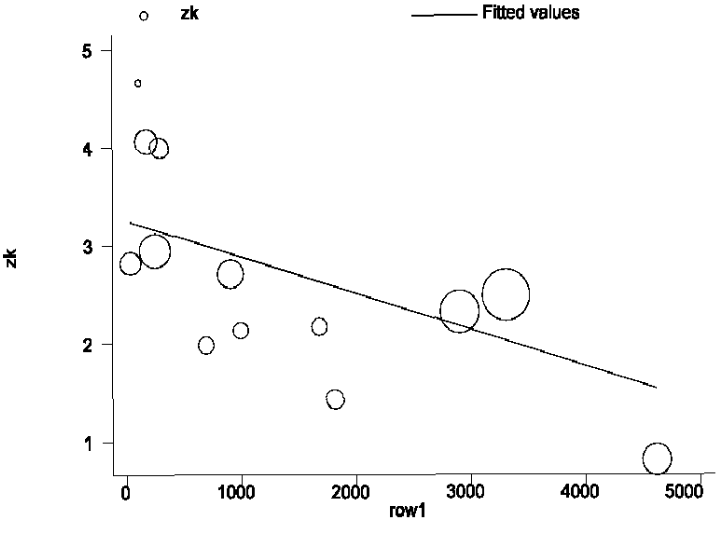

Figure 4.1.2.3-4 Car driver fatality risk in collisions with SUVs, versus impulse on row 1 of sensors (kN• s). Each circle represents a SUV vehicle group. The sizes of the circles are proportional to the statistical precision of the risk estimates.

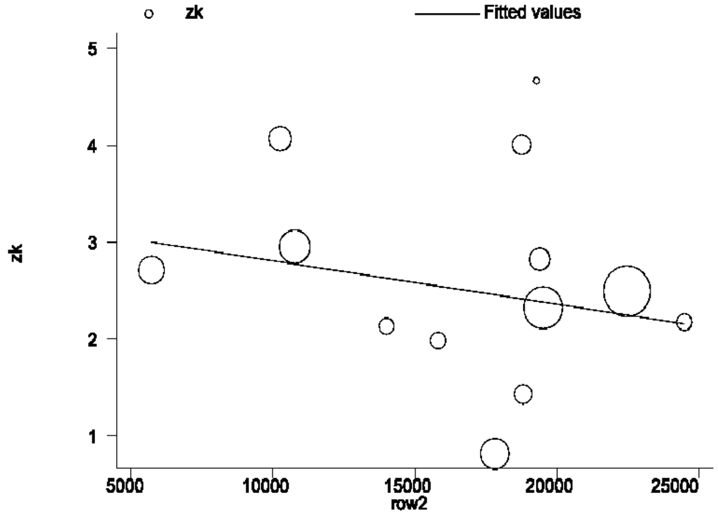

Figure 4.1.2.3-5 Car driver fatality risk in collisions with SUVs, versus impulse on row 2 of sensors (kN• s). Each circle represents a SUV vehicle group. The sizes of the circles are proportional to the statistical precision of the risk estimates.

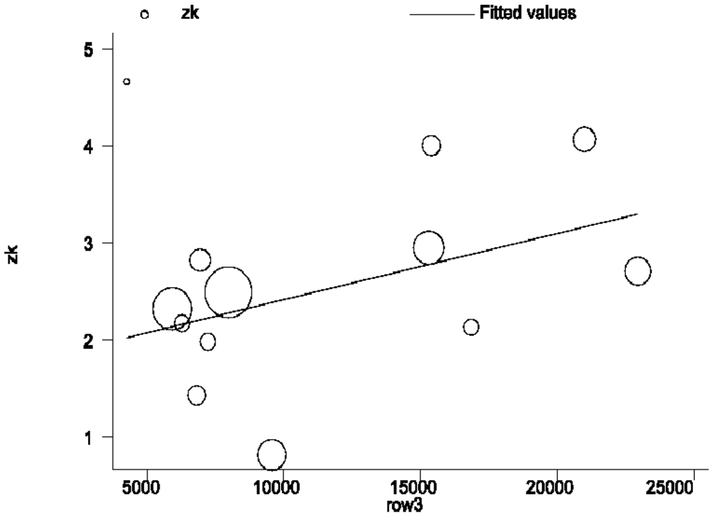

Figure 4.1.2.3-6 Car driver fatality risk in collision with SUVs, versus impulse on row 3 of sensors (kN• s). Each circle represents a SUV vehicle group. The sizes of the circles are proportional to the statistical precision of the risk estimates.

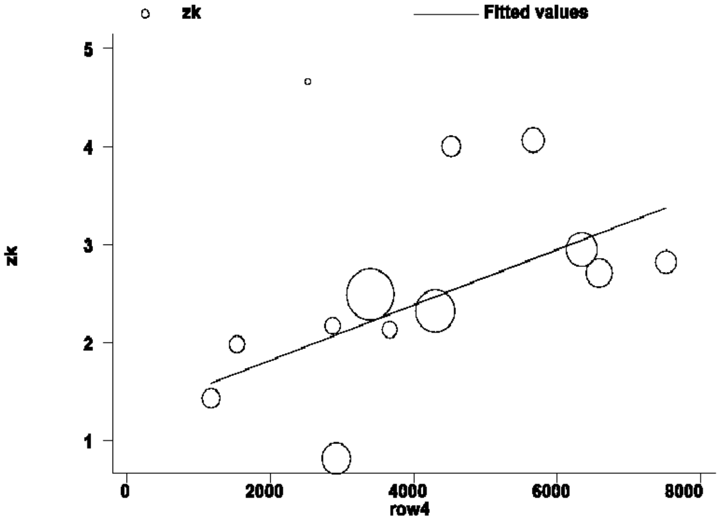

Figure 4.1.2.3-7 Car driver fatality risk in collision with SUVs, versus impulse on row 4 of sensor (kN• s). Each circle represents a SUV vehicle group. The sizes of the circles are proportional to the statistical precision of the risk estimates.

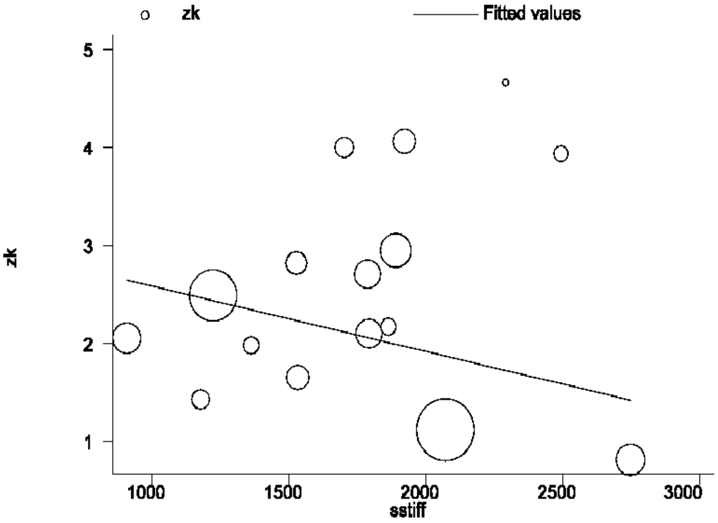

Figure 4.1.2.3-8 Car driver fatality risk in collisions with SUVs, versus static stiffness (kN/m) of SUV. Each circle represents a SUV vehicle group. The sizes of the circles are proportional to the statistical precision of the risk estimates.

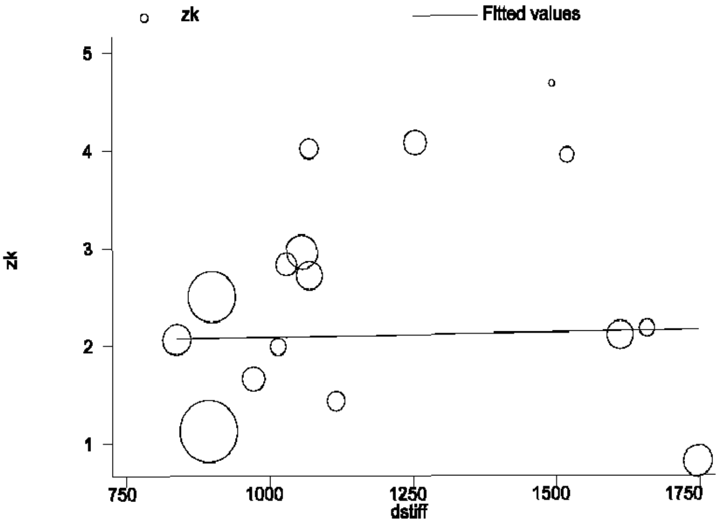

Figure 4.1.2.3-9 Car driver fatality risk in collisions with SUVs, versus dynamic stiffness (kN/m) of SUV. Each circle represents a SUV vehicle group. The sizes of the circles are proportional to the statistical precision of the risk estimates.

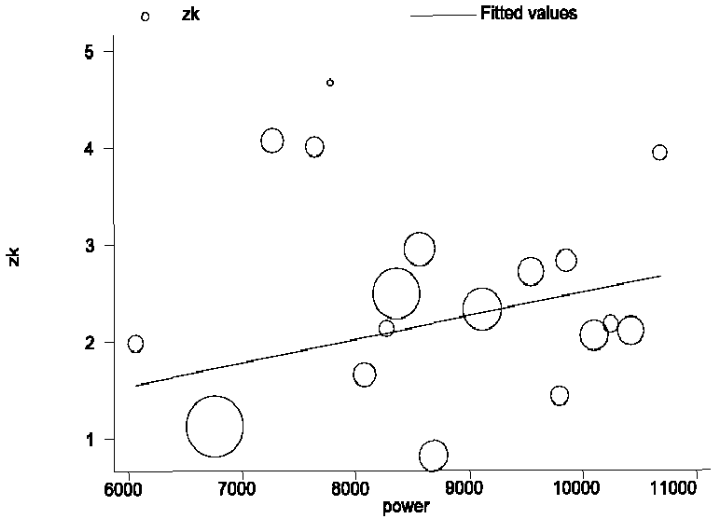

Figure 4.1.2.3-10 Car driver fatality risk in collisions with SUVs, versus peak power (kNm/s) of SUV. Each circle represents a SUV vehicle group. The sizes of the circles are proportional to the statistical precision of the risk estimates.

Figure 4.1.2.3-11 shows the CGFG versus weight with the fatality risk for the corresponding SUV group used as symbol for each point. The points fall within a narrow angle reflecting the close correlation between the two vehicle characteristics. The point with the lowest weight, the lowest CGFG, and the lowest risk of 1.1 is an outlier. Since this point has also the smallest error (greatest statistical weight), it will strongly influence all statistical analyses; in extreme cases, such a point can reverse the sign of a strong relationship which exists among the other points. Therefore, it was omitted for the following analyses.

The remaining points can be naturally divided into two groups, vehicles below 3,500 lb, and above 3,500 lb. Within each of these groups, a slight tendency for the risk to increase with increasing CGFG is apparent. To test this more formally, within each of these groups, the regression of risk versus CGFG was calculated. The results are shown in Table 4.1.2.3-1 and Figure 4.1.2.3-12.

Compared with the regression coefficient 0.15 of CGFG in the statistical model based on all usable vehicle groups, those for the two weight ranges are lower, though their difference is not, or only a little larger than the non-standard error. While the coefficient for the overall model is highly “significant” by conventional standards, that for the model for the lower weight range is barely “significant”, that for the higher weight range not at all. This is not surprising, since reducing the range of the independent variable normally increases standard errors and lowers the significance of coefficients.

It is interesting to illustrate the relation between CGFG and fatality risk. In the overall model, a 10 cm increase in CGFG increases the fatality risk by 1.5, which is 60% of the average fatality risk of about 2.5. The model for the lower weight range gives .96 which corresponds to 38%, and that for the higher weight range .65 which corresponds to 26%. The value of 60% can not be considered realistic, because one can not separate the effects from CGFG and from vehicle weight. The other two values, at least very crudely controlled for vehicle weight suggest a more realistic range of the order of 25-40%, to which the non-standard error has to be added.

Further insight can be gained from Figure 4.1.2.3-12. One notices that the slope of the regression line for the lower weight range is steeper than that of the line for the higher weights, which is also shown in Table 4.1.2.3-1. One also notices that in the CGFG range where the lighter and the heavier SUVs overlap, the risk difference is small, compared with the average weight difference of about 700 lb. This suggests that the “height” of a SUV is relatively more important than its weight, for the fatality risk of the car driver.

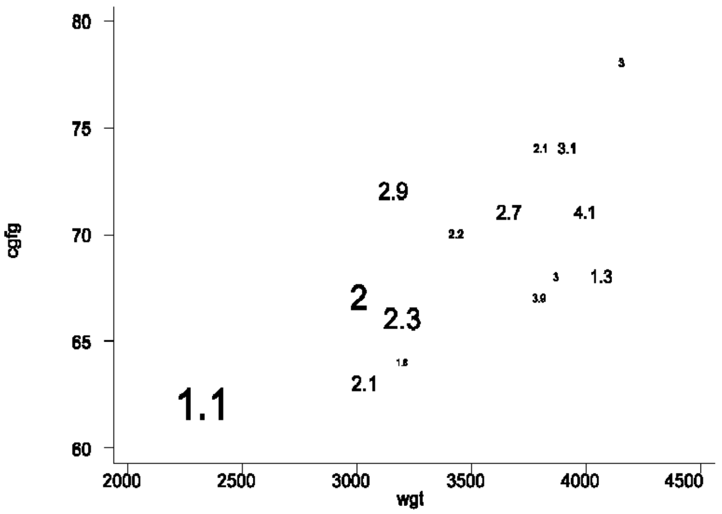

Figure 4.1.2.3-11 Height of the center of gravity from the ground versus SUV weight. The numbers representing the data points are the fatality risks for car drivers colliding with the SUVs. Their sizes are proportional to their statistical precision.

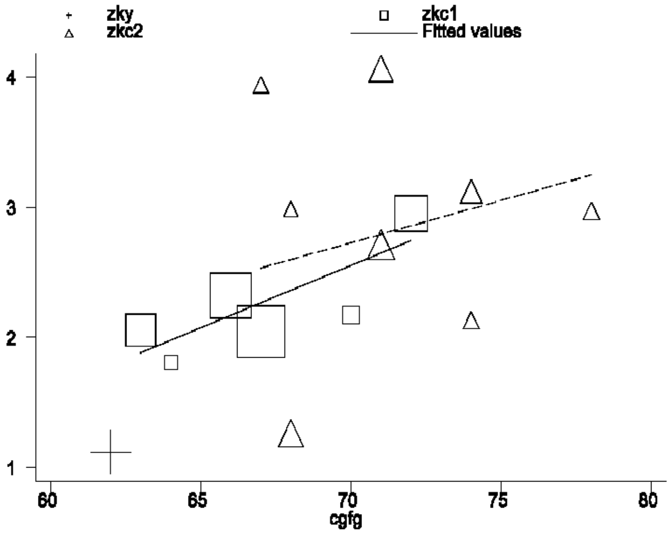

Figure 4.1.2.3-12 Car driver fatality risks in collisions with SUVs versus height of the center of gravity from the ground (CGFG, cm). The cross represents collisions with the 2 door Suzuki Sidekick, the squares collisions with SUVs in the weight range 3,000 to 3,500 lb, and the triangles collisions with SUVs heavier than 3,500 lb. The solid regression line is fitted to the points in the weight range 3,000-3,500 lb, the broken to the points in the higher weight range. The sizes of the symbols are proportional to the statistical precision of the risks.

One also notices that the two lines would intersect at a CGFG of about 75 cm, if the solid line were extended. Drawing a line from this intersection to the cross representing a SUV group of 2,400 lb encourages the speculation that the slope of the regression lines is a function of SUV weight. If one quantifies these arguments, one obtains for the Sidekick, represented by the cross, a fatality risk of 1.3 compared with the actual risk of 1.1. This fairly good agreement encourages a more formal analysis.

The hypothesized change of the slope of the CGFG regression line with SUV weight requires an interaction term. Therefore, a regression model using weight, CGFG, and their interaction was developed, using all SUVs with the necessary information. All coefficients of the resulting model were not “significant”; but were very highly correlated.

This is usually the case if the independent variables are highly correlated, as weight, CGFG, and their interaction are in our case. Such a model can still give a good representation of the data. We do not show the coefficients of the regression model, but rather the model derived from it which corresponds to our initial argument:

$$\text{risk} = (0.31 - 6.5 \cdot \text{weight}/100{,}000\ \text{lb}) \cdot (\text{CGFG} - 73) + 2.91$$

Figure 4.1.2.3-13 shows the actual risks versus those estimated by the model. The overall trend is well represented. At first glance, the scatter of the points for the higher risks appears large. However, a look at the bars representing a range of +/- one non-standard error of the data points show that only 3 out of 15 are farther away from the line representing equality. In the case of normally distributed errors, one can expect one third of the cases to be outside of the +/- one standard error range. Thus, the scatter of the points is by no means too large.

Another way to assess the fit of the model with the interaction of weight and CGFG, and an illustration of its mathematical structure is shown in Figure 4.1.2.3-14. The actual and the modelled risks are fairly close, but the relationship expressed by the model appears complicated. However, if one considers only the area of the graph which is covered by actual values, one notices that the lines of constant risk can be adequately replaced by straight lines of varying slopes. However, while the graphical appearance would be simplified, the relation between “z” and CGFG and weight could be more complicated, for instance.

$$z = (\text{CGFG} - q - s \cdot \text{weight})/(p + r \cdot \text{weight}),$$

where p, q, r, s are the model parameters.

The only conclusion one should draw from this analysis is that SUV weight has a weaker influence on the car driver fatality risk, than the effect of CGFG. However, this effect appears to depend on SUV weight; the lighter the SUV, the stronger is the effect of CGFG on car driver fatality risk.

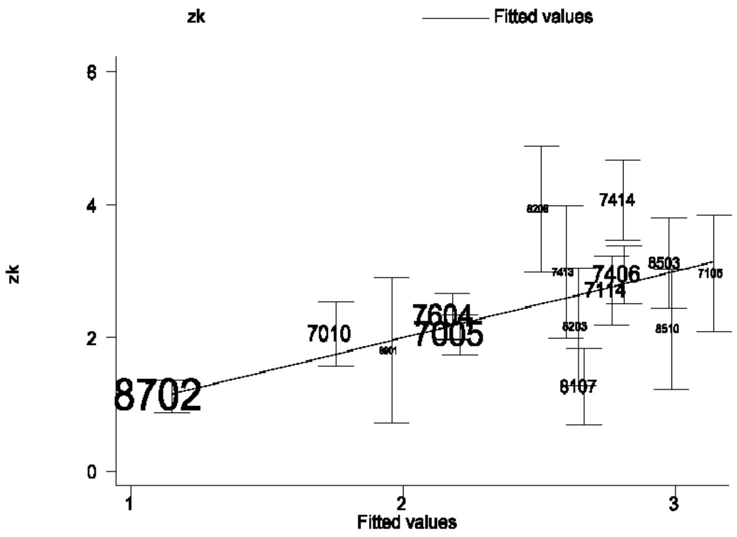

Figure 4.1.2.3-13 Actual car driver fatality risk in collisions with SUVs, versus modelled risk, using the model with SUV weight and CGFG interaction. Numbers are the Kahane codes for the SUV groups, their sizes are proportional to their statistical weights. Bars represents the +/- one non-standard error range.

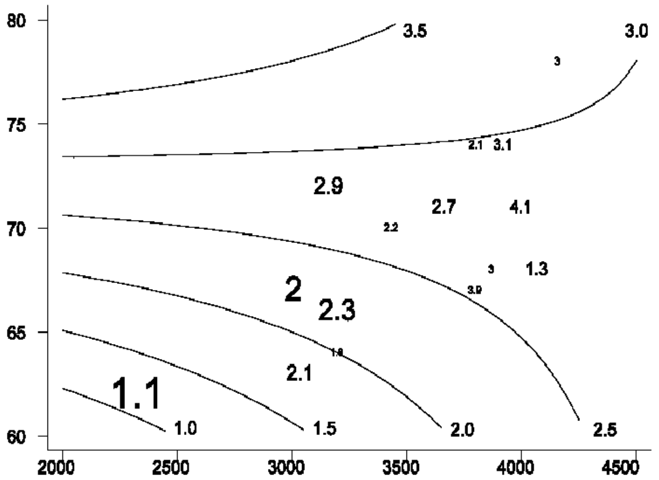

Figure 4.1.2.3-14 Car driver fatality risk as a function of SUV weight and CGFG. The numbers represent SUV vehicle groups, their value is the car driver fatality risk (per 1,000 involvements), their sizes are proportional to their statistical weights. The curves show constant values of the risk (from 1.5 through 3.5) as expressed by the model which includes an interaction of SUV weight and CGFG.

The second strongest relationship with the fatality risk has the average height of force in the barrier test. Since it is a quantity derived from an actual impact, one would expect it to be more relevant than the height of the center of mass. However, while the height of the center of mass can be quite precisely determined, the average height of the center of force is much less precise than one might expect, as it is calculated from the reading of sensors at only four different heights.

As the CGFG, the AHOF is also correlated with vehicle weight. Figure 4.1.2.3-15 shows AHOF versus weight. The correlation is less close than for CGFG, and without the leftmost point it would be weak. There seems to be a slight increase of the risk with weight, and a stronger increase with AHOF. To separate their effects, the data were separated into three groups: vehicles from 2,800 to 3,500 lbs; between 3,500 and 4,300 lbs; and above 4,300 lbs. The leftmost point for the 2 door Suzuki Sidekick was omitted. Within each weight range, the regression of the risk on AHOF was calculated. The result is shown in Table 4.1.2.3-2, and Figure 4.1.2.3-16. They show that the regression lines for the weight range 2,800 to 3,500 lb, and between 3,500 and 4,300 lb practically coincide; their coefficients agree within their non-standard errors. Thus, in the middle weight ranges, there is an effect of AHOF, but none of vehicle weight. However, the regression covering SUVs of all weights has a coefficient about 50% higher. This indicates that the lightest and heaviest SUVs create an overall weight effect. The regression line for the heaviest vehicle has a much steeper slope, but it has a large non-standard error. Changing the boundaries of the three weight ranges changes the picture quantitatively, but not qualitatively. There seemed to be no reasonably simple model which combined effects of weight and AHOF.

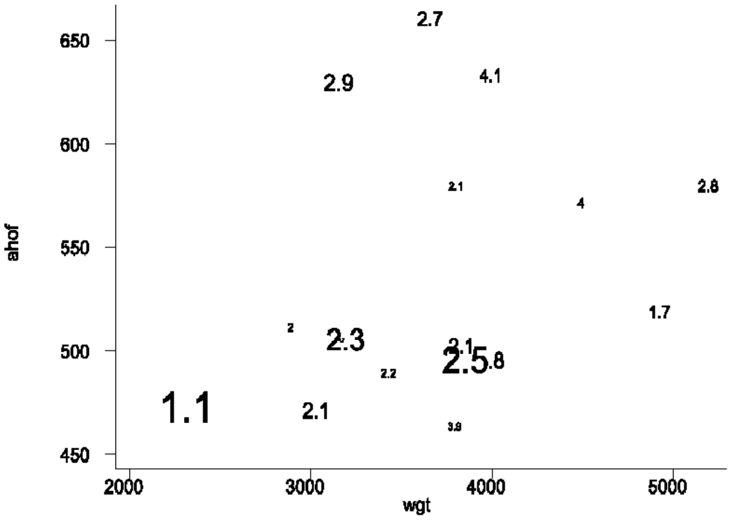

Figure 4.1.2.3-15 Average height of the center of force versus SUV weight. The numbers representing the data points are the fatality risks for car driver colliding with SUVs. Their sizes are proportional to their statistical weights.

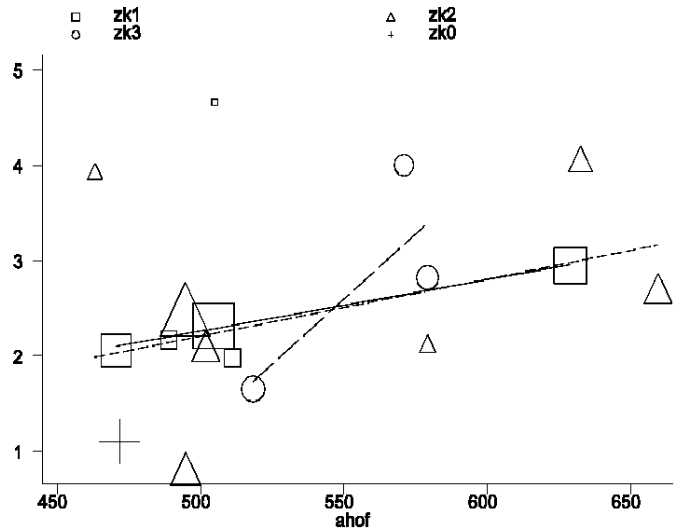

Figure 4.1.2.3-16 Car driver fatality risk in collision with SUVs. The cross represents collisions with the 2 door Suzuki Sidekick; the squares collisions with SUVs in the 2,800 to 3,500 lb weight range; the triangle with those in the 3,500 - 4,300 weight ranges; and the circles with those over 4,200 lb. The solid regression line is fitted to the squares; the dotted to the triangles; and the broken one to the circles. The sizes of the symbols are proportional to the statistical weights of the risks.

Table 4.1.2.3-2 Regression coefficients for models of the car driver fatality risk in collisions with SUVs. AHOF is the average height of the center of force in crash tests (in cm). Non-standard error are in parentheses.

	All SUVs		2800<weight<3500		3500<weight<4300		4300<weight	
variable	coefficient	non-standard error	coefficient	non-standard error	coefficient	non-standard error	coefficient	non-standard error
AHOF (cm)	0.094	(.029)	0.054	(0.021)	.060	(.054)	.27	(.19)
constant	-2.76	(1.53)	-.44	(1.09)	-.79	(2.91)	-12.4	(10.8)

In the weight range of 2,800 - 4,300 lb the coefficients of 0.054 and 0.060 mean that a 10 cm difference in AHOF corresponds to differences of 0.54 and 0.60 in risk. With an average risk of about 2.5, this amounts to 22% and 24%. For the CGFG, we found that a 10 cm difference corresponds to a 25% to 40% difference in risk. Considering that the vehicle populations from which these statistics are obtained do overlap only partially, and that the two measures measure different, though somewhat related, physical vehicle characteristic, the agreement is surprising. The overall coefficient of 0.094 corresponds to a risk increase of .94 for a 10 cm increase in AHOF which is 38% of the average risk of about 2.5. This corresponds to the result for CGFG in the 3,000 to 3,500 lb weight range. The coefficient for the highest weights in 0.27. A 10 cm increase in AHOF would correspond to an increase of 2.7 which would more than double the average risk. However, the coefficient of 0.27 has a very large non-standard error.

The AHOF is calculated from the forces measured on four rows of sensors located at different heights at the crash barrier. These measurements are summarized by the impulses imparted to these rows during the crash by row 1, row 2, row 3, and row 4. Not only do these four variables provide more detailed information on the vertical distribution of the force, but also on its total. To separate these two effects, we also experimented with variables.

rowall = row1 + row2 + row3 + row4,

and

row1/rowall, row2/rowall, row3/rowall, and row4/rowall.

These analyses gave no better models that those with row 1, row 2, row 3, and row 4 and were not further pursued.

Table 4.1.2.3-3, and Figures 4.1.2.3-17 and 18 show a model which contains row 1, row 2, row 3, and row 4, and a constant term. Figure 4.1.2.3-19 shows that the data are well represented, possibly even over-fitted, since there is only one SUV group (7628) which deviates from the modelled value by more than one non-standard error, and five others are near to it.

It is surprising that row 1 has a very “significant” negative value. This does not necessarily mean that increasing the force acting on the lowest row will decrease the car driver’s fatality risk. It may just mean that, given the current vehicle design pattern, a high force in the lowest row measures a more uniform distribution of force over the entire front, thereby reducing the car driver’s fatality risk.

The coefficients of row 2 and row 3 agree within one non-standard error. They are also very closely negatively correlated. The first means that shifting forces between the second and third rows of sensors has practically no effect on the car driver’s fatality risk. The second means that under current SUV design patterns the main difference among SUVs is a shift in force between the second and third rows, with much less variation of the combined force in these rows.

Table 4.1.2.3-3 Coefficients of a model for the car driver's fatality risk in collisions with a SUV. Impulses are in MN• s.

variable	coefficient	non-standard error
row 1	-.35	(.13)
row 2	.16	(.06)
row 3	.12	(.06)
row 4	.16	(.13)
constant	-1.46	(1.80)

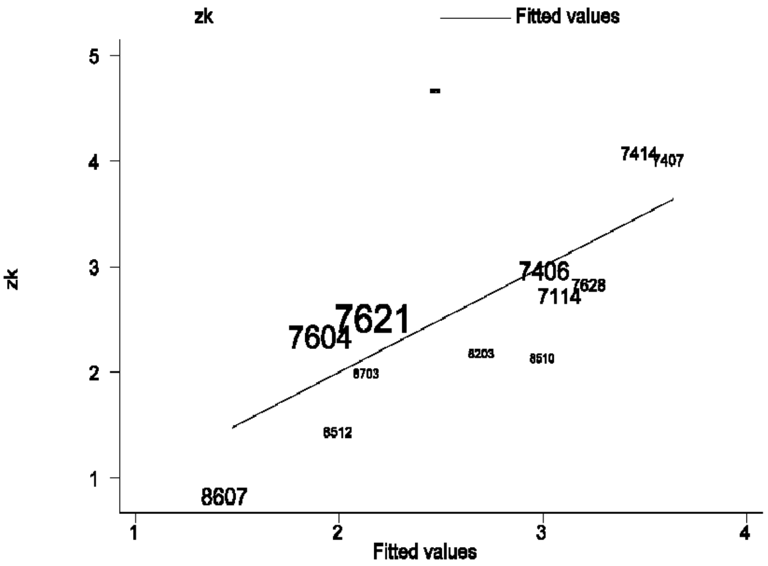

Figure 4.1.2.3-17 Actual car driver fatality risk versus that resulting from the model in Table 4.1.2.3-3. The numbers show the Kahane codes for the SUV groups, their sizes are proportional to the statistical weights of the risks. The line represents equality of actual and modelled risks.

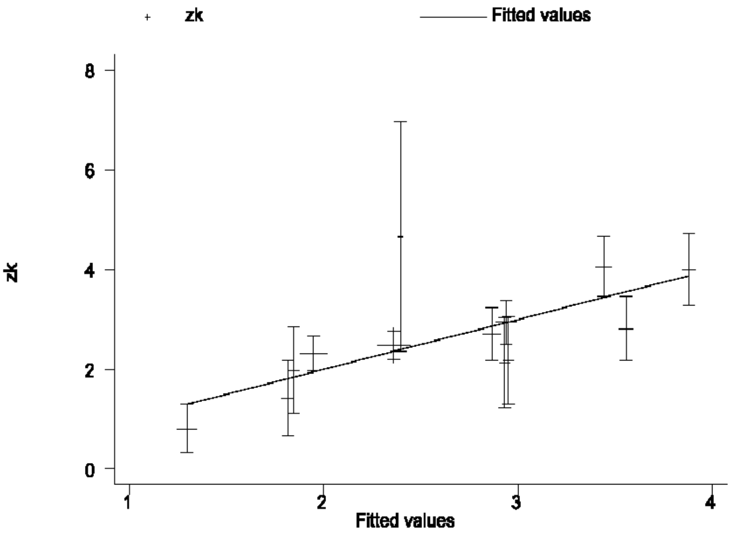

Figure 4.1.2.3-18 Actual car driver fatality risk versus that resulting from the model in Table 4.1.2.3-3. The vertical bars shows the +/- one non-standard error ranges for the actual risks. The straight line represents equal actual and modelled risks.

Therefore we replaced the two variables row 1 and row 2 by their sum row23. The resulting model was practically indistinguishable from that of Table 4.1.2.3-3. Further experimenting suggested to combine the three rows into row234 = row3 + row3 + row4, and drop the constant term. The resulting model is shown in Table 4.1.2.3-4, and Figures 4.1.2.3-20, 21, and 22. Figure 4.1.2.3-21 shows that the fit of this model is practically as good as that of the model using the impulses on the four rows of sensors separately. In practical terms this suggests that the critical difference is that between row 1 and row 2; how the impulse is distributed over rows2 and3 and4 does not seem to make any difference. The coefficient of 0.1 for (row2 + row3 + row4) means that a difference of 1MegaNewton• second between two current SUVs corresponds to a difference of 0.1 in the driver's fatality risk; with an average risk of about 2.5 this is 4%. One could be inclined to interpret this as a casual relationship.

Table 4.1.2.3-4 Coefficient of a model for the car driver's fatality risk in collisions with a SUV. Impulses are in MN m.

variable	coefficient	non-standard error
row1	-.31	(.08)
row2 + row3 + row4	.10	(.01)

On the other hand, a difference of 1 MegaNewton• second in row 1 corresponds to a difference of 0.38 between the fatality risks, which is 12%, in the counter-intuitive direction that the greater force reduces the risk. One should not interpret this causally to mean that simply increasing the force in row 1, but keeping everything else as large could result in a risk reduction.

Figure 4.1.2.3-21 shows the model of Table 4.1.2.3-4 by lines of constant risk in the coordinate row 1, and row234. Also shown are the actual risks. The size of the numbers representing the actual risks is proportional to their statistical weight.

Models containing more variables were also explored. None were noticeably better in representing the risks, or added “significant” terms and had a plausible structure. An example of an implausible model is the following. Neither adding to the last model static stiffness (even less if using dynamic stiffness) alone or maximum power alone resulted in a significant coefficient, or a noticeable improvement of the fit. If both were added, however, the two coefficients together are very significant (p=.015), and the fit of the model dramatically improved, as shown in Figure 4.1.2.3-23. However, both coefficients were negative, which appears physically implausible. Therefore, the coefficients of the model are not shown.

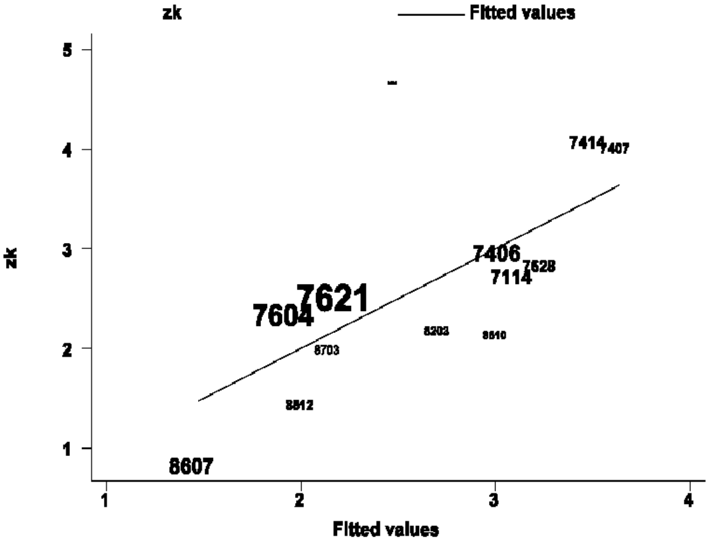

Figure 4.1.2.3-19 Actual car driver fatality risk versus that resulting from the model in Table 4.1.2.3-4. The numbers show the Kahane codes for the SUV groups, their sizes are proportional to the statistical weights of the risks. The line represents equality of actual and modelled risks.

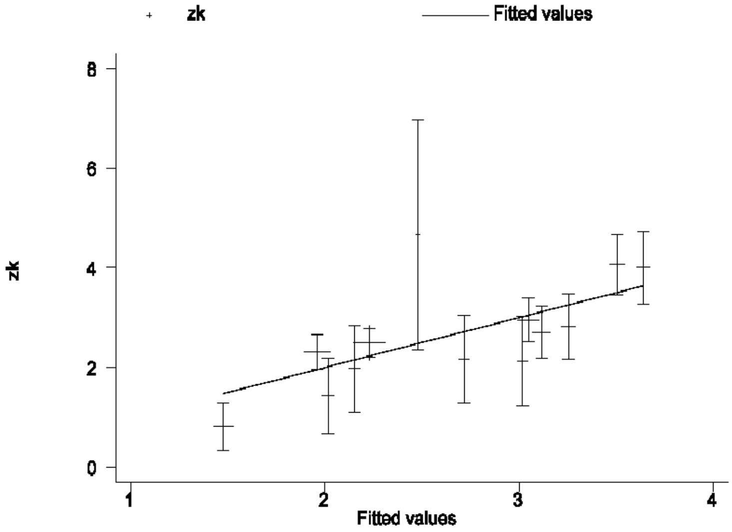

Figure 4.1.2.3-20 Actual car driver fatality risk versus that resulting from the model in Table 4.1.2.3-4. The vertical bars shows the +/- one non-standard error ranges for the actual risks. The straight line represents equality of actual and modelled risks.

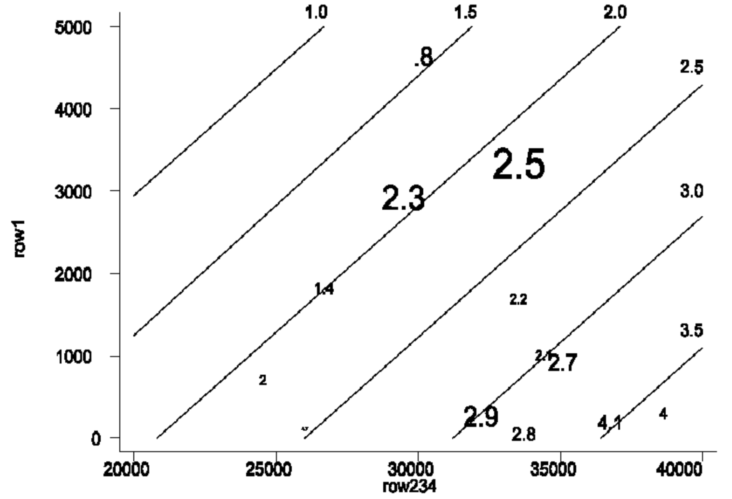

Figure 4.1.2.3-21 Representation of the actual and modelled (by the model of Table 4.1.2.3-4) car driver fatality risks as function of row2 + row3 + row4, and row 1. The numbers show the actual risks, their sizes are proportional to their statistical weights. The lines represent constant values of the modelled risk, from 1.0 to 3.5.

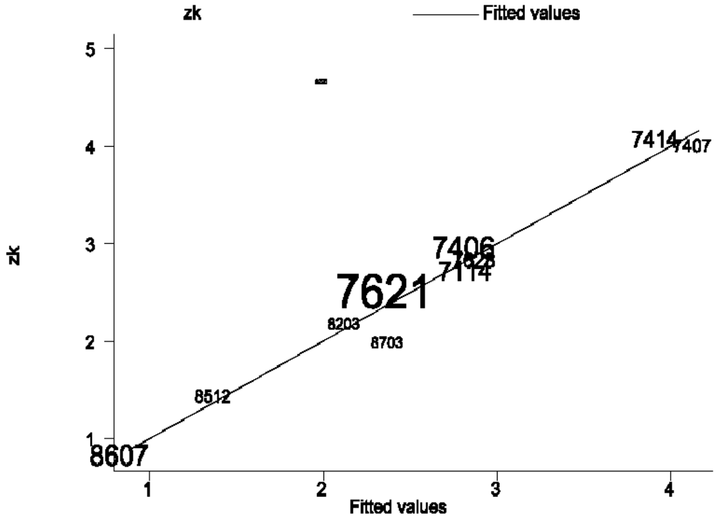

Figure 4.1.2.3-22 Actual car driver fatality risk in collisions with SUVs versus modelled risks. The model contained the impulse on row 1, the combined impulses on rows 2, 3, and 4, and the static stiffness and peak power. The last two variables had negative coefficients. The figure shows that a physically implausible model can fit the data very well. The numbers representing data points are the Kahane codes for the SUV groups, their sizes are proportional to the statistical weights of the risks.

<u>4.1.3 Left Side of Car Impacted by Front of SUV</u>

For these analyses, collisions were used with SUV impact code “12" in FARS; “1" in GES; and car impact codes “9" or “3", respectively. The number of SUV groups with sufficient numbers of crashes was much lower than in the case of “all” collisions; this limited the possible scope of the analyses, and the reliability of any result dramatically.

After thorough inspection of Figures 4.1.3-1 through 18, and several preliminary analyses, it was concluded that AHOF seemed to be the only vehicle characteristic which possibly had some relation to the risk. Though one would expect CGFG to have similar relations, because of the close correlation between weight and CGFG, it was not possible to separate their effect.

To separate the effects of AHOF and weight, we proceeded as follows. First, we noticed that one SUV group with very low vehicle weight, and two with very high vehicle weights (Figures 4.1.3-1 and 2) had very strong influences on the result of regression analyses. Therefore, we restricted the analyses to the weight range of 3,000 to 4,100 lb, where AHOF and weight are only weakly correlated. We divided the SUV groups once by weight – under and over 3,500 lb – and once by AHOF – under and above 55 cm. The vehicles in the lighter group have an average AHOF of about 50, those in the heavier group of about 60 cm.

To account for the variation of weight within these groups, within each group we regressed the absolute risk on weight. Figure 4.1.3-19 shows the regression lines. The risk difference between these two lines reflects a possible effect of the 10 cm difference in AHOF. The difference of the slopes of the lines, however, is not at all significant. Therefore, also a regression was run where the two slopes were forced to be equal. The result is shown in Figure 4.1.3-20. The slope of the lines in relation to weight is practically equal to zero, indicating that in this range weight seems to have no effect on the risk. Table 4.1.3-1 shows the numerical values of the off-sets of the two lines.

In the other approach to the question, the risk was regressed on AHOF for SUV groups under 3,500 lb, and for those over 3,500 lb. Figures 4.1.3-21 and 22 show the results. Here, the lines are close to each other, indicating that the weight difference between the two groups has only a very small effect on the risk.

Table 4.1.3-2 shows the regression coefficients of AHOF in the three models. Note that only the coefficient for the low weight range is significant; the others are not even approaching it. The regression coefficient of 0.18 correspond to a risk difference of 1.8 for a difference of 10 cm in AHOF. This agrees well within the wide error limits with the 2.5 obtained from the offset in the joint model. This is not too surprising, since both are based on the same data.

The same was done for the relative risks. The results are shown in Figure 4.1.3-23 through 26, and Tables 4.1.3-3 and 4. Though the pattern is consistent, the apparent effect of AHOF on the relative risk is only about one sixth of its effect on the absolute risk. This suggests that there are confounding factors which we have not identified and for which we could not control. All differences and regression coefficients are far from significant. In sum, we have found suggestions of an effect of AHOF on the car driver fatality risk in cars impacted on the left side by SUVs, but its magnitude is very uncertain.

Table 4.1.3-1 Modelled car driver fatality risks for SUV weights of 3,500 lb and risk differences. For details see the text. Non-standard errors are in parentheses.

	risk per 1,000 involvements	
AHOF<55cm (average 50 cm)	6.9	(1.2)
AHOF>55cm (average 60 cm)	10.4	(1.8)
difference	3.5	(1.6)
offset in joint model	2.5	(2.0)

Table 4.1.3-2 Regression coefficients of AHOF (cm) for the car driver fatality risk, by weight range of the SUV. For details see the text. Non-standard errors are in parentheses.

	regression coefficient	
SUV weight<3,500 lb	0.28	(.02)
SUV weight>3,500 lb	0.15	(.21)
joint model	0.18	(.14)

Table 4.1.3-3 Modelled relative car driver fatality risk for SUV weights of 3,500 lb and risk differences. For details see the text. Non-standard errors are in parentheses.

	relative risk	
AHOF<55cm (average 50cm)	2.3	(.10)
AHOF>55cm (average 60cm)	2.7	(.40)
difference		(.45)
offset in joint model		

Table 4.1.3-4 Regression coefficient of AHOF (cm) for the relative car driver fatality risk by weight range of the SUV. For details, see the text. Non-standard errors are in parentheses.

	regression coefficient	
SUV weight <3,500 lb	.042	(.057)
SUV weight >3,500 lb	.021	(.033)
joint model	.026	(.022)

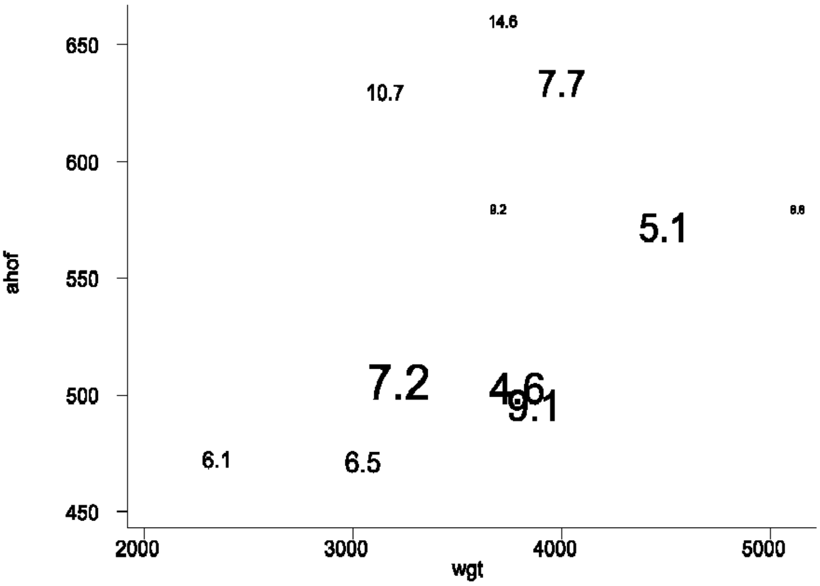

Figure 4.1.3-1 Car Driver fatality risk (per 1,000 involvements) in collisions with SUVs versus AHOF (mm) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the risks, their size is proportional to their statistical weights.

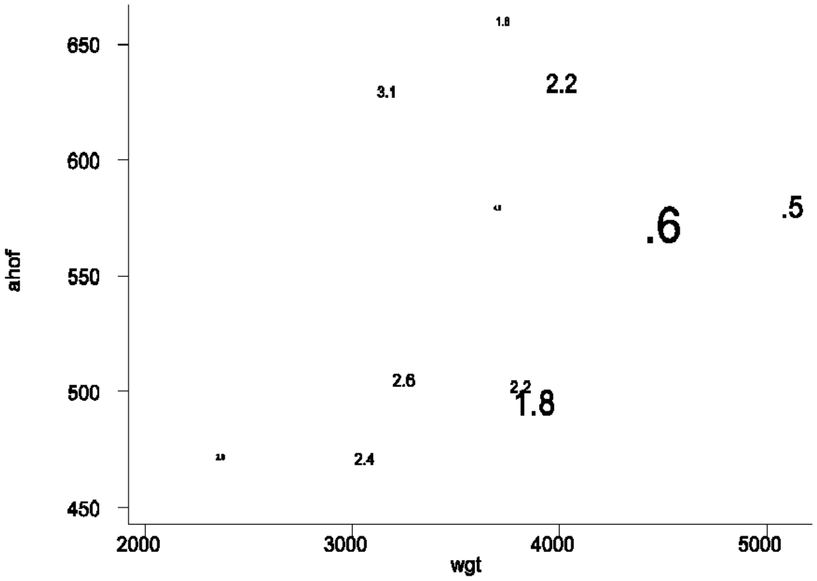

Figure 4.1.3-2 Relative (to collisions with comparable cars) car driver fatality risk in collisions with SUVs versus AHOF (mm) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the relative risks, their size is proportional to their statistical weights.

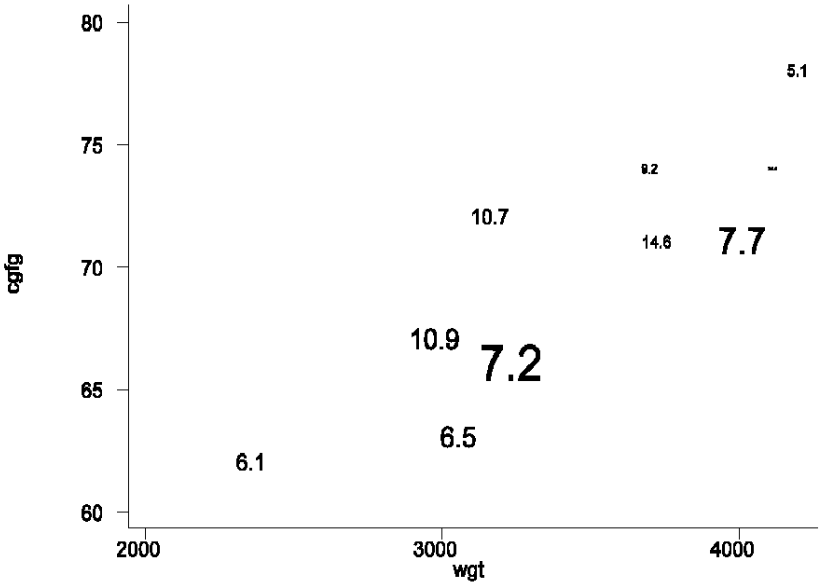

Figure 4.1.3-3 Car Driver fatality risk (per 1,000 involvements) in collisions with SUVs versus CGFG (cm) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the risks, their size is proportional to their statistical weights.

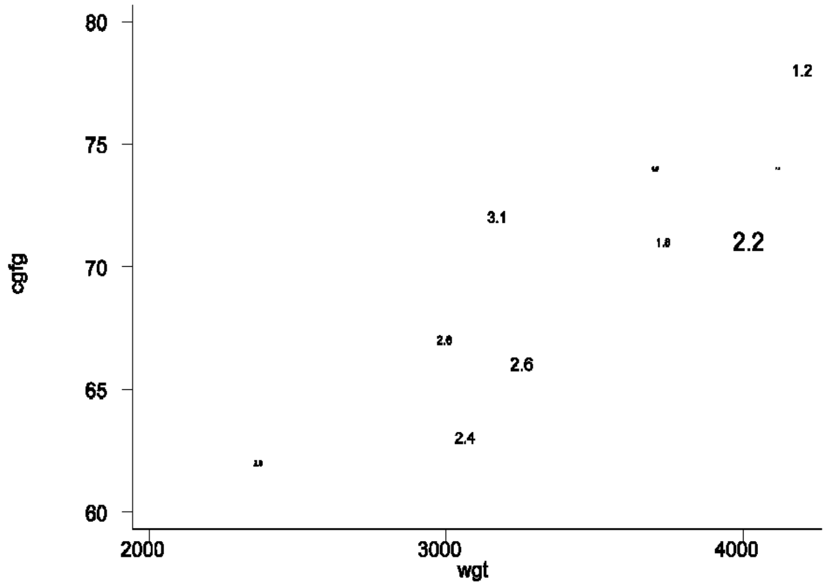

Figure 4.1.3-4 Relative (to collisions with comparable cars) car driver fatality risk in collisions with SUVs versus CGFG (cm) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the relative risks, their size is proportional to their statistical weights.

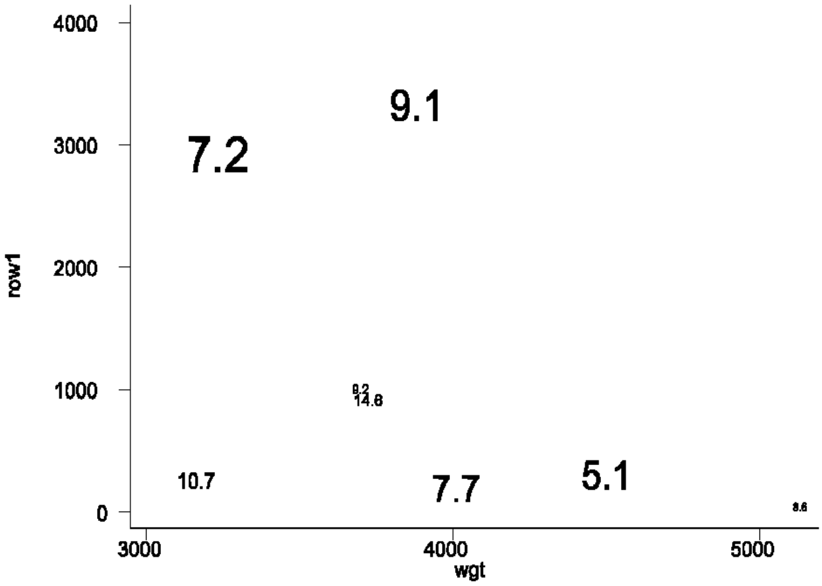

Figure 4.1.3-5 Car Driver fatality risk (per 1,000 involvements) in collisions with SUVs versus impulse on row 1 of crash sensors (kN• s) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the risks, their size is proportional to their statistical weights.

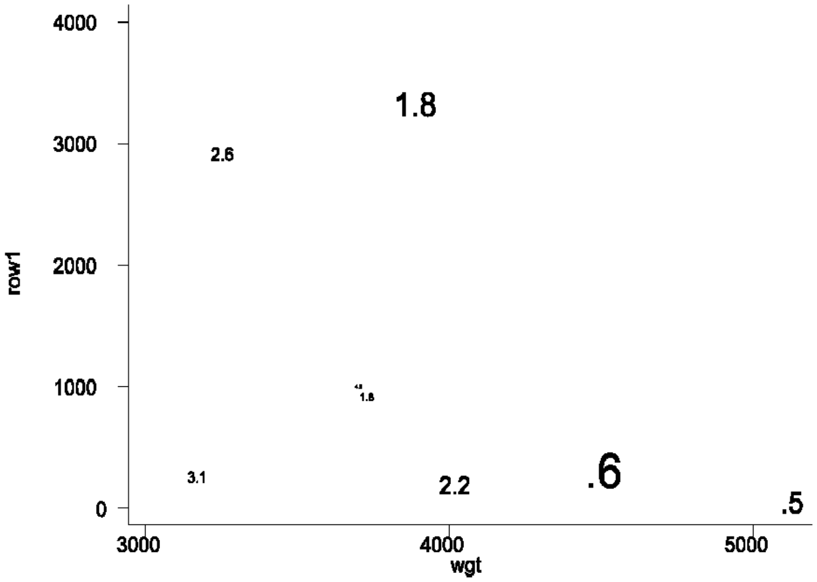

Figure 4.1.3-6 Relative (to collisions with comparable cars) car driver fatality risk in collisions with SUVs versus impulse on row 1 of crash sensor (kN• s) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the relative risks, their size is proportional to their statistical weights.

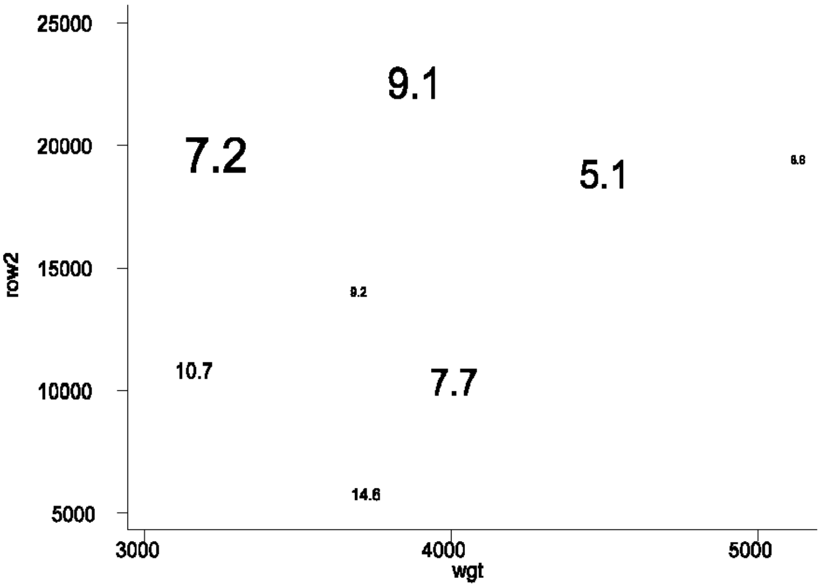

Figure 4.1.3-7 Car Driver fatality risk (per 1,000 involvements) in collisions with SUVs versus impulse on row 2 of crash sensors (kN• s) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the risks, their size is proportional to their statistical weights.

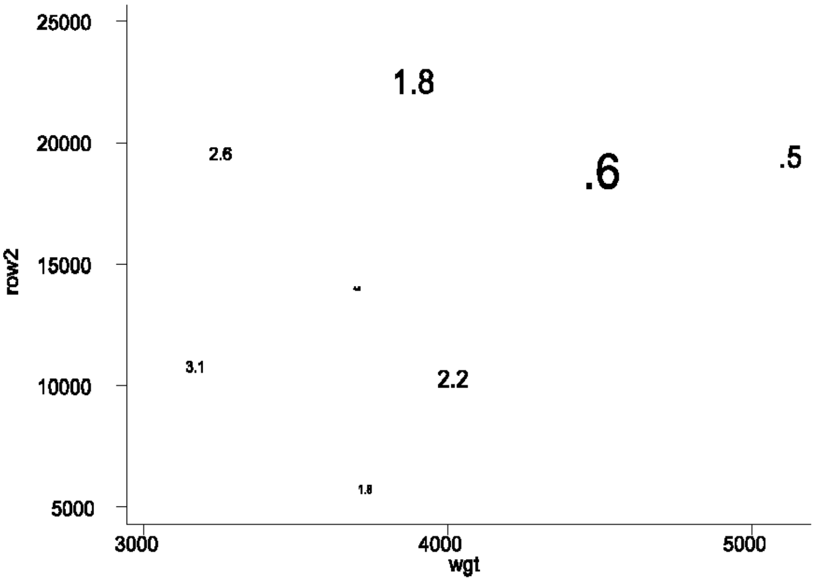

Figure 4.1.3-8 Relative (to collisions with comparable cars) car driver fatality risk in collisions with SUVs versus impulse on row 2 of crash sensor (kN• s) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the relative risks, their size is proportional to their statistical weights.

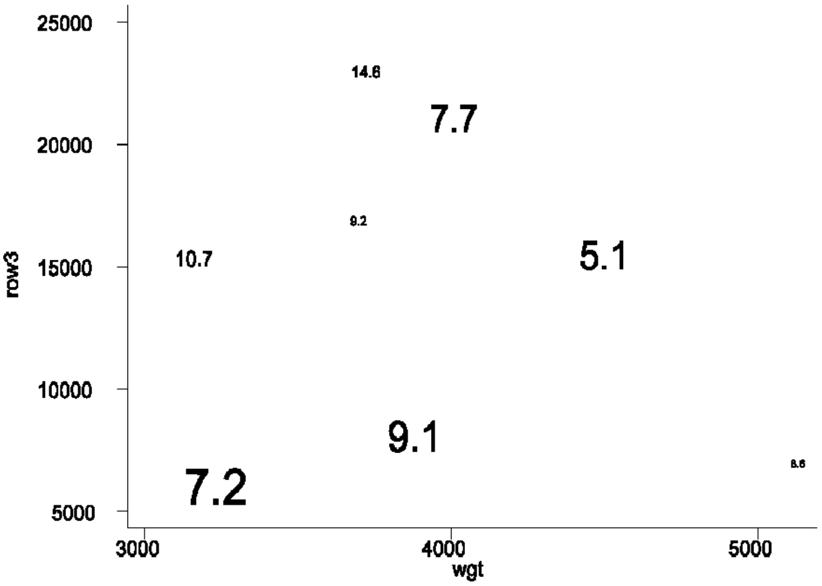

Figure 4.1.3-9 Car Driver fatality risk (per 1,000 involvements) in collisions with SUVs versus impulse on row 3 of crash sensors (kN• s) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the risks, their size is proportional to their statistical weights.

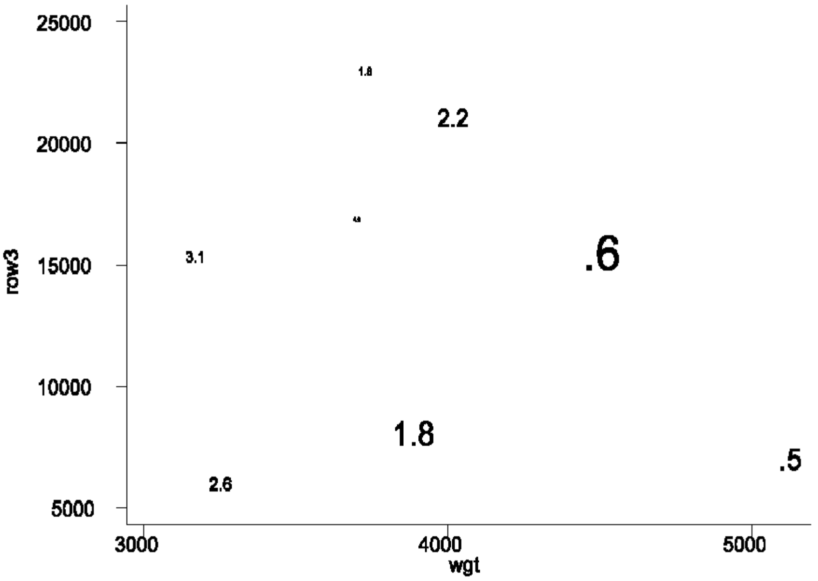

Figure 4.1.3-10 Relative (to collisions with comparable cars) car driver fatality risk in collisions with SUVs versus impulse on row 3 of crash sensor (kN• s) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the relative risks, their size is proportional to their statistical weights.

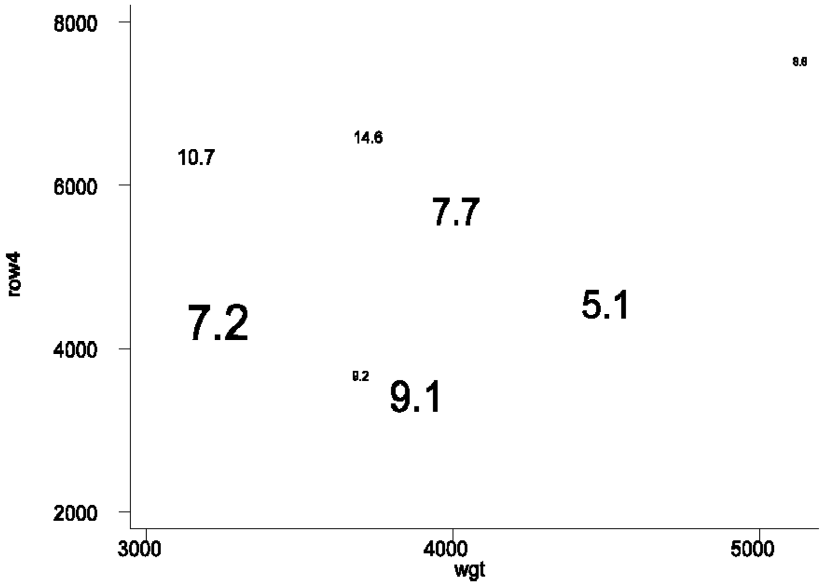

Figure 4.1.3-11 Car Driver fatality risk (per 1,000 involvements) in collisions with SUVs versus impulse on row 4 of crash sensors (kN• s) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the risks, their size is proportional to their statistical weights.

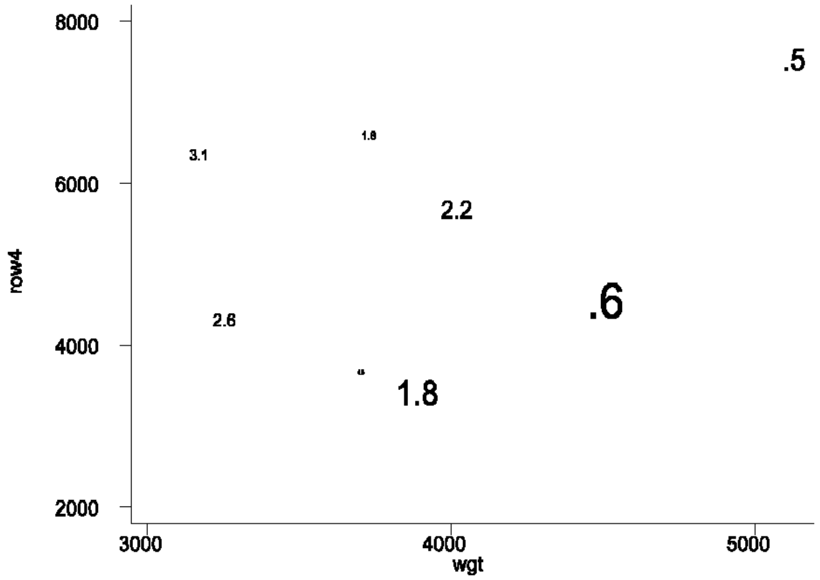

Figure 4.1.3-12 Relative (to collisions with comparable cars) car driver fatality risk in collisions with SUVs versus impulse on row 4 of crash sensor (kN• s) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the relative risks, their size is proportional to their statistical weights.

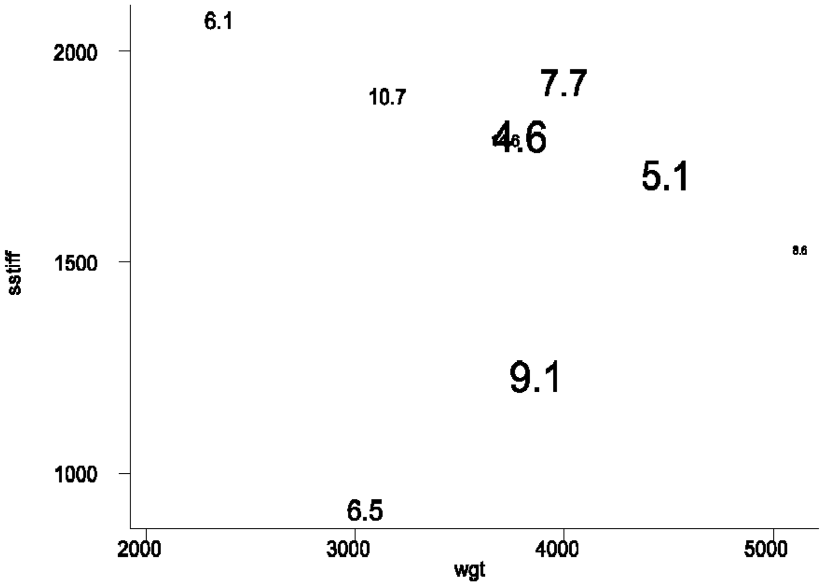

Figure 4.1.3-13 Car Driver fatality risk (per 1,000 involvements) in collisions with SUVs versus static stiffness (kN/m) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the risks, their size is proportional to their statistical weights.

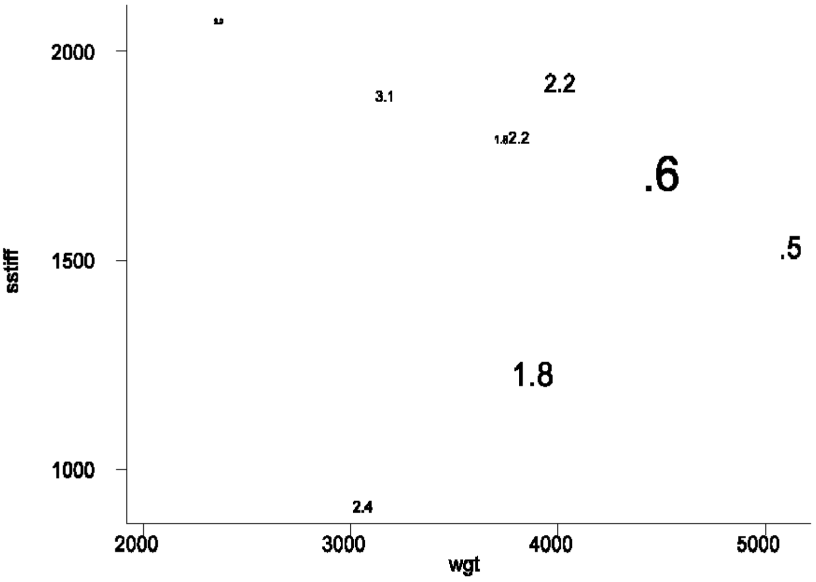

Figure 4.1.3-14 Relative (to collisions with comparable cars) car driver fatality risk in collisions with SUVs versus static stiffness (kN/m) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the relative risks, their size is proportional to their statistical weights.

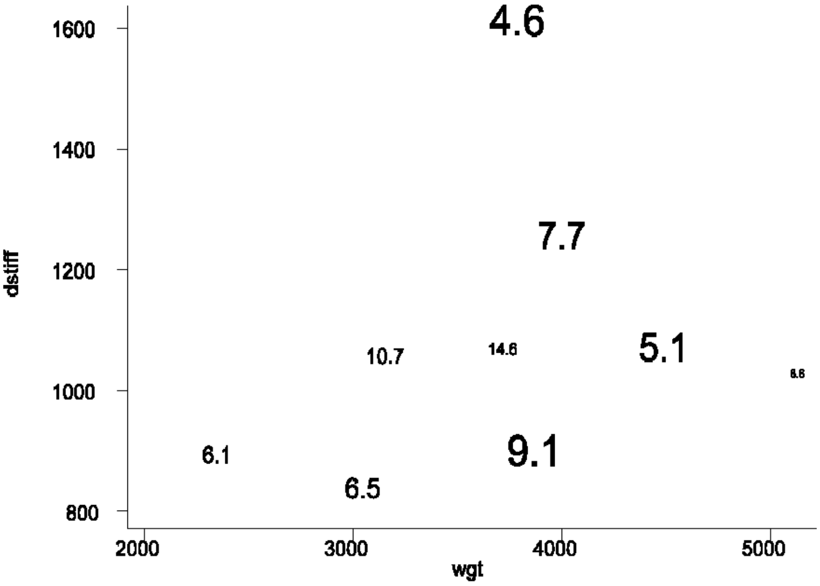

Figure 4.1.3-15 Car Driver fatality risk (per 1,000 involvements) in collisions with SUVs versus dynamic stiffness (kN/m) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the risks, their size is proportional to their statistical weights.

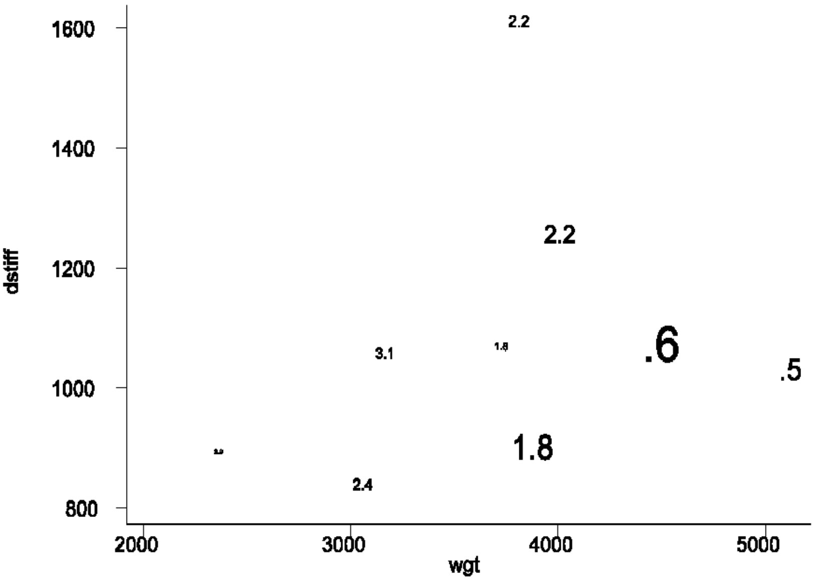

Figure 4.1.3-16 Relative (to collisions with comparable cars) car driver fatality risk in collisions with SUVs versus dynamic stiffness (kN/m) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the relative risks, their size is proportional to their statistical weights.

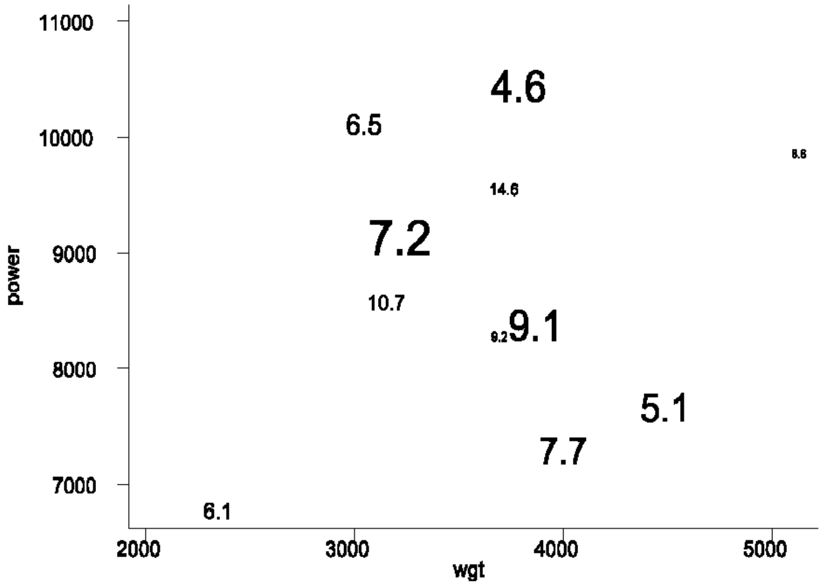

Figure 4.1.3-17 Car Driver fatality risk (per 1,000 involvements) in collisions with SUVs versus peak power (kN• m/s) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the risks, their size is proportional to their statistical weights.

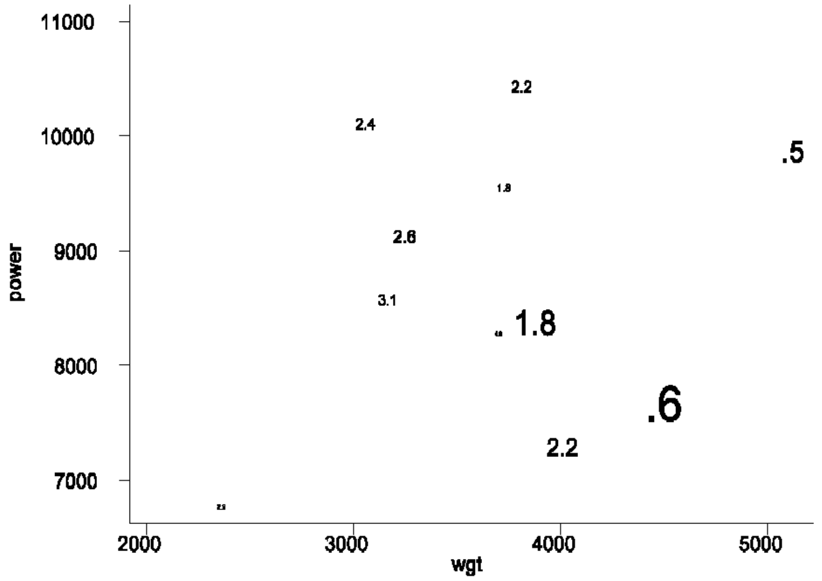

Figure 4.1.3-18 Relative (to collisions with comparable cars) car driver fatality risk in collisions with SUVs versus peak power (kN• m/s) and weight of SUV. Front of SUV striking left side of car. The numbers representing the points show the relative risks, their size is proportional to their statistical weights.

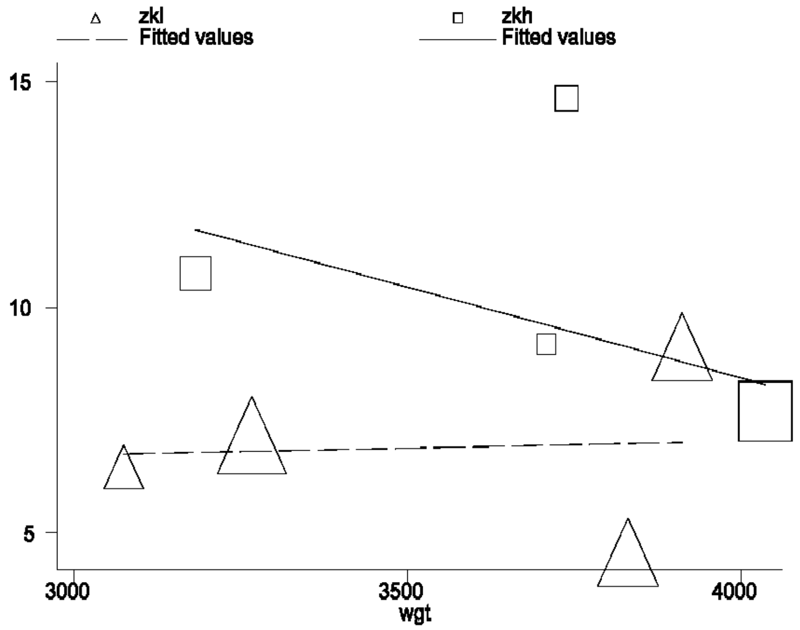

Figure 4.1.3-19 Car driver fatality risk in per 1,000 involvements in collisions with a SUV versus weight of SUV. Car impacted on the left side by the SUV. Triangles represent the actual risks for SUVs between 3,000 and 4,100 lb with AHOF <55 cm. The broken line is a linear fit to these points. Squares represent the actual risks for SUVs between 3,000 and 4,100 lb with AHOF >55 cm. The solid line is a linear fit to these points. The sizes of the triangles and squares are proportional to their statistical weights.

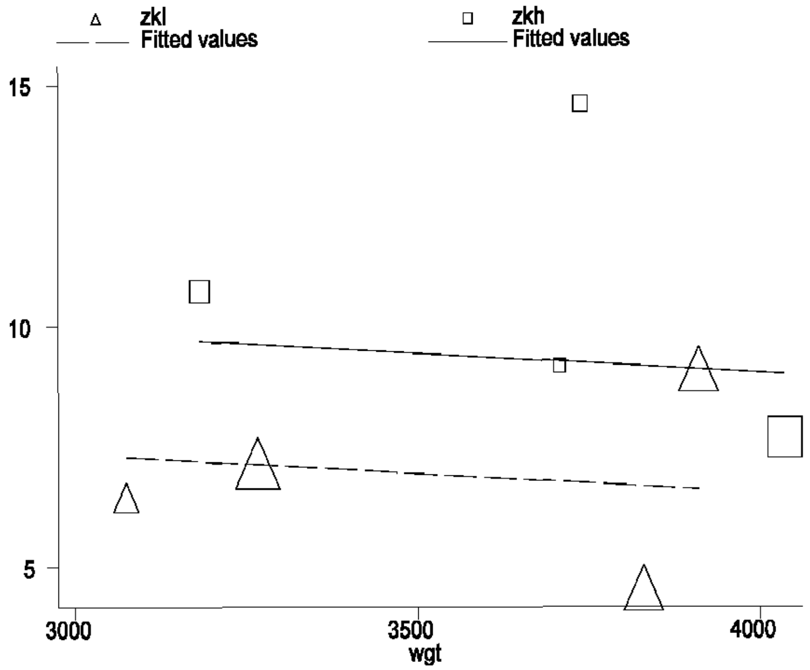

Figure 4.1.3-20 Car driver fatality risk in per 1,000 involvements in collisions with a SUV versus weight of SUV. Car impacted on the left side by the SUV. Triangles represent the actual risks for SUVs between 3,000 and 4,100 lb with AHOF <55 cm. Squares represent the actual risks for SUVs between 3,000 and 4,100 lb with AHOF >55 cm. The lines represent a linear fit to the data, with one slope for all points, but allowing an offset between the SUVs with higher, and those with lower AHOF. The sizes of the triangles and squares are proportional to their statistical weights.

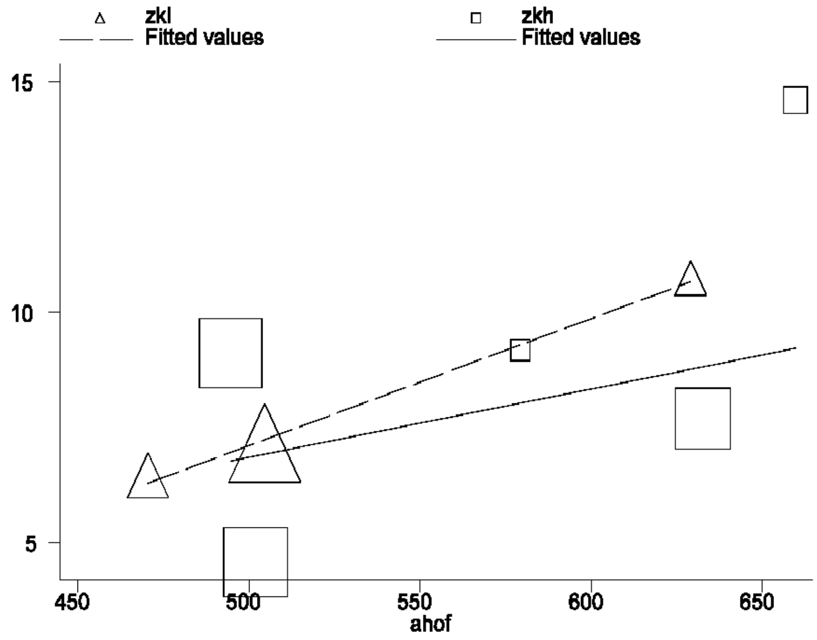

Figure 4.1.3-21 Car driver fatality risk in per 1,000 involvements in collisions with a SUV versus AHOF of SUV. Triangles represent the actual risks for SUVs between 3,000 and 3,500 lb, squares those for SUVs between 3,500 and 4,100 lb. The broken line is a linear fit to the triangles, the solid line to the squares. The sizes of the triangles and squares are proportional to their statistical weights.

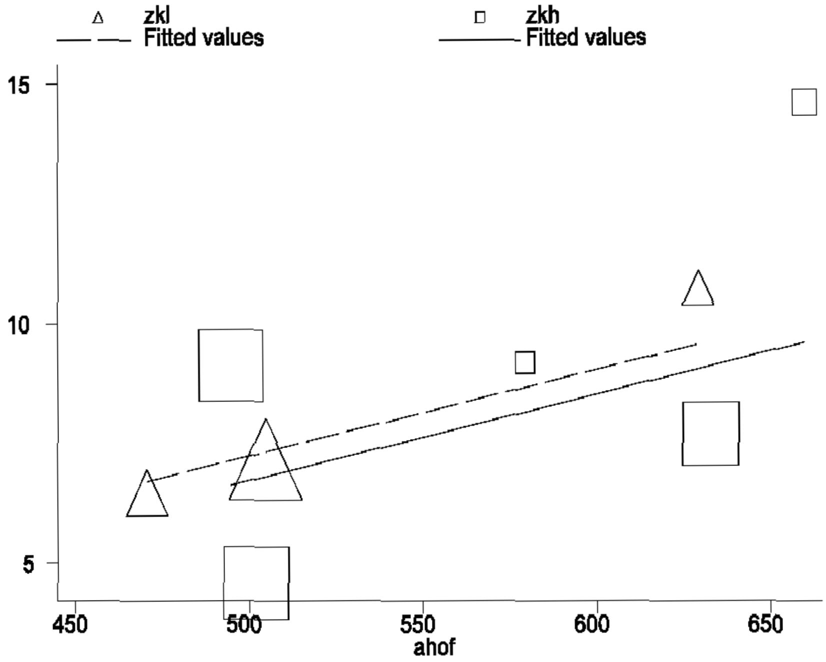

Figure 4.1.3-22 **Car driver fatality risk in per 1,000 involvements in collisions with a SUV versus AHOF of SUV. Triangles represent the actual risks for SUVs between 3,000 and 3,500 lb, squares those for SUVs between 3,500 and 4,100 lb. The lines represent a linear fit with one slope for all points, but allowing an offset between the SUVs with lower, and those with higher weights. The sizes of the triangles and squares are proportional to their statistical weights.**

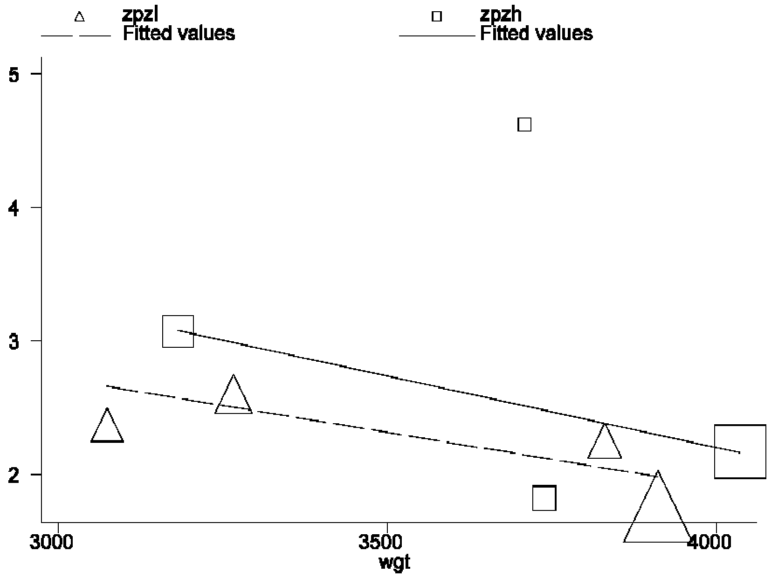

Figure 4.1.3-23 Relative (to car-car collisions) car driver fatality risk in collisions with a SUV versus weight of SUV. Car impacted on the left side by the SUV. Triangles represent the actual risks for SUVs between 3,000 and 4,100 lb with AHOF <55 cm. The broken line is a linear fit to these points. Squares represent the actual risks for SUVs between 3,000 and 4,100 lb with AHOF >55 cm. The solid line is a linear fit to these points. The sizes of the triangles and squares are proportional to their statistical weights.

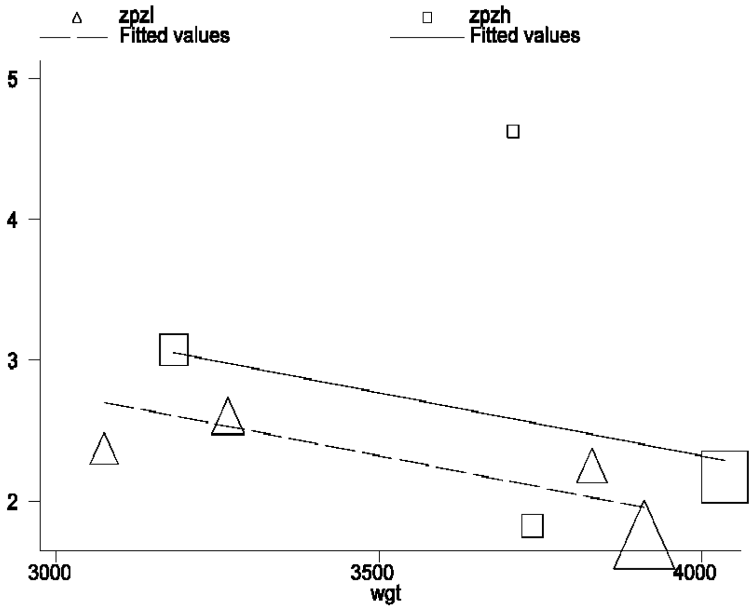

Figure 4.1.3-24 **Relative (to car-car collisions) car driver fatality risk in collisions with a SUV versus weight of SUV. Car impacted on the left side by the SUV. Triangles represent the actual risks for SUVs between 3,000 and 4,100 lb with AHOF <55 cm. Squares represent the actual risks for SUVs between 3,000 and 4,100 lb with AHOF >55 cm. The lines represent a linear fit to the data, with one slope for all points, but allowing an offset between the SUVs with higher, and those with lower AHOF. The sizes of the triangles and squares are proportional to their statistical weights.**

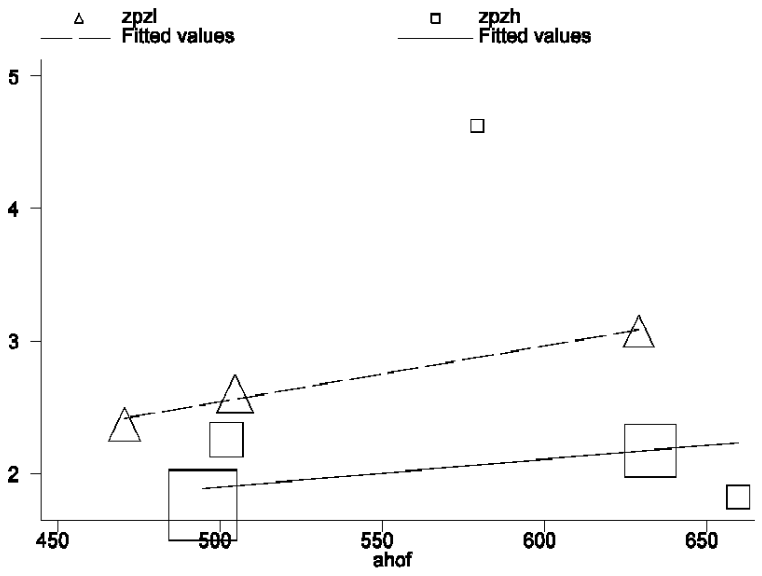

Figure 4.1.3-25 Relative (to car-car collisions) car driver fatality risk in collisions with a SUV versus AHOF of SUV. Triangles represent the actual risks for SUVs between 3,000 and 3,500 lb, squares those for SUVs between 3,500 and 4,100 lb. The broken line is a linear fit to the triangles, the solid line to the squares. The sizes of the triangles and squares are proportional to their statistical weights.

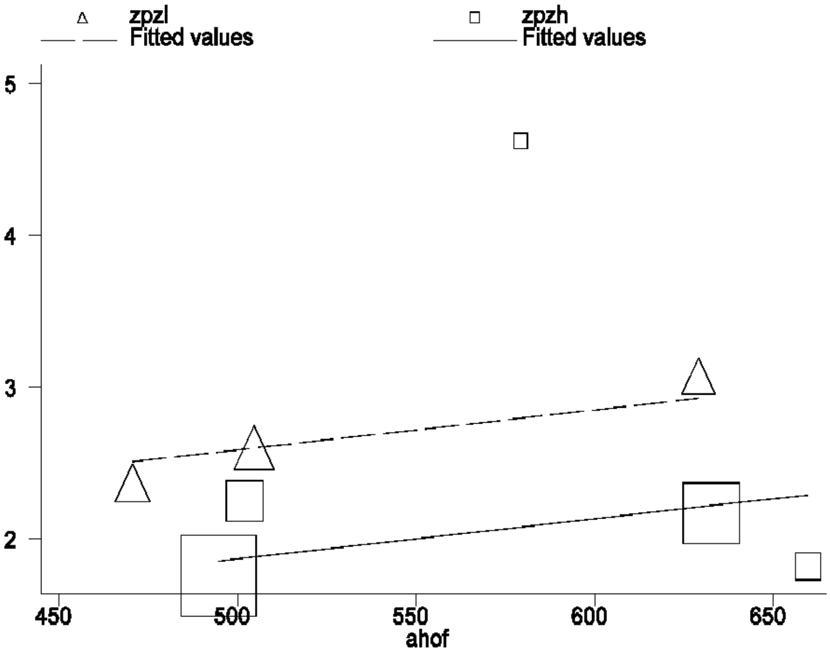

Figure 4.1.3-26 Relative (to car-car collisions) car driver fatality risk in collisions with a SUV versus AHOF of SUV. Triangles represent the actual risks for SUVs between 3,000 and 3,500 lb, squares those for SUVs between 3,500 and 4,100 lb. The lines represent a linear fit with one slope for all points, but allowing an offset between the SUVs with lower, and those with higher weights. The sizes of the triangles and squares are proportional to their statistical weights.

4.1.4 Front-Front Collisions With SUVs

Figures 4.1.4-1 and 2 show the absolute (per 1,000 involvements) and the relative (to comparable car-car collisions) car driver fatality risks in front-front collisions with SUVs versus weight of the SUV. In both cases, the statistically most heavily weighted points show no trend of risk versus weight. Some less weighted points may suggest increasing trends with weight, but regression analyses confirm that there are no trends; the regression coefficients are negative and comparable with or much smaller than their non-standard errors.

Inspections of bivariate plots of risk versus SUV weight and each one of the SUV parameters at a time, and exploratory regressions suggested no relations between the risks and weight or one of the parameters, with one exception. Peak power showed “significant” negative relations with the risks. Figures 4.1.4-3 and 4 show the relations of the risks with peak power and SUV weight. First, we notice that we have effectively only five data points, since the statistical weights of the other two are so small that they have practically no influence on the regression results. Risks tend to increase with weight, and to decline with increasing peak power. However, peak power and weight are fairly strongly correlated. This makes a separation of their effects by regression analysis practically impossible.

In some cases, a more detailed analysis of the data can separate such effects. We developed models for different parts of the data set, we used estimates of weight effects from all 11 cases, instead of only those 7 for which the peak power was known, and we examined residuals more closely. We found that peak power alone gave a better fit than weight alone, and that adding weight to a model including only power improved the fit only little, whereas adding power to a model containing only weight improved the fit greatly. Introducing a “kink” at 3,750 lb into the weight relation improved the fit and provided an excellent fit for absolute risks. Models for the relative risk were only little improved by allowing the kink. Of course, the good fit of the models should not be over-interpreted; with four coefficients only three degrees of freedom are left, and with two data points having only very low statistical weights, the practical effect may be closer to having only one degree of freedom.

Table 4.1.4-1 shows the coefficients of the regression models. It shows that, despite the close correlation with SUV weight, the effect of peak power may not be spurious. Of course, one should not conclude that increasing peak power will decrease the fatality risk. Rather, one should search for other factors related to peak power which might cause the observed relation.

Table 4.1.4-1 Regression coefficients of models for car driver fatality risk in front-front collisions with SUVs. “Model 1" includes only peak power, “Model 2" also SUV weight, and a term for SUV weight in excess of 3,759 lb. Non-standard errors are in parentheses.

variable	absolute risk (per 1,000 involvements)		relative risk (to car-car collisions)	
	model 1	model 2	model 1	model 2
peak power (mN• m/s)	-8.9 (2.4)	-9.2 (4.2)	-.65 (.13)	-.89 (.28)
weight (1,000 lb)		-7.9 (7.6)		-.48 (.56)
(weight-3,750) • (weight>3,750) (1,000 lb)		28.3 (33)		-.16 (.11)
constant	98 (23)	126 (57)	7.2 (1.2)	

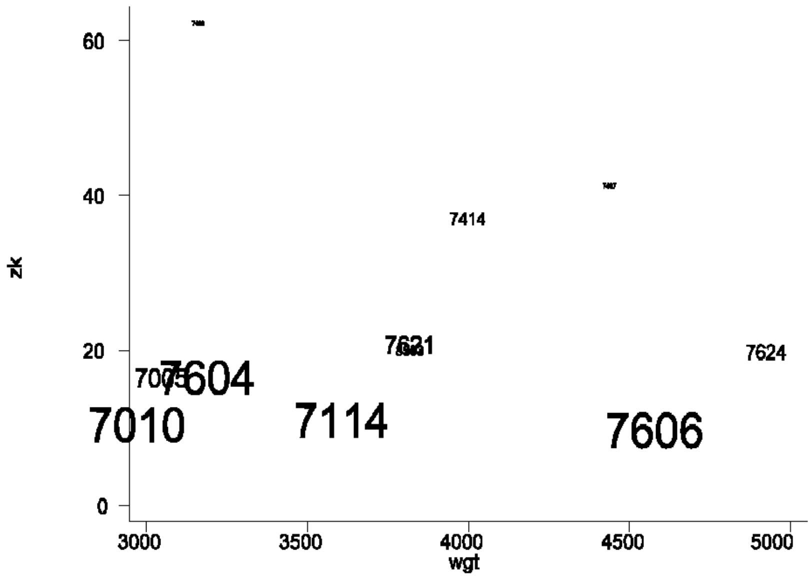

Figure 4.1.4-1 Car driver fatality risk (per 1,000 involvements) in front-front collisions with SUVs versus weight of SUV. The numbers indicating the data points are Kahane's codes for the SUV groups. Their sizes are proportional to their statistical weights.

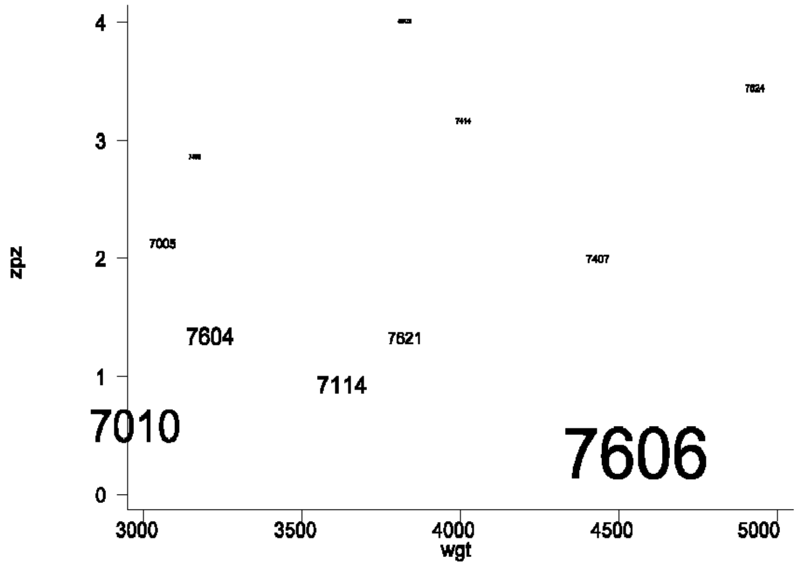

Figure 4.1.4-2 Relative (to car-car collisions) car driver fatality risk in front-front collisions with SUVs versus weight of SUV. The numbers indicating the data points are Kahane's codes for the SUV groups. Their sizes are proportional to their statistical weights.

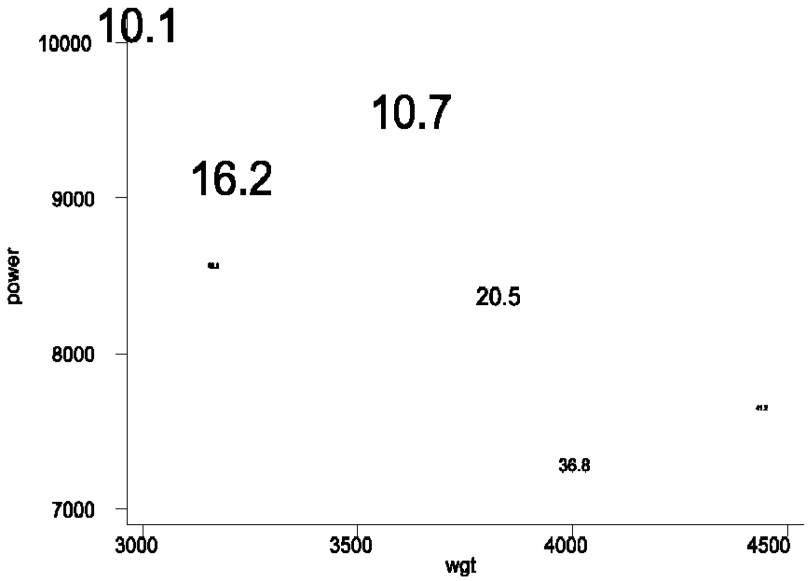

Figure 4.1.4-3 Car driver fatality risk (per 1,000 involvements) in front-front collisions with SUVs versus weight of SUV and peak power in crash tests. The numbers representing the data points show the risks, their sizes are proportional to their statistical weights.

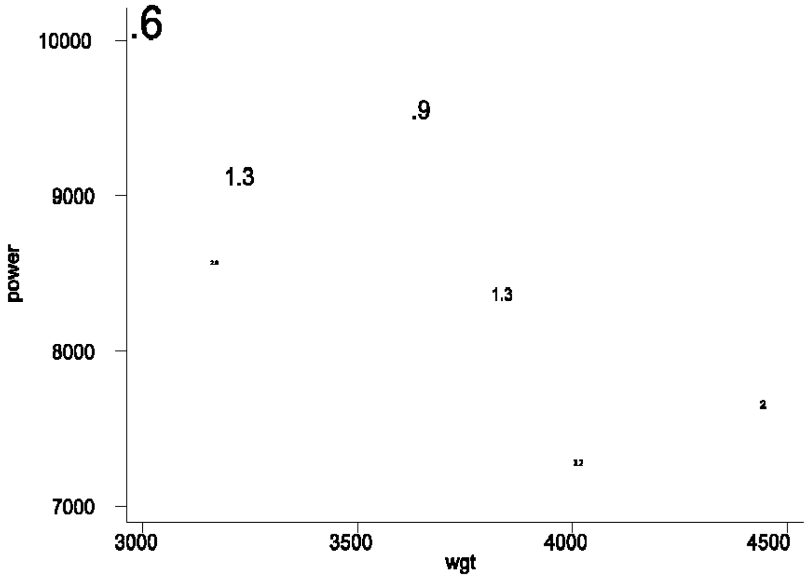

Figure 4.1.4-4 Relative (to car-car collisions) car driver fatality risk in front-front collisions with SUVs versus weight of SUV and peak power in crash tests. The numbers representing the data points show the risks, their sizes are proportional to their statistical weights.

4.2 Pickup Trucks

4.2.1 Vehicle Parameters

As with SUVs, the characteristics of pickup trucks are correlated across vehicle groups. Figure 4.2.1-1 (Figure 4.2.1-2 presents the same information, but uses the Kahane codes to identify the points) shows AHOF versus vehicle weight for those vehicle groups for which good crash test results and sufficient crash numbers were available. The data points form two distinct groups: that of compact pickup trucks (represented by "1") and that of large pickup trucks (represented by "2"). Within the compact pickups there is a clear correlation between AHOF and vehicle weight. For large pickup trucks, however, the AHOF is not higher than for the heaviest vehicles in the first group. This might possibly simplify separating any effects of AHOF and vehicle weight. However, all AHOF values are below 600 mm. For the SUVs, we found an indication that there might be a threshold around 600 mm for an effect of AHOF on the fatality risk, and that there might be little variation of the risk with lower AHOF values. Thus, the separation of any effects might be difficult.

CGFG is correlated with vehicle weight, but not with AHOF. Because it was only known for a few vehicle groups we did not study it.

Figure 4.2.1-3 shows the scatter plots for AHOF and the impulses on rows 1, 2, 3, and 4 of the crash test sensors. AHOF is negatively correlated with row 1, and positively with row 2, 3 and 4. Among themselves, rows 1 and 2 are negatively correlated, rows 3 and 4 positively.

Figure 4.2.1-4 shows the scatterplots between vehicle weight, impulses on rows 1, 2, 3 and 4, static stiffness, dynamic stiffness, and peak power. Weight is very weakly negatively correlated with the impulse on row 1, somewhat more positively with the impulse on row 2, and even more so with those on row 3 and 4 of the crash sensor. Weight has no apparent correlation with static stiffness, and dynamic stiffness, and neither with peak power. Static stiffness and dynamic stiffness are fairly closely correlated.

This means that it should be possible to separate any sufficiently large effect of weight, static stiffness and dynamic stiffness, and peak power.

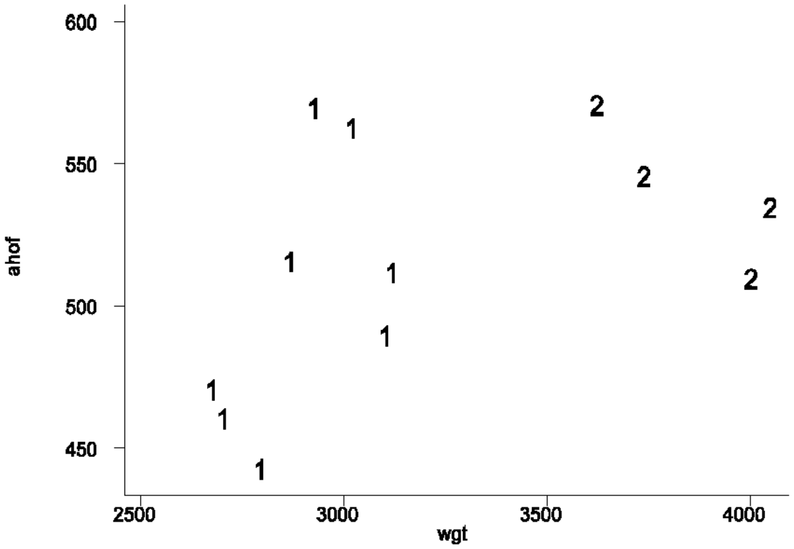

Figure 4.2.1-1 Average height of force versus vehicle weight, pickup trucks. “1" indicates a compact pickup truck group, “2" a large pickup truck group.

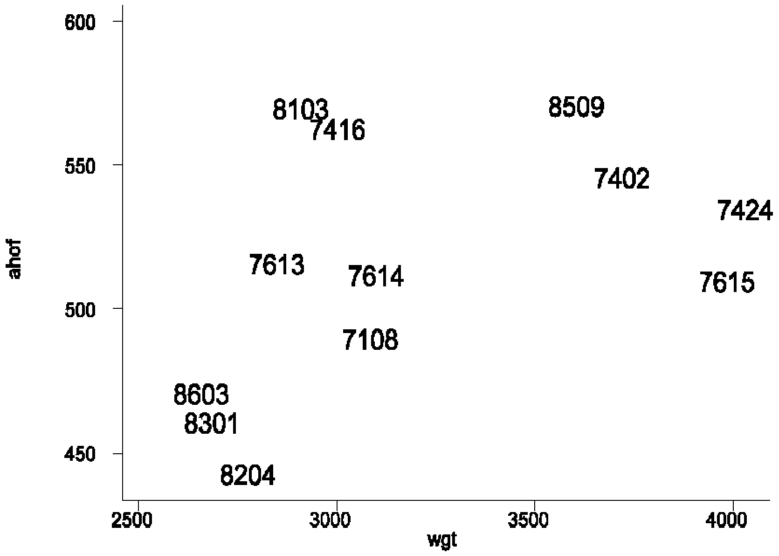

Figure 4.2.1-2 Average height of force versus vehicle weight, pickup trucks. The numbers are Kahane’s vehicle group codes.

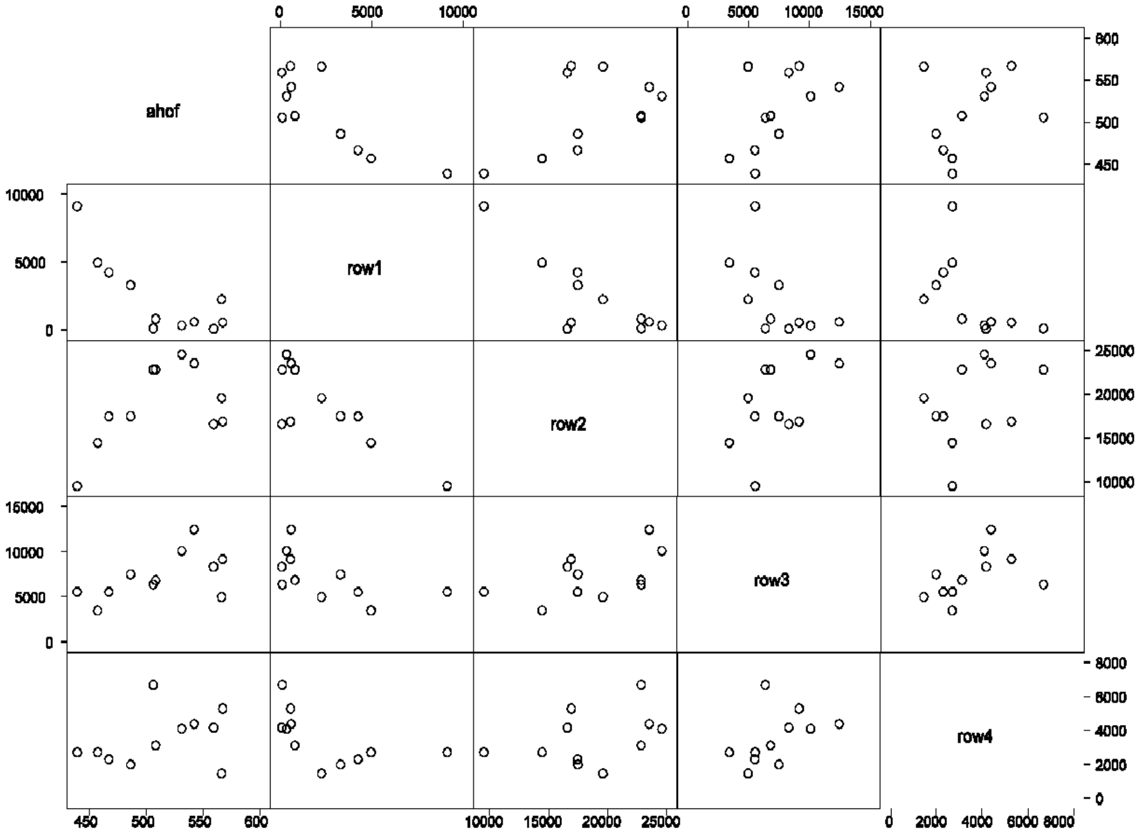

Figure 4.2.1-3 Matrix plot of all pairs of AHOF, impulses on row 1, row 2, row 3, and row 4 of the sensors. Pickup trucks.

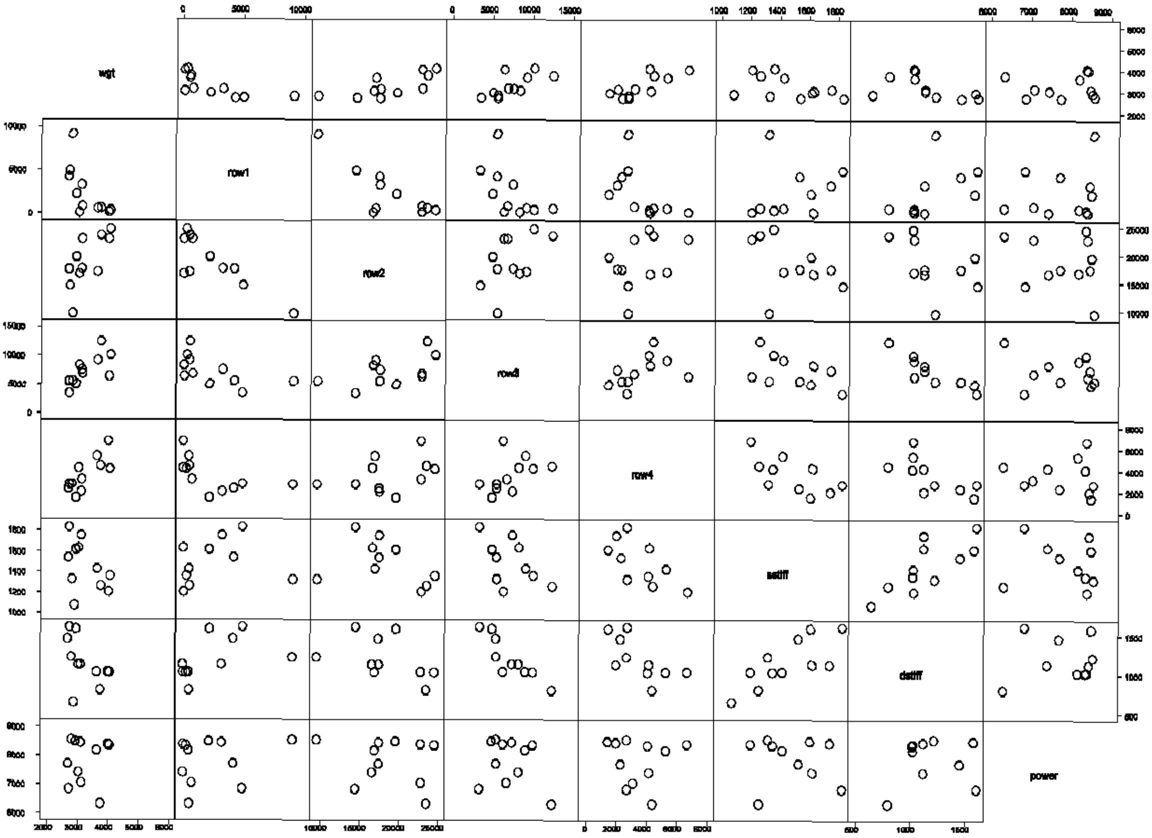

Figure 4.2.1-4 Matrix plot of all pairs of vehicle weight, impulses on row 1, row 2, row 3, and row 4 of the sensors, static stiffness, dynamic stiffness, and peak power. Pickup trucks.

4.2.2.1 Absolute and Relative Risks

Figures 4.2.2.1-1 and 2 show patterns roughly similar to those in Figures 4.1.2.1-1 and 2, but with important differences in the details. In both cases, the relative risks decline with increasing weight, the absolute risks increase with increasing weight. Differences are that in the case of pickup trucks, the relative risk drops greatly even in the lower weight range, and the absolute risk increases even in the highest weight range and does not level off.

To explore patterns in the widely scattered points, regressions against vehicle weight were run. First, separate regressions were run for compact, and for large pickups. The results are show as solid lines in the figures. Then, the weight range was divided into three parts: up to 3,200 lb, between 3,200 and 4,200, and above 4,200 lb. For these three ranges, separate regressions were run. The results are shown as broken lines in the figures (in Figure 4.2.2.1-2, the broken line for the lower weight range is practically indistinguishable from the solid line for compact pickups).

If one extends the solid line for the large pickups to the lower weights, it intersects the line for the lower weights near the center of the cloud of points for the lighter vehicles. Also, the slopes of the two lines differ by less than one standard error. This shows that one simple line could represent the points as well as two separate lines. The situation in Figure 4.2.2.1-2 is very similar, except that the difference in the slopes is 1.3 times its standard error; this is still small enough to consider the actual slopes as equal.

The situation is very different when the weight range is split into three parts; as shown in Figure 4.2.2.1-1, three practically parallel regression lines appear, and they are set off by nearly the same amount at the limits of the three ranges.

In the case of the absolute risk (Figure 4.2.2.1-2), the situation is similar, but not quite as neat, since the three broken lines are nearly, but not quite, parallel (but the non-standard error of the slope of the highest line is so large that the line could be horizontal). The offsets at the range limits are still roughly equal.

Figure 4.2.2.1-1 can be so interpreted that a single overall relation between relative risk and weight has a lower slope than any real relation, because it is confounded by another factor. The “real” relation might be reflected by the steeper slopes of the three broken lines, and the offset might reflect the effect of the confounding factor which increases with vehicle weight.

In the case of absolute risks (Figure 4.2.2.1-2), the corresponding interpretation is that the horizontal broken lines indicate no direct effect of weight, but only an effect of the confounding factor which is again correlated with weight, and that this effect appears as offsets at the limits of the weight ranges. Of course, these arguments do not prove the existence of such a factor. They just suggest to look for a factor which has the necessary properties.

To get some insight into the relation between fatality risk and vehicle parameters, bivariate plots were made (Figures 5.2.1-3 through 18). The coordinates are weight of the pickup truck, and one of its test characteristics. Each data point is represented by a number which equals either the absolute, or the relative fatality risk of the car driver. The size of each number is proportional to its statistical weight.

If the data points fall into a narrow band or angle, any effect of weight and the selected characteristics are difficult, or often practically not at all separable.

One feature common to all graphs, is the points fall into two distinct groups: vehicles with weights under 3,200 lb; and those with weights between 3,600 and 4,100 lb. There are no points for higher weights, none of the relatively few test results for heavier vehicles were considered sufficiently reliable. Therefore, we can not utilize the patterns shown in Figures 4.2.2.1-1 and 3, which suggest comparing three weight groups. In addition, there are only 4 pickup groups in the higher weight range, which allows to recognize only very strong trends of risk versus test characteristics.

Therefore, in a first step, only the group of lighter vehicles was examined in Figures 4.2.2.1-3 through 18. For each combination of pickup truck weight and test result, once the absolute, once the relative risk is shown. Nowhere can a strong trend between risk and test result be found, but in some cases trends are suggested, e.g. between relative risk and dynamic stiffness (Figure 4.2.2.1-16); a weaker one also between relative risk and dynamic stiffness (Figure 4.2.2.1-14).

To explore this further, corresponding regressions were also run. For those, where the coefficient of a crash parameter was significant or approached significance, or where the fit between actual and predicted risks was good, the coefficients of the crash test parameters are shown in Table 4.2.2.1-1.

For absolute risks, the relation to the impact on row 4 is strong, Figures 4.2.2.1-19 and 20, as reflected by the regression coefficient being about 3 times its non-standard error. Implausibly, however, its sign is negative. For the dynamic stiffness, its relation to the absolute risk was fairly weak and the regression coefficient only 40% greater than its non-standard error (Figure 4.2.2.1-21). For the relative risk, however, the relation was very strong (Figure 4.2.2.1-22); its regression coefficient being 5 times its non-standard error.

We further explored the crash test results for which the possibility of a relation appeared, by using all pickup trucks without regard to weight, and including also pickup truck weight into the regression model, to account for the confounding effects of weight.

Static and dynamic stiffness remained as test characteristics with a strong apparent effect on the relative risk. The coefficients are also shown in Table 4.2.2.1-1. Figure 4.2.2.1-23 shows only a weak relation between the absolute risk and static stiffness; the regression coefficient is only 20% larger than its non-standard error. However, the relation with the relative risk is unusually close (Figure 4.2.2.1-24), and its regression coefficient 2.5 times its non-standard error.

The relation between the dynamic stiffness and the absolute risk is also fairly weak (Figure 4.2.2.1-25), and its regression coefficient .63 not much larger than its non-standard error (.44). For the relative risk, however, the relation is close (Figure 4.2.2.1-26), and its regression coefficient three times as large as its non-standard error.

Overall, we find only one test crash characteristic which is consistently related to the relative car driver fatality risk, the static stiffness. It is also related, though not as strongly, to the absolute risk, with a slightly higher coefficient. For pickup trucks of all weights, the coefficients of static and of dynamic stiffness are practically the same, not too surprising because they are closely correlated. This is strong evidence that the aggressivity of pickup trucks may be related to their stiffness.

It is surprising that AHOF does not appear as an important factor. Therefore, it was further explored as described in the next section.

Table 4.2.2.1-1 Regression coefficients for models of absolute and of relative car driver fatality risk in car-pickup truck collisions, versus pickup truck crash test characteristics. Non-standard errors are in parentheses.

test characteristic	pickup weight <3,500 lb		all pickup trucks	
	absolute risk (per 1,000 involvements)	relative risk (to car-car collisions)	absolute risk (per 1,000 involvements)	relative risk (to car-car collisions)
impulse on row 4 (mN• s)	-.57 (.18)	-.21 (.17)		
dynamic stiffness (mN/m)	.70 (.52)	.63 (.12)	.63 (.44)	.48 (.15)
static stiffness (mN/m)			.68 (.56)	.55 (.21)

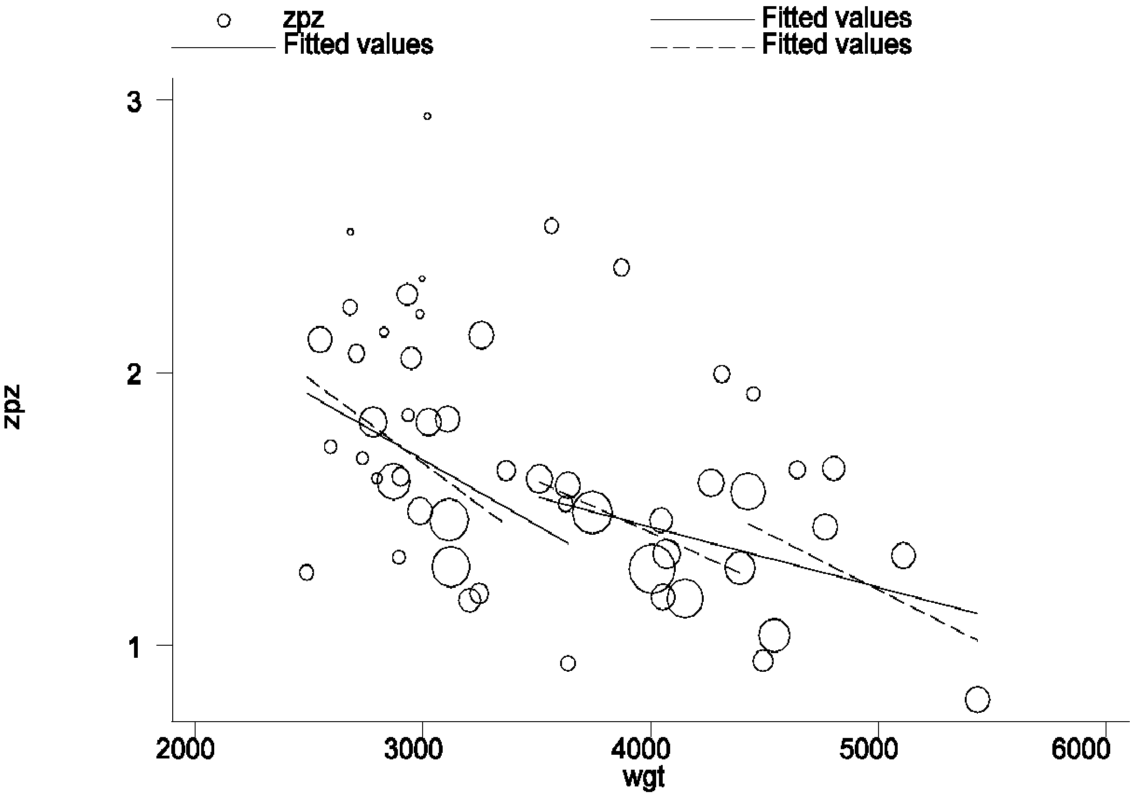

Figure 4.2.2.1-1 Relative (to car-car collisions) car driver fatality risk in car-pickup truck collisions, versus weight of pickup truck. The solid lines are regression lines fitted to the points for compact, and for large pickup trucks. The broken lines are fitted to the points in the weight ranges up to 3,200 lb, between 3,200 and 4,200, and above 4,200 lb. The sizes of the circles are proportional to the statistical weights of the data.

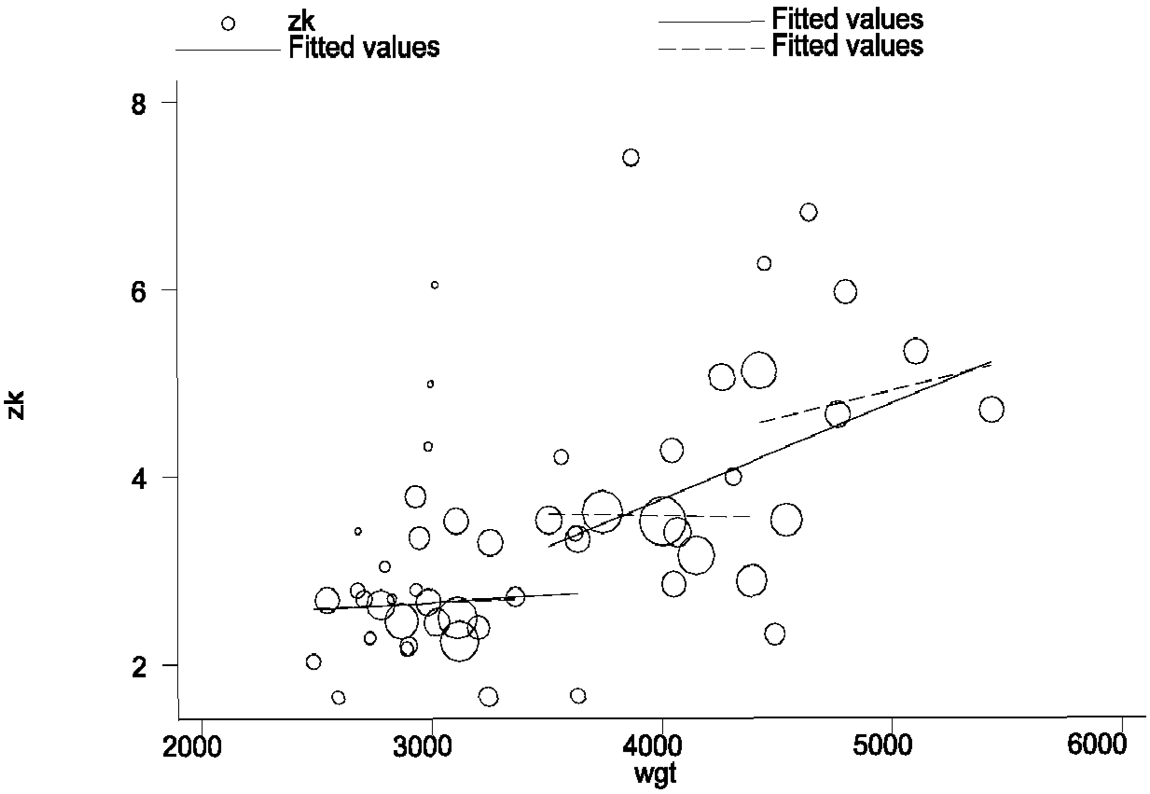

Figure 4.2.2.1-2 Car driver fatality risk (per 1,000 involvements) in car-pickup truck collisions, versus weight of pickup truck. The solid lines are regression lines fitted to the points for compact, and for large pickup trucks. The broken lines are fitted to the points in the weight ranges up to 3,200 lb, between 3,200 and 4,200 lb, and above 4,200 lb. The sizes of the circles are proportional to the statistical weights of the data.

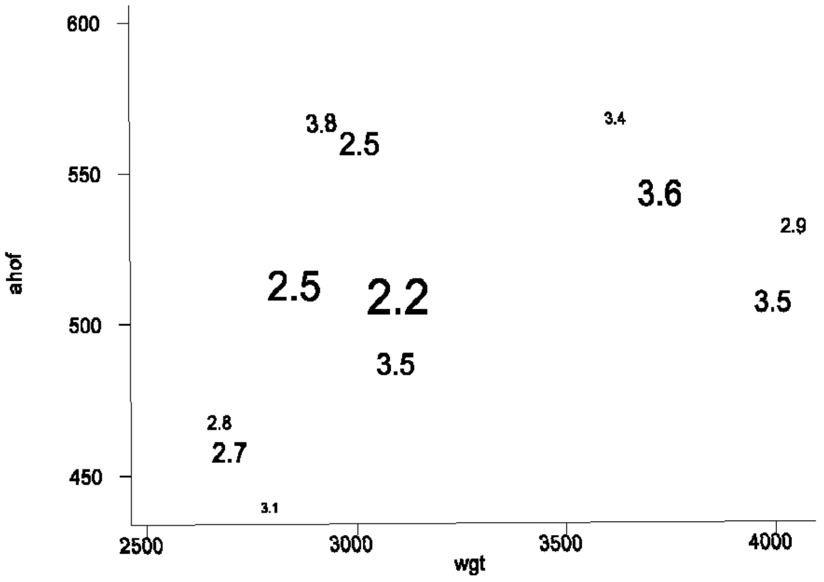

Figure 4.2.2.1-3 Car driver fatality risk (per 1,000 involvements) in car-pickup truck collisions versus AHOF (mm) and weight of pickup truck (lb). The number representing the points shows the risk, its size is proportional to its statistical weight.

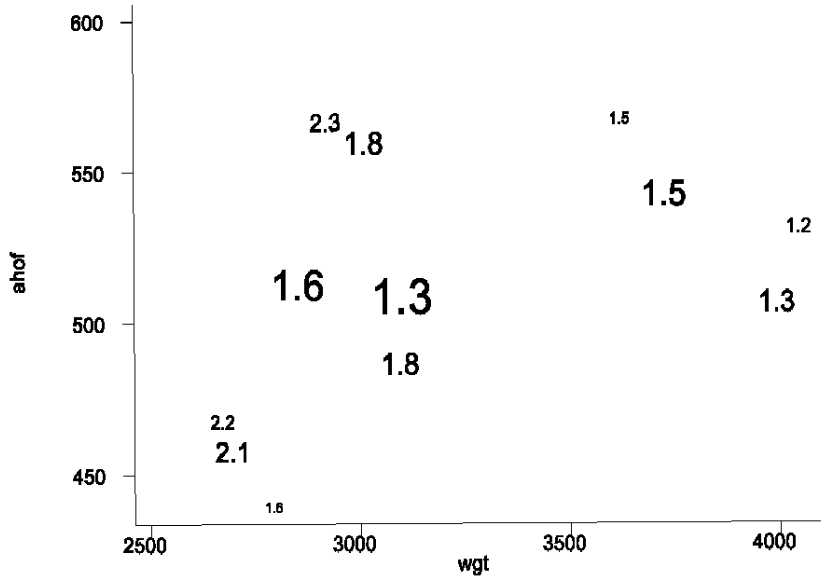

Figure 4.2.2.1-4 Relative (to collisions with comparable cars) car driver fatality risk in car-pickup truck collisions versus AHOF (mm) and weight of pickup truck (lb). The numbers representing the points are the relative risks, their sizes are proportional to the statistical weights of the relative risks.

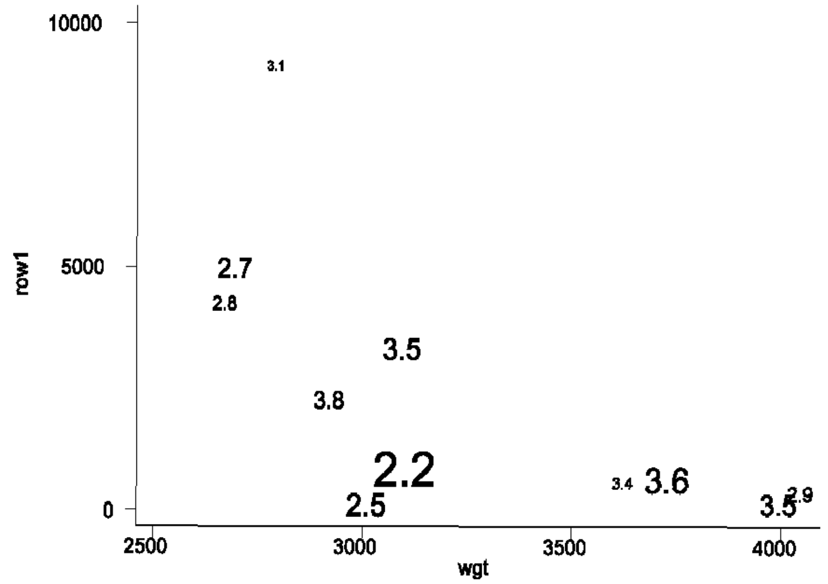

Figure 4.2.2.1-5 Car driver fatality risk (per 1,000 involvements) in car-pickup truck collisions versus impulse on row 1 (kN• s) and weight of pickup truck (lb). The numbers representing the points show the risks, their sizes are proportional to their statistical weights.

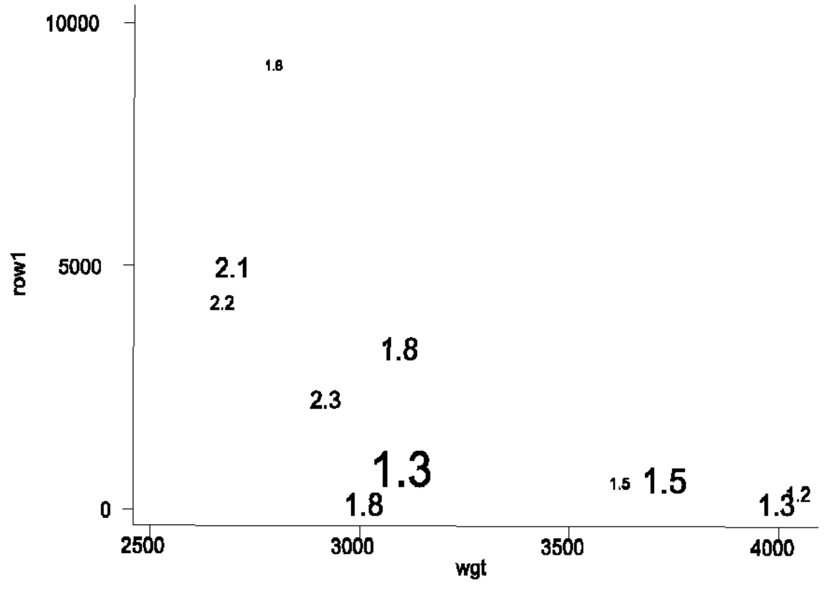

Figure 4.2.2.1-6 Relative (to collisions with comparable cars) car driver fatality risk in car-pickup truck collisions versus impulse on row 1 (kN• s) and weight of pickup truck (lb). The numbers representing the points show the risks, their sizes are proportional to their statistical weights.

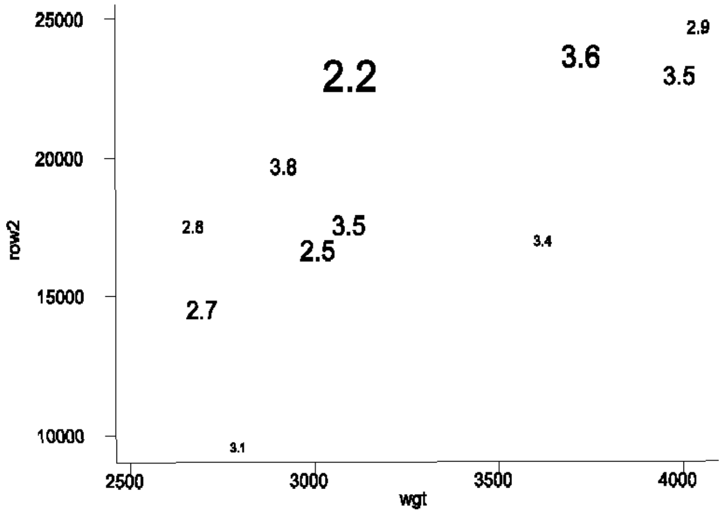

Figure 4.2.2.1-7 Car driver fatality risk (per 1,000 involvements) in car-pickup truck collisions versus impulse on row 2 (kN• s) and weight of pickup truck (lb). The numbers representing the points show the risks, their sizes are proportional to their statistical weights.

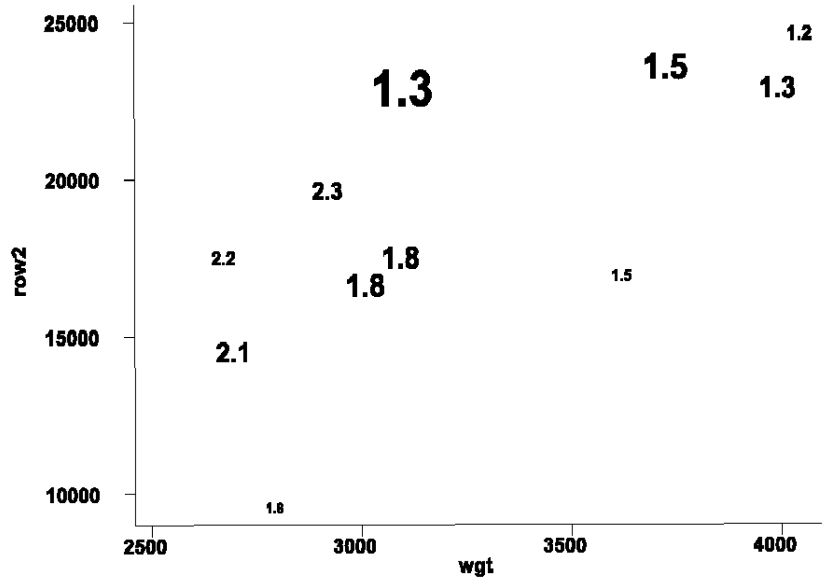

Figure 4.2.2.1-8 Relative (to collisions with comparable cars) car driver fatality risk in car-pickup truck collisions versus impulse on row 2 (kN• s) and weight of pickup truck (lb). The numbers representing the points show the risks, their sizes are proportional to their statistical weights.

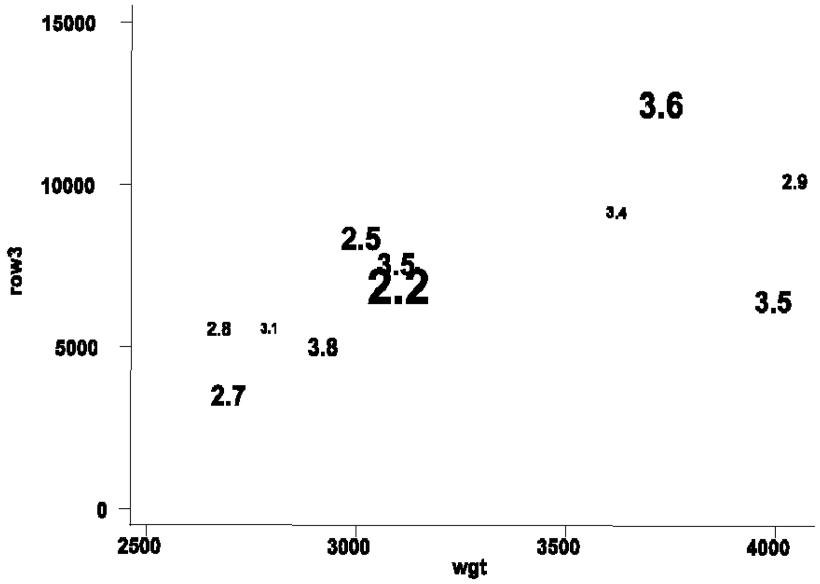

Figure 4.2.2.1-9 Car driver fatality risk (per 1,000 involvements) in car-pickup truck collisions versus impulse on row 3 (kN• s) and weight of pickup truck (lb). The numbers representing the points show the risks, their sizes are proportional to their statistical weights.

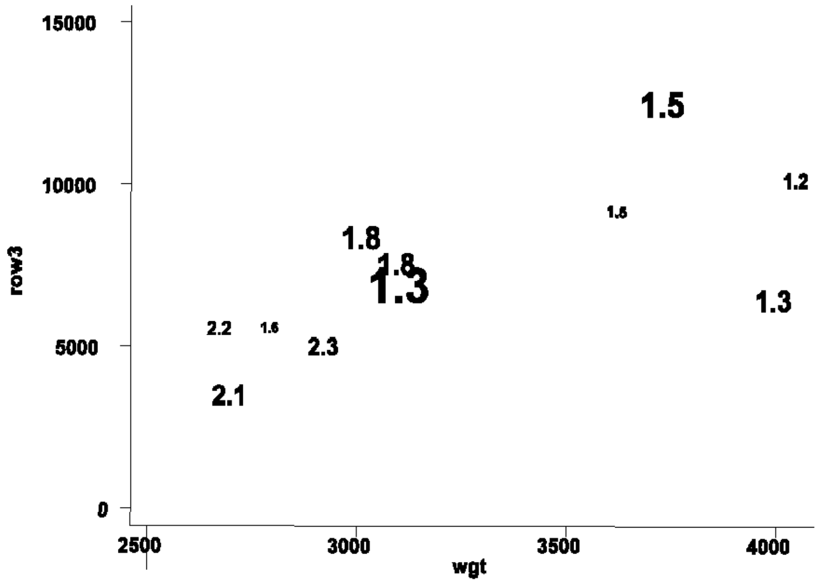

Figure 4.2.2.1-10 Relative (to collisions with comparable cars) car driver fatality risk in car-pickup truck collisions versus impulse on row 3 (kN• s) and weight of pickup truck (lb). The numbers representing the points show the risks, their sizes are proportional to their statistical weights.

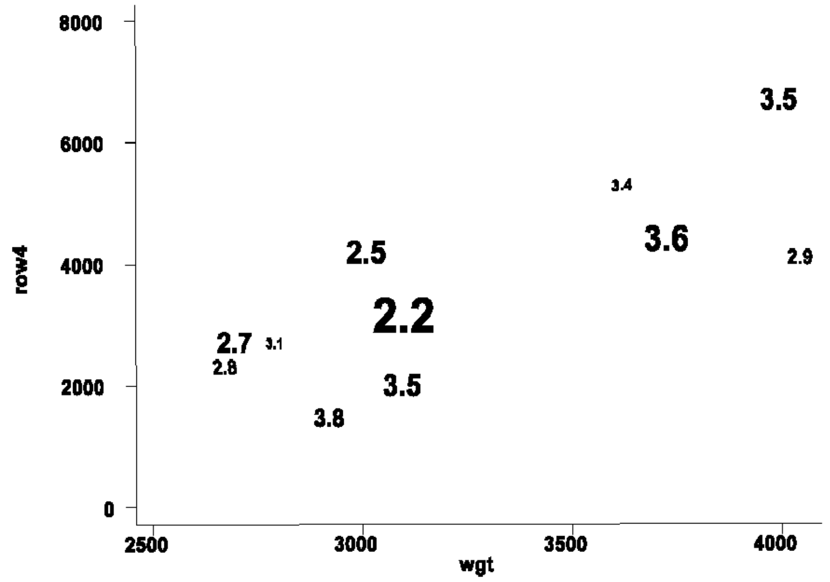

Figure 4.2.2.1-11 Car driver fatality risk (per 1,000 involvements) in car-pickup truck collisions versus impulse on row 4 (kN• s) and weight of pickup truck (lb). The numbers representing the points show the risks, their sizes are proportional to their statistical weights.

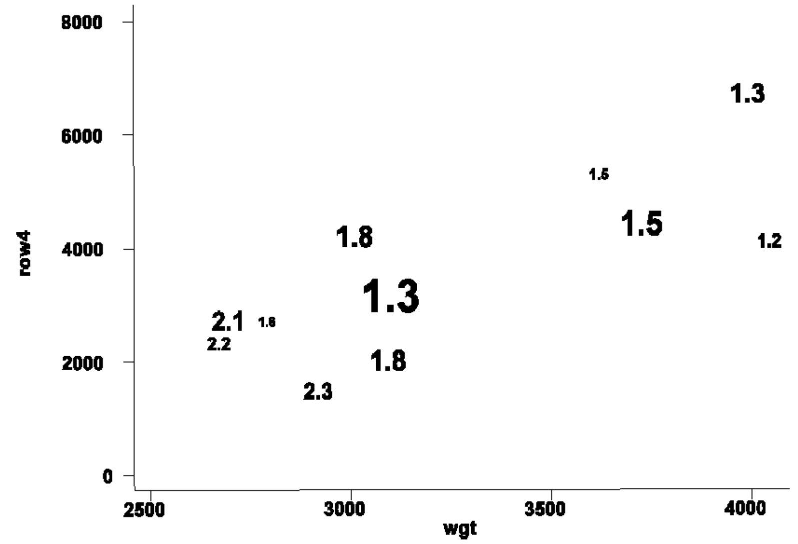

Figure 4.2.2.1-12 Relative (to collisions with comparable cars) car driver fatality risk in car-pickup truck collisions versus impulse on row 4 (kN• s) and weight of pickup truck (lb). The numbers representing the points show the risks, their sizes are proportional to their statistical weights.

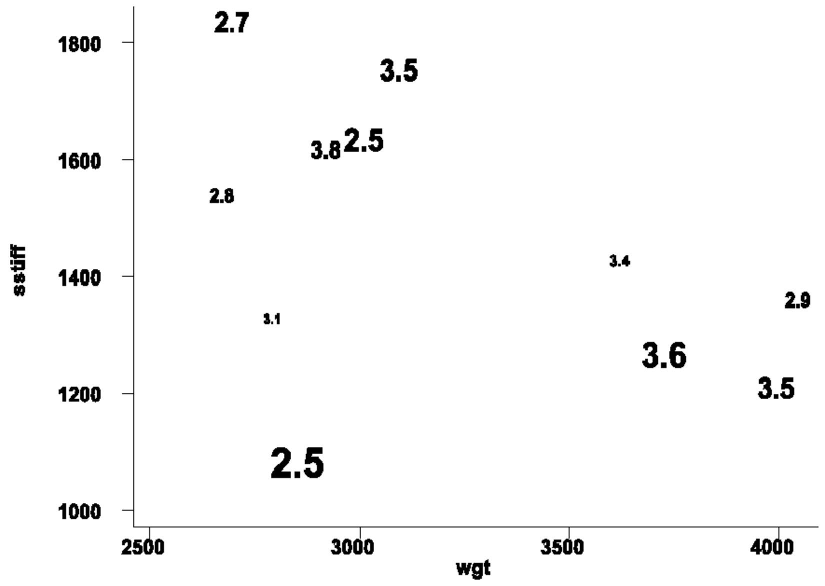

Figure 4.2.2.1-13 Car driver fatality risk (per 1,000 involvements) in car-pickup truck collisions versus static stiffness (kN/m) and weight of pickup truck (lb). The numbers representing the points show the risks, their sizes are proportional to their statistical weights.

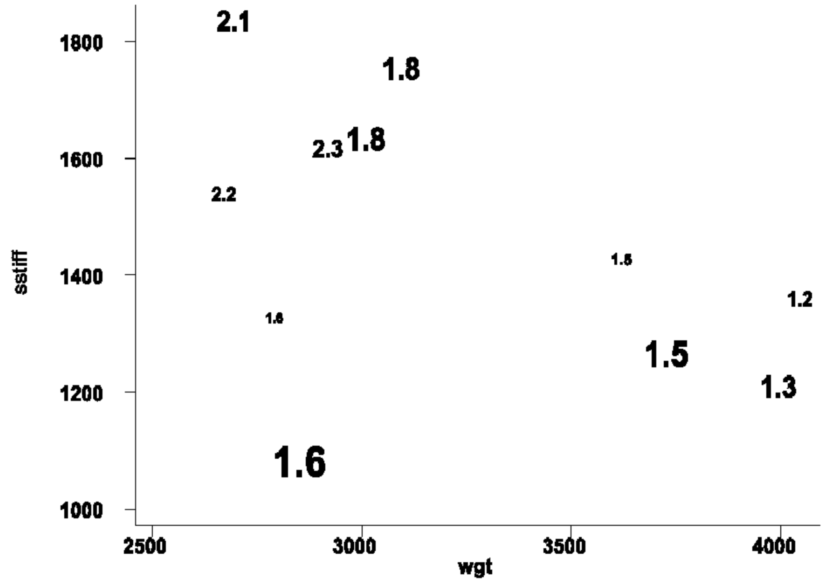

Figure 4.2.2.1-14 Relative (to collisions with comparable cars) car driver fatality risk in car-pickup truck collisions versus static stiffness (kN/m) and weight of pickup truck (lb). The numbers representing the points show the risks, their sizes are proportional to their statistical weights.

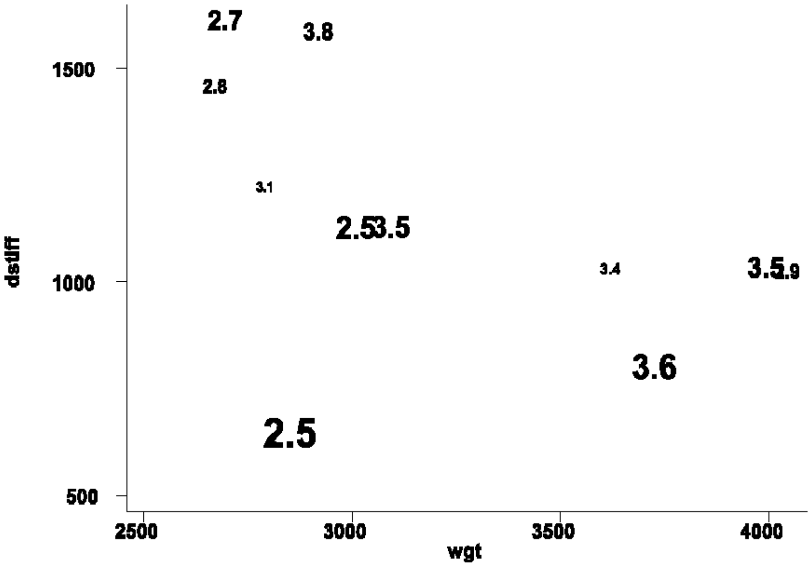

Figure 4.2.2.1-15 Car driver fatality risk (per 1,000 involvements) in car-pickup truck collisions versus dynamic stiffness (kN/m) and weight of pickup truck (lb). The numbers representing the points show the risks, their sizes are proportional to their statistical weights.

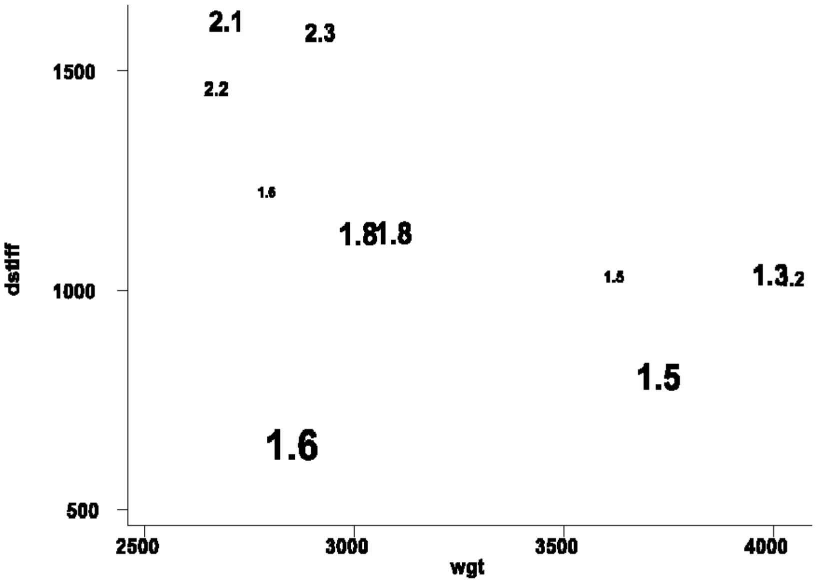

Figure 4.2.2.1-16 Relative (to collisions with comparable cars) car driver fatality risk in car-pickup truck collisions versus dynamic stiffness (kN• s) and weight of pickup truck (lb). The numbers representing the points show the risks, their sizes are proportional to their statistical weights.

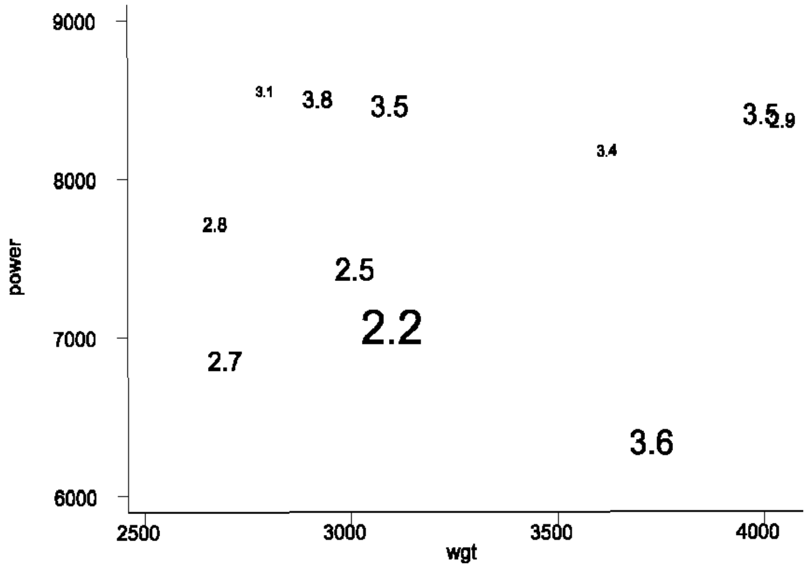

Figure 4.2.2.1-17 Car driver fatality risk (per 1,000 involvements) in car-pickup truck collisions versus peak power and weight of pickup truck (lb). The numbers representing the points show the risks, their sizes are proportional to their statistical weights.

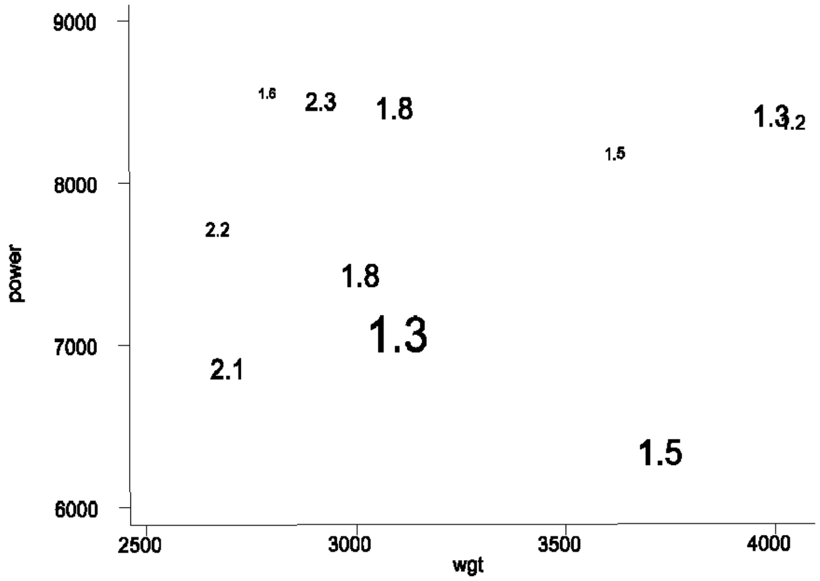

Figure 4.2.2.1-18 Relative (to collisions with comparable cars) car driver fatality risk in car-pickup truck collisions versus peak power and weight of pickup truck (lb). The numbers representing the points show the risks, their sizes are proportional to their statistical weights.

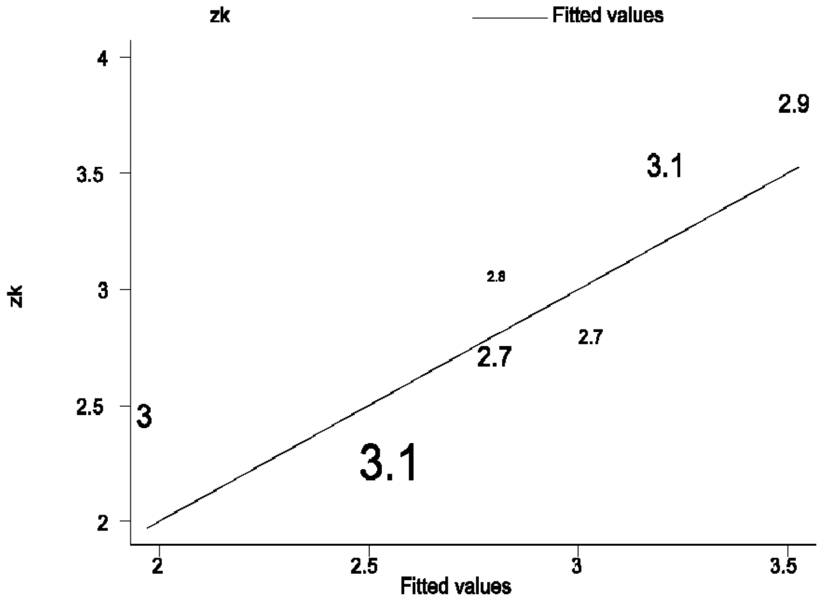

Figure 4.2.2.1-19 Actual car driver fatality risk in collisions with pickup trucks versus modelled risk. Weight of pickup trucks under 3,500 lb. Model includes only impulse on row 4. The numbers representing the points are the weights of the pickup trucks (1,000 lb), their sizes are proportional to their statistical weights.

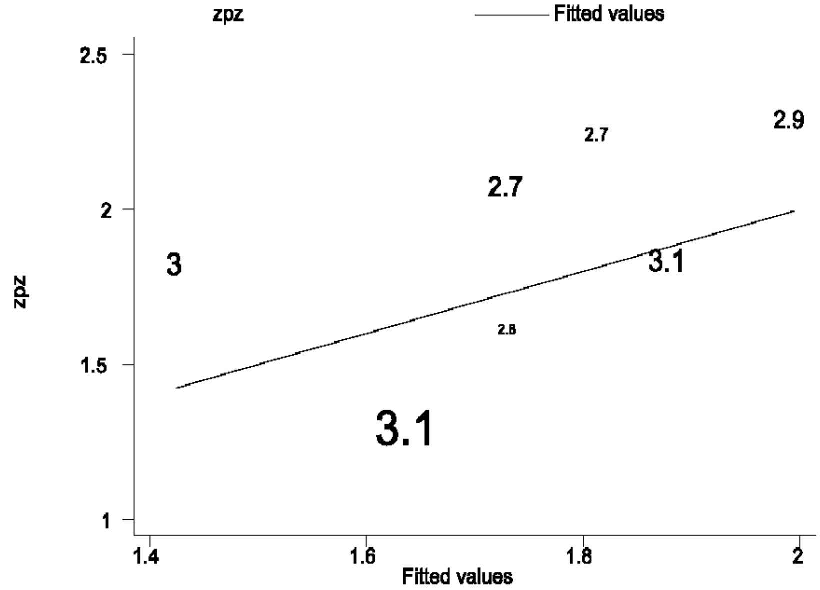

Figure 4.2.2.1-20 Relative (to car-car collisions) car driver fatality risk in collisions with pickup trucks versus modelled risk. Model includes only impulse on row 4. The numbers representing the points are the weights of the pickup trucks (1,000 lb), their sizes are proportional to their statistical weights.

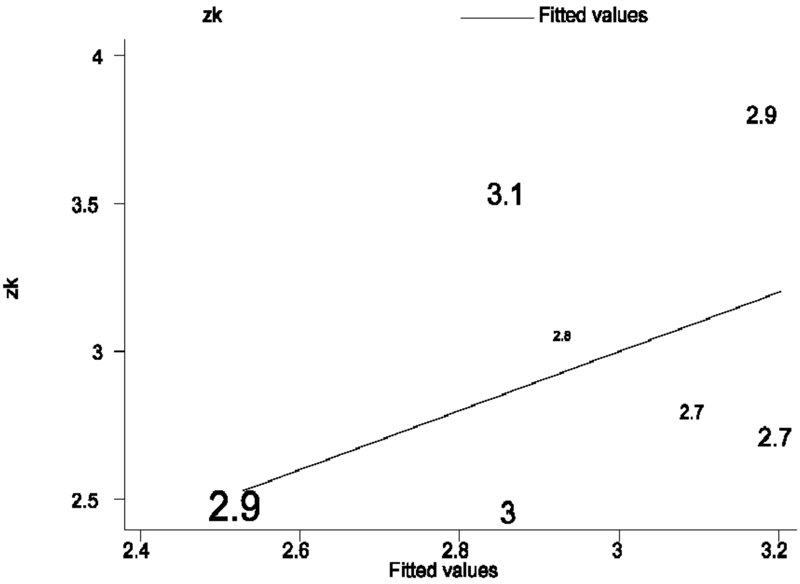

Figure 4.2.2.1-21 Actual car driver fatality risk in collisions with pickup trucks versus modelled risk. Weight of pickup trucks under 3,500 lb. Model includes only dynamic stiffness. The numbers representing the points are the weights of the pickup trucks (1,000 lb), their sizes are proportional to their statistical weights.

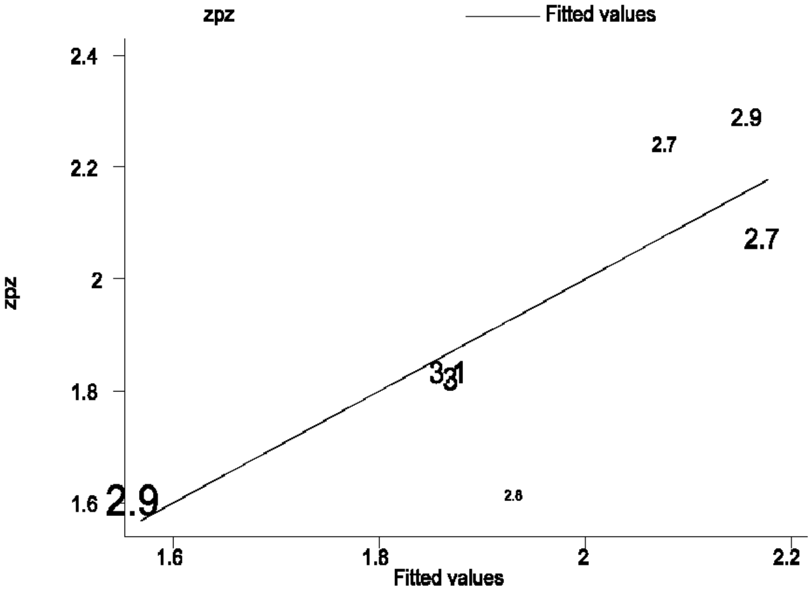

Figure 4.2.2.1-22 Relative (to car-car collisions) car driver fatality risk in collisions with pickup trucks versus modelled risk. Weight of pickup truck under 3,500 lb. Model includes only dynamic stiffness. The numbers representing the points are the weights of the pickup trucks (1,000 lb), their sizes are proportional to their statistical weights.

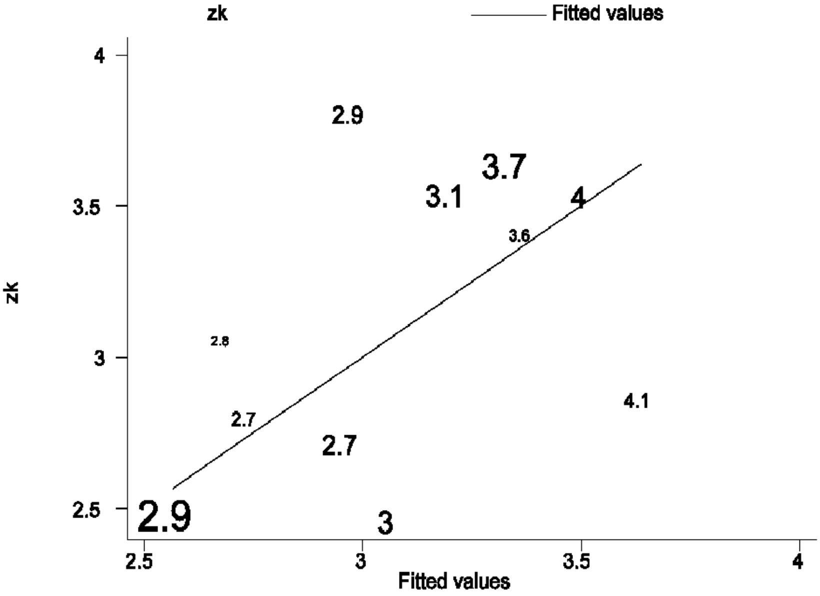

Figure 4.2.2.1-23 Actual car driver fatality risk in collisions with pickup trucks versus modelled risk. Model includes static stiffness and weight of pickup truck. The numbers representing the points are the weights of the pickup trucks (1,000 lb), their sizes are proportional to their statistical weights.

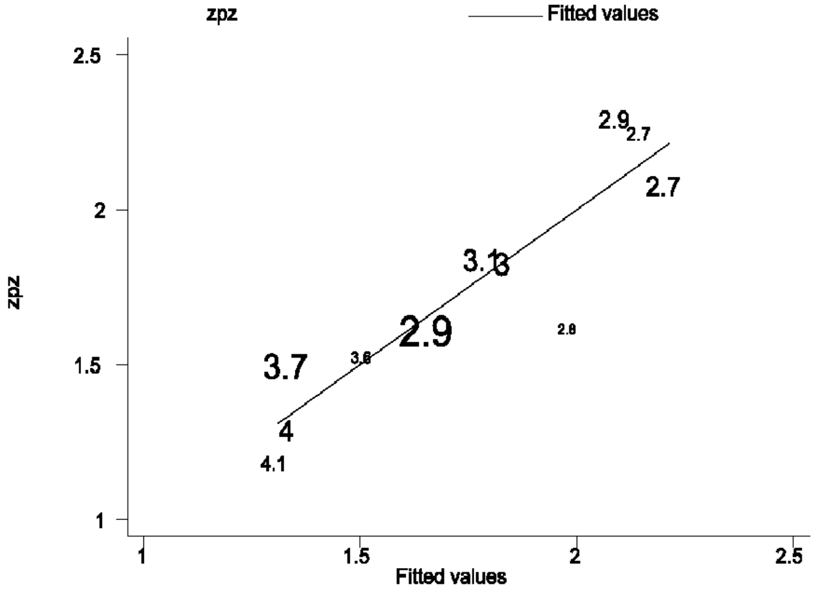

Figure 4.2.2.1-24 Relative (to car-car collisions) car driver fatality risk in collisions with pickup trucks versus modelled risk. Model includes static stiffness and weight of pickup truck. The numbers representing the points are the weights of the pickup trucks (1,000 lb), their sizes are proportional to their statistical weights.

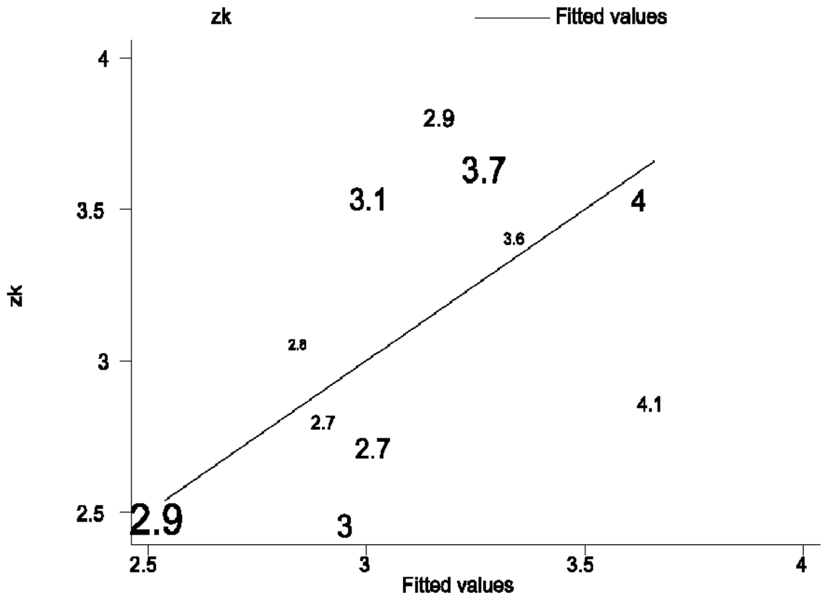

Figure 4.2.2.1-25 Actual car driver fatality risk in collisions with pickup trucks versus modelled risk. Model includes dynamic stiffness and weight of pickup truck. The numbers representing the points are the weights of the pickup trucks (1,000 lb), their sizes are proportional to their statistical weights.

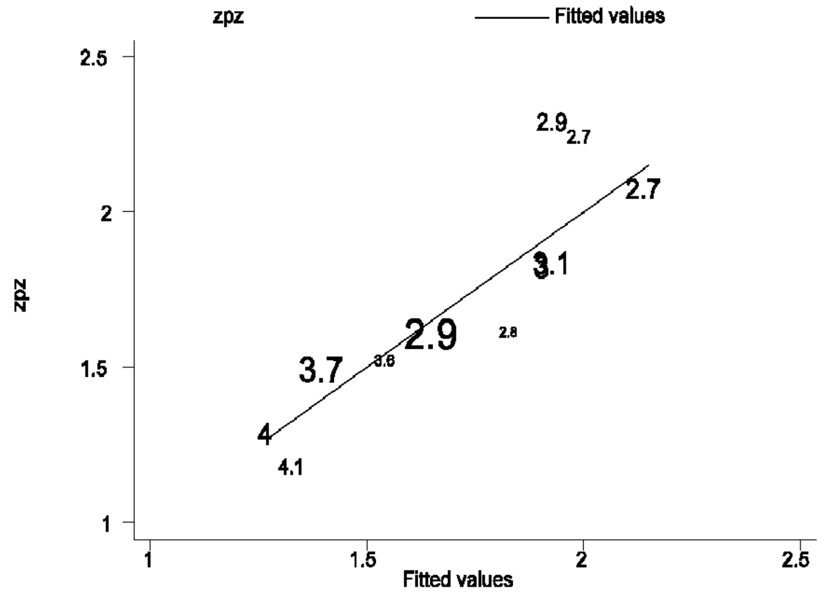

Figure 4.2.2.1-26 Relative (to car-car collisions) car driver fatality risk in collisions with pickup trucks versus modelled risk. Model includes dynamic stiffness and weight of pickup truck. The numbers representing the points are the weights of the pickup trucks (1,000 lb), their sizes are proportional to their statistical weights.

4.2.2.2 Adding Pickup Truck Groups

In the previous section, we used 12 pickup truck groups for which NHTSA considered the crash test results reliable. There are 8 additional pickup truck groups for which crash test results are available, though they might not be reliable. We used these also to study any potential effect of AHOF on the car driver fatality risk. In both the original set of pickup trucks, and the additional set, distinguishing a low weight group, under 3,500 lb, and a high weight group, above that, appeared to be natural. To control for weight in a very crude manner, regressions were run against AHOF only in each weight range. This assumed that effects of weight differences within each weight range are negligible. Figures 4.2.2.3-1 and 2 show the results for the relative car driver fatality risks.

Table 4.2.2.2-1 Coefficients of AHOF in simple models for car driver fatality risk in car-pickup truck collisions; models include only AHOF (cm). For relative risks, coefficients for SUVs with good test data, for others, and for both combined are shown. For absolute risks, only the coefficients of the models for combined data are shown.

weight range	relative risks						absolute risks	
	good data		additional data		combined data		combined data	
	coefficient	non-standard error	coefficient	non-standard error	coefficient	non-standard error	coefficient	non-standard error
low	.015	(.041)	.030	(.016)	.021	(.022)	.020	(.035)
high	.046	(.030)	.024	(.094)	.039	(.030)	.049	(.064)

It is surprising that for both sets of pickup trucks the patterns are similar, even though the regression coefficients were far from being "significant" (and are therefore not shown). Table 4.2.2.3-1 shows these coefficients of AHOF in the models. While they disagree percentagewise widely from each other, they agree well within their non-standard error. This supports the suspicion that there is a real, though quantitatively uncertain effect of AHOF.

The results of modelling the absolute fatality risks are shown in Figures 4.2.2.3-3 and 4. In Figures 4.2.2.3-3, no trend with AHOF is apparent. In Figure 4.2.2.3-4, very roughly parallel, weak trends with AHOF– far from even approaching "significance"– appear. However, if one combines the SUVs with good test results and the other, one obtains regression coefficients– also shown in Table 4.2.2.3-1– which are surprisingly similar to this for the combined model for the absolute risk. They are based on the same cases, therefore not independent. However, their similarity between the two models suggests that they are not artifacts of the model.

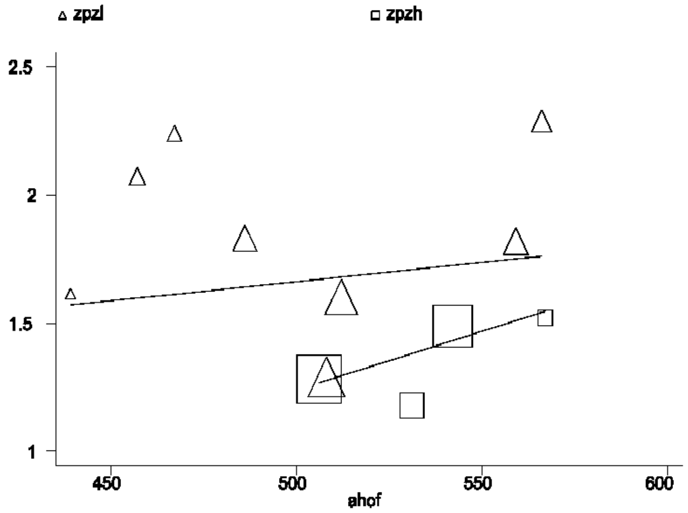

Figure 4.2.2.2-1 Relative (to car-car collisions) car driver fatality risk in car-pickup truck collisions. Actual values (triangles for pickup trucks under 3,500 lb, squares for heavier ones) and modelled values, versus AHOF. Pickup trucks with good crash results.

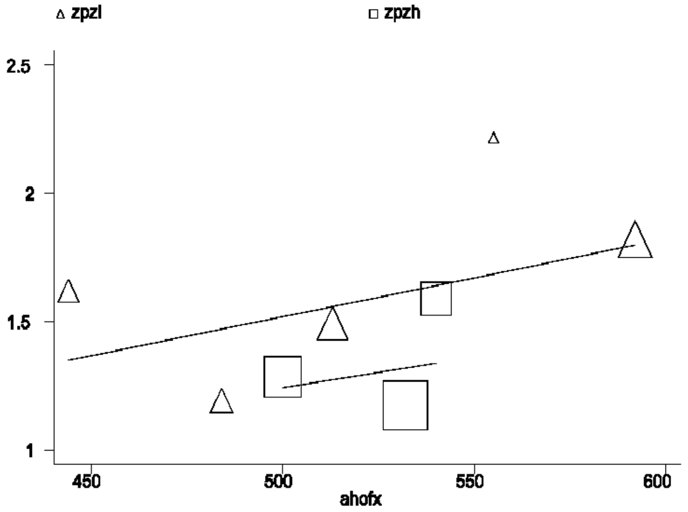

Figure 4.2.2.2-2 Relative (to car-car collisions) car driver fatality risk in car-pickup truck collisions. Actual values (triangles for pickup trucks under 3,500 lb, squares for heavier ones) and modelled values, versus AHOF. Other pickup trucks.

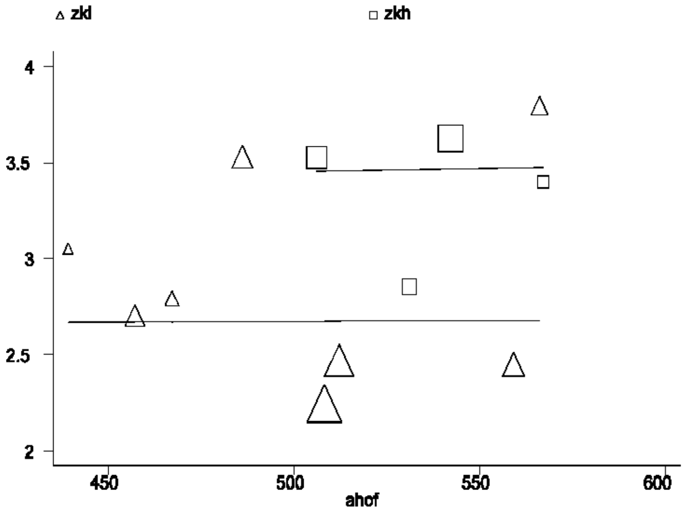

Figure 4.2.2.2-3 Relative (to car-car collisions) car driver fatality risk in car-pickup truck collisions. Actual values (triangles for pickup trucks under 3,500 lb, squares for heavier ones) and modelled values, versus AHOF. Pickup trucks with good crash test data.

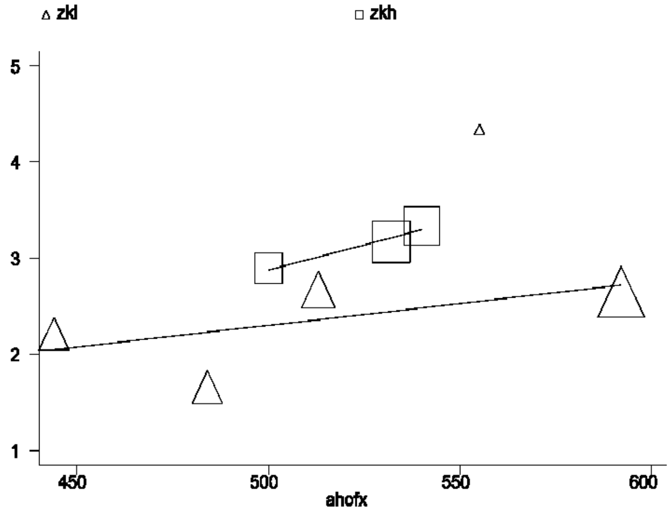

Figure 4.2.2.2-4 Car driver fatality risk in car-pickup truck collisions. Actual vales (triangles for pickup trucks under 3,500 lb, squares for heavier ones) and modelled values, versus AHOF. Other pickup trucks.

4.2.3 Left Side Impacts by Pickup Trucks

Figures 4.2.3-1 and 2 show the absolute and relative car driver fatality risks, when the car is struck on the left by the front of a pickup truck, versus weight of the pickup truck. The absolute risks (Figure 4.2.3-1) show an increasing trend up to weights around 3,500 lb, thereafter a leveling off, possibly even a slight decline for the points with the greatest statistical weights. This is very different from the relation for all collision configurations (Figure 4.2.2.1-2) which shows a strong increase of the risk with weights above 4,000 lb. Relative risks (Figure 4.2.3-2) increase also up to about 3,500 lb, but clearly decrease with higher weights. Again, this is very different from the corresponding relation for all collision configurations (Figure 4.2.2.1-1), which shows a consistent decline over the entire weight range. This suggests that in left side impacts other vehicle characteristics are important than in other impacts.

Figures 4.2.3-3 and 4 show absolute and relative car driver fatality risks versus weight and AHOF of the pickup truck. Increasing trends of the risks with AHOF are obvious in all graphs. There are also differences between the two weight groups of pickup trucks.

Table 4.2.3-1 shows the coefficients of regression models fitted to the data. Most are not “significant”, but that does not necessarily mean that the observed relations are only due to chance. It can also mean that the linear model fits the actual relations poorly. Because of the magnitude of the error, the coefficients should not be quantitatively interpreted, but only used as qualitative indicators that the “height” of a pickup truck appears to have an effect on the car driver fatality risk in front-left collisions.

Patterns with regard to the impulses on the different rows of reason support this conclusion (of course, this support is not independent, since AHOF is derived from the measurements by the sensors). Figures 4.2.3-5 and 6 show that risks decline with increasing impulse on row 1, Figures 4.2.3-7 and 8 that risks tend to increase with the impulse on row 2, and Figure 4.2.3-9 and 10 that risks increase, but not as closely, with the impulse on row 3.

With regard to impulse on row 4, to static and dynamic stiffness, and to peak power, no pattern was found.

Table 4.2.3-1 Regressions coefficients of models for car driver fatality risks in collisions with the front of a pickup truck striking the left side of car. Non-standard errors are in parentheses.

variable	absolute risk (per 1,000 involvements)		relative risk (to car-car collisions)	
AHOF (car)	0.19	(0.24)	0.14	(0.8)
weight (1,000 lb)	1.8	(1.7)	-0.5	(6.0)
constant	-6.8	(12.4)	-3.8	(3.5)

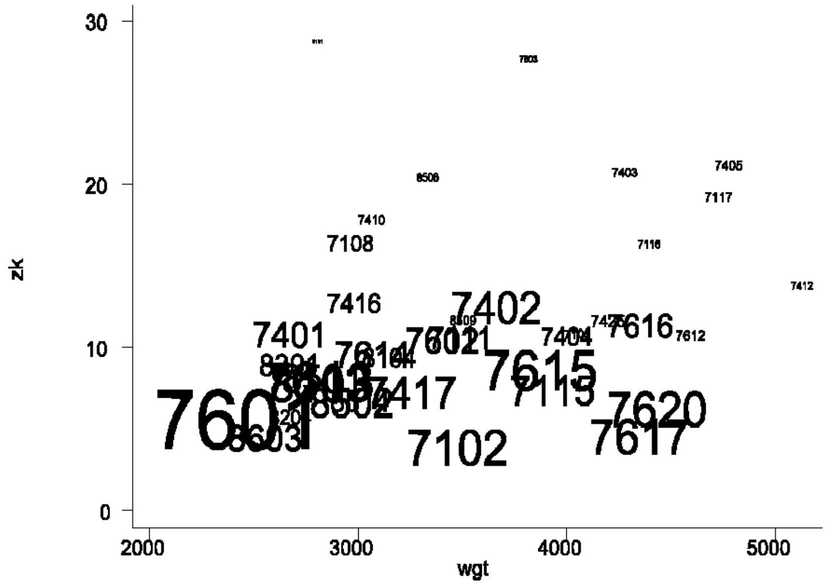

Figure 4.2.3-1 Car driver fatality risk (per 1,000 involvements) in collisions where the front of a pickup truck struck the left side of a car, versus weight of the pickup truck. The numbers representing the data points are Kahane's group codes for the pickup trucks, their sizes are proportional to their statistical weights.

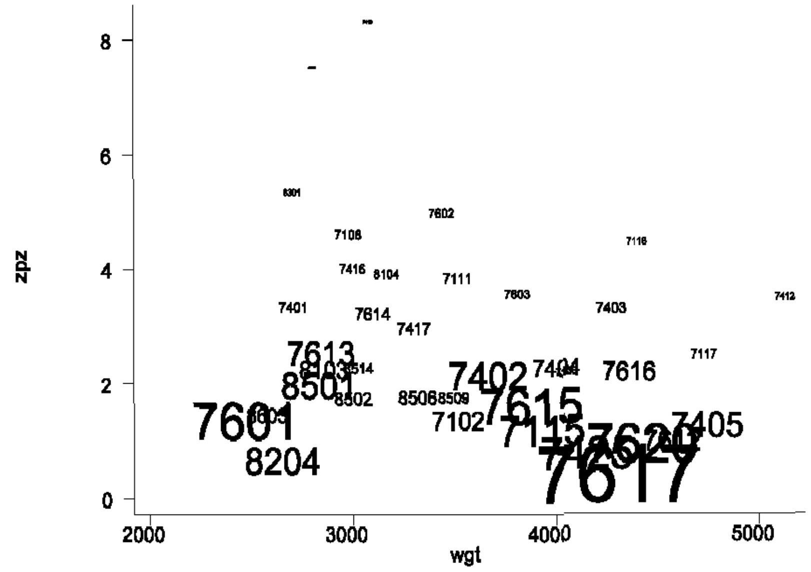

Figure 4.2.3-2 Relative (to comparable car-car collisions) car driver fatality risk in collisions where the front of a pickup truck struck the left side of a car, versus weight of the pickup truck. The numbers representing the data points are Kahane's group codes for the pickup trucks, their sizes are proportional to their statistical weights.

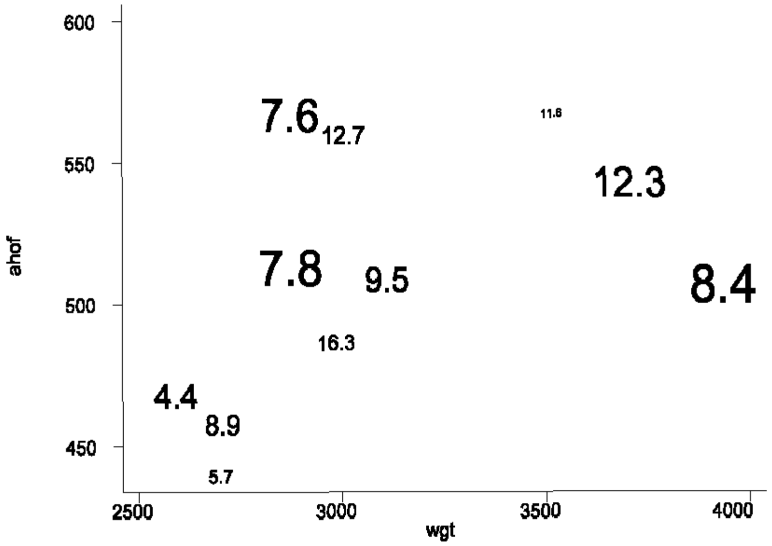

Figure 4.2.3-3 Car driver fatality risk (per 1,000 involvements) in collisions where the front of a pickup truck struck the left side of a car, versus AHOF and weight of the pickup truck. The numbers representing the data points are the risks, their sizes are proportional to their statistical weights.

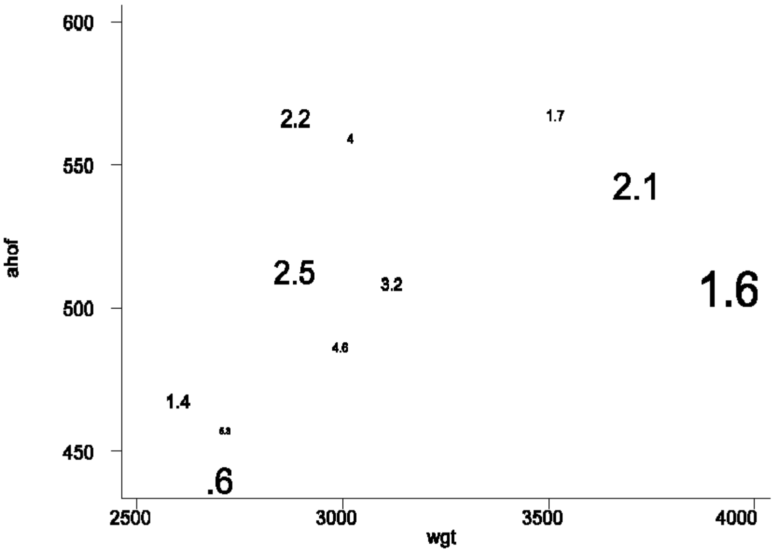

Figure 4.2.3-4 Relative (to comparable car-car collisions) car driver fatality risk in collisions where the front of a pickup truck struck the left side of a car, versus AHOF and weight of the pickup truck. The numbers representing the data points are the risks, their sizes are proportional to their statistical weights.

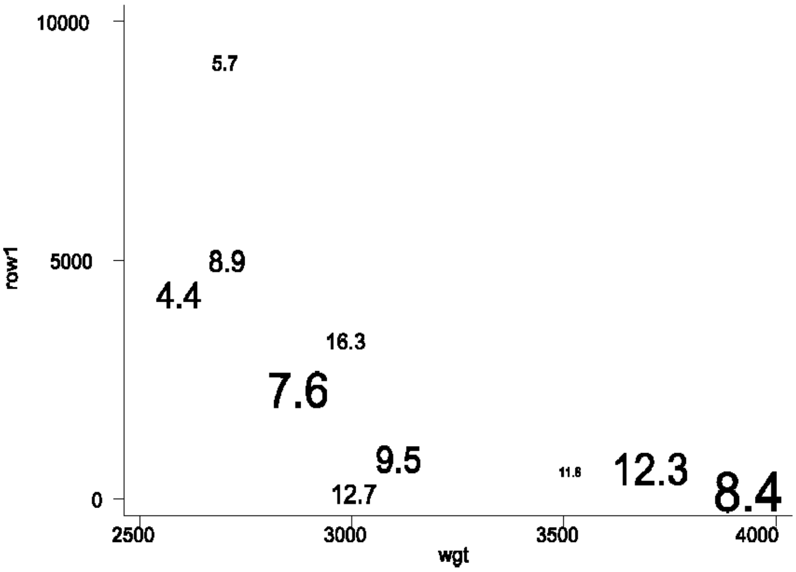

Figure 4.2.3-5 Car driver fatality risk (per 1,000 involvements) in collisions where the front of a pickup truck struck the left side of a car, versus impulse on row 1 and weight of the pickup truck. The numbers representing the data points are the risks, their sizes are proportional to their statistical weights.

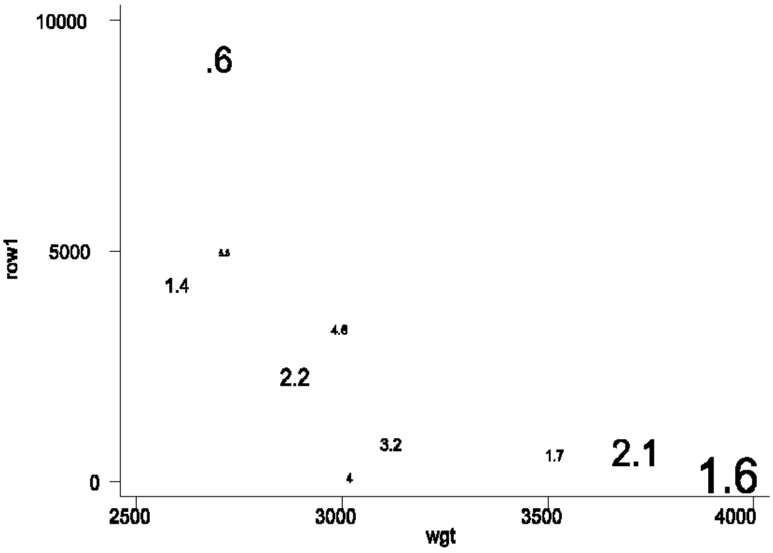

Figure 4.2.3-6 Relative (to comparable car-car collisions) car driver fatality risk in collisions where the front of a pickup truck struck the left side of a car, versus impulse on row 1 and weight of the pickup truck. The numbers representing the data points are the risks, their sizes proportional to their statistical weights.

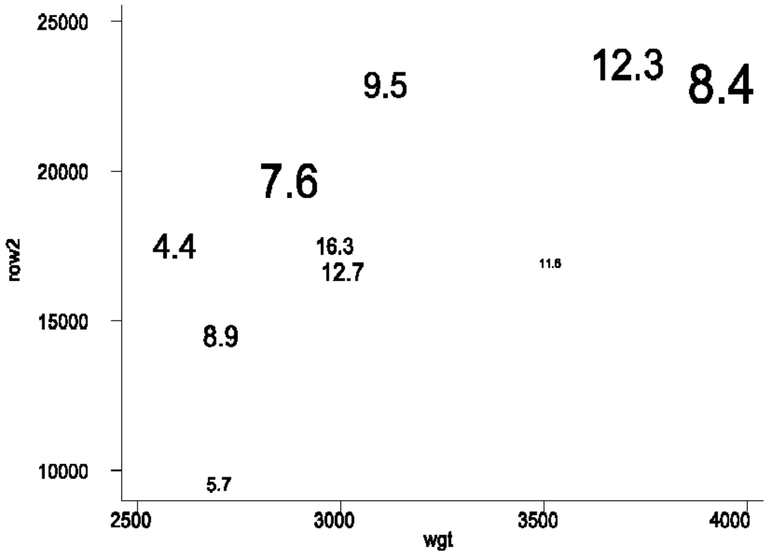

Figure 4.2.3-7 Car driver fatality risk (per 1,000 involvements) in collisions where the front of a pickup truck struck the left side of a car, versus impulse on row 2 and weight of the pickup truck. The numbers representing the data points are the risks, their sizes are proportional to their statistical weights.

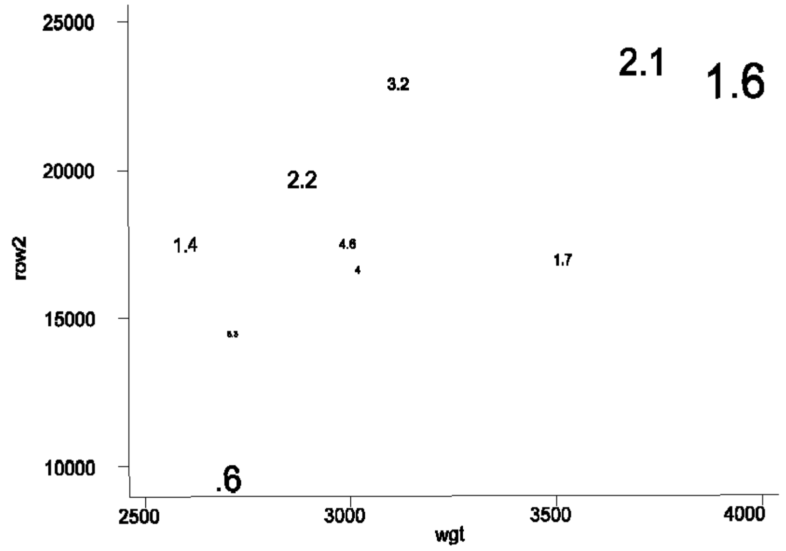

Figure 4.2.3-8 Relative (to comparable car-car collisions) car driver fatality risk in collisions where the front of a pickup truck struck the left side of a car, versus impulse on row 1 and weight of the pickup truck. The numbers representing the data points are the risks, their sizes are proportional to their statistical weights.

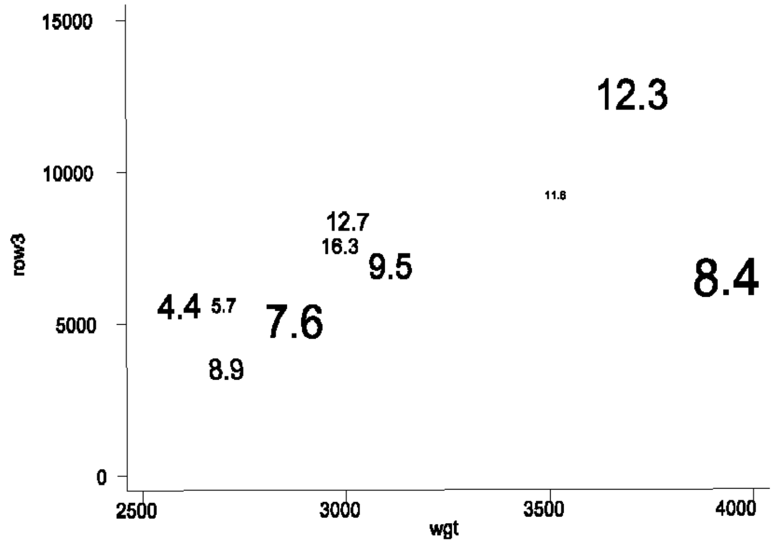

Figure 4.2.3-9 Car driver fatality risk (per 1,000 involvements) in collisions where the front of a pickup truck struck the left side of a car, versus impulse on row 3 and weight of the pickup truck. The numbers representing the data points are the risks, their sizes are proportional to their statistical weights.

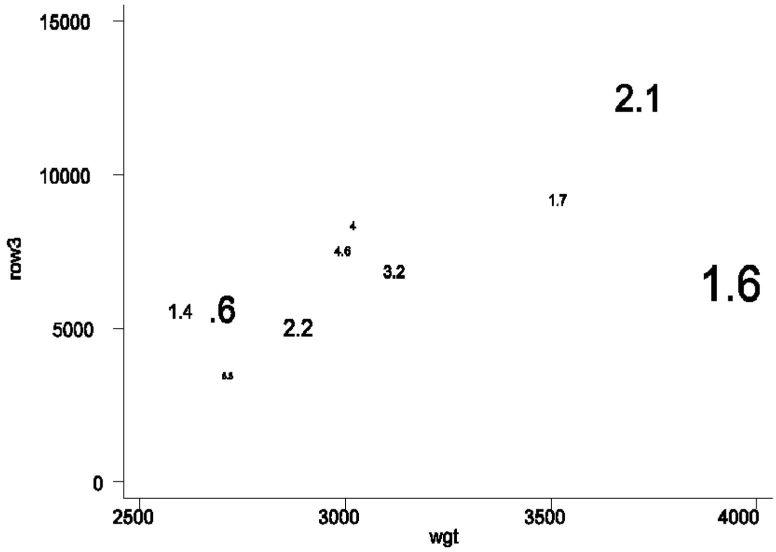

Figure 4.2.3-10 Relative (to comparable car-car collisions) car driver fatality risk in collisions where the front of a pickup truck struck the left side of a car, versus impulse on row 3 and weight of the pickup truck. The numbers representing the data points are the risks, their sizes are proportional to their statistical weights.

4.2.4 Front-Front Collisions with Pickup Trucks

Figure 4.2.4-1 shows the car driver fatality risk (per 1,000 involvements) in front-front collisions with pickup trucks versus weight of the pickup truck. It shows a fairly smooth increase of the risk with weight. This differs from the risk in all collisions between cars and pickup trucks (Figure 4.2.2.1-2), where a “step” at about 3,500 lb appears a plausible alternative to a smooth increase with weight. A comparison with the risk in left side collisions (Figure 4.2.3-1) shows a clear difference; in the front-left-side collisions, this risk does not seem to increase for weights over 3,500 lb.

The driver fatality risk relative to comparable car-car collisions is shown in Figure 4.2.4-2. It shows a fairly smooth increase with weight up to about 4,300 lb; the two points for higher weights are compatible with an accelerating trend for higher weights, though not necessarily suggesting it. This pattern is very different from that for all car-pickup-truck collisions (Figure 4.2.2.1-1) which shows clearly a declining trend with the weight of the pickup truck. A comparison with front-left-side collisions (Figure 4.2.3-2) shows a distinctly different pattern, where the relative risk increases for weights up to about 3,300 to 3,500 lb, but declines with higher weights; these differences suggest that very different mechanisms cause injury in frontal, left side, and other impacts, and that one can therefore expect different vehicle characteristics to have noticeable effects on the fatality risk in different collisions configurations.

In the preceding section, we examined graphs showing the absolute and the relative fatality risk versus weight of the pickup truck, and several of its crash test characteristics characteristics, one at a time. We also made exploratory regression analyses of the two risks versus each characteristics, with and without weight. The surprising result was that AHOF showed no relation with the risks. The impulses on the four rows of sensors showed only some weak indications of relations with the risks. Therefore, only weight, stiffness and peak power were studied further. Figures 4.2.4-3 through 8 show the plots of risk versus weight and one of the vehicle parameters, and Table 4.2.4-1 the coefficients of regression models fitting the data.

Figure 4.2.4-3 shows a clear trend of increasing risk with static stiffness for the lower weights, Figure 4.2.4-4 shows a similar, not quite as strong trend. The regression coefficients in Table 4.2.4-1 show the same. That the coefficients for the absolute risks are not “significant”, despite of the strong visual trend, whereas those for the relative risk are “significant”, even though the visual trend is not as strong, is due to the points for the higher weights.

For the dynamic stiffness, Figures 4.2.3-5 and 6, we have similar visual patterns, and similar coefficients, in this case both significant.

For the peak power (Figures 4.2.3-7 and 8), the trend of risk with peak power is not very strong for the lower weights. However, the two points for high weights also have high statistical weights, very different values for the peak power, and show a “trend” of increasing risk with power. This leads to the strong significance of the regression coefficients in Table 4.2.4-1.

In sum, while none of the measurements of the relevant “height” of the pickup truck appears related to the car driver fatality risk, stiffness and peak power are clearly related to it.

Table 4.2.4-1 Regression coefficients of models for car driver fatality risks in front-front collisions with pickup trucks. Non-standard errors are in parentheses. "Model I" includes weight of the pickup truck, "model 2" not. Non-standard errors are in parentheses.

variable	absolute risk (per 1,000 involvements)		relative risk (to car-car collisions)	
	model 1	model 2	model 1	model 2
static stiffness (mN/m)	14 (8)	11 (8)	1.5 (0.5)	1.6 (0.5)
weight (1,000lb)	5.7 (4.1)		.15 (.19)	
constant	-15 (20)	7.5 (11.2)	-1.4 (.9)	-.94 (.61)
dynamic stiffness (mN/m)	13 (4)	12 (5)	1.3 (.3)	1.3 (.3)
weight (1,000 lb)	5.5 (3.1)		.075 (.15)	
constant	-8.9 (11.6)	10.5 (5.1)	-.34 (.54)	-.10 (.24)
peak power (mN• m/s)	4.6 (1.8)	4.5 (1.7)	.17 (.09)	.18 (.10)
weight (1,000 lb)	1.9 (3.3)		-.40 (.23)	
constant	-16 (19)	-8.7 (12.7)	1.44 (1.07)	-.09 (.73)

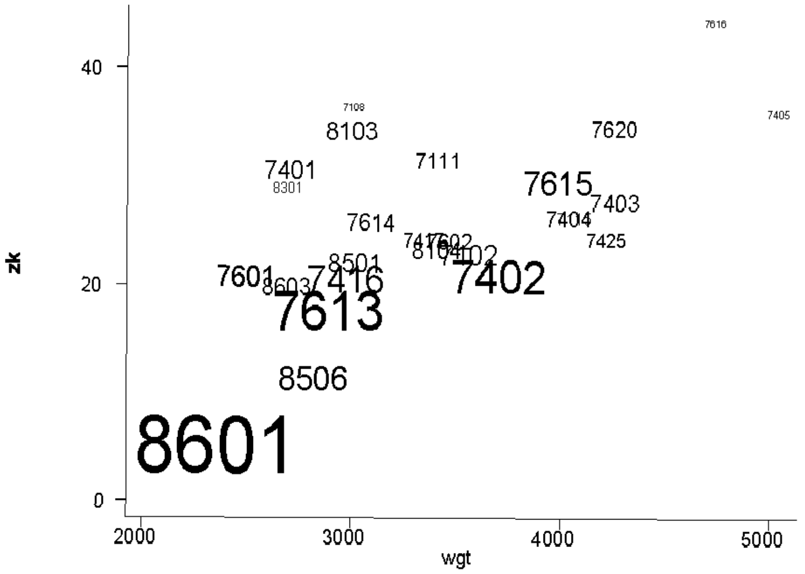

Figure 4.2.4-1 Car driver fatality risk (per 1,000 involvements) in front-front collisions with pickup trucks, versus weight of the pickup truck. The numbers representing the data points are Kahane's group codes for the pickup trucks, their sizes are proportional to their statistical weights.

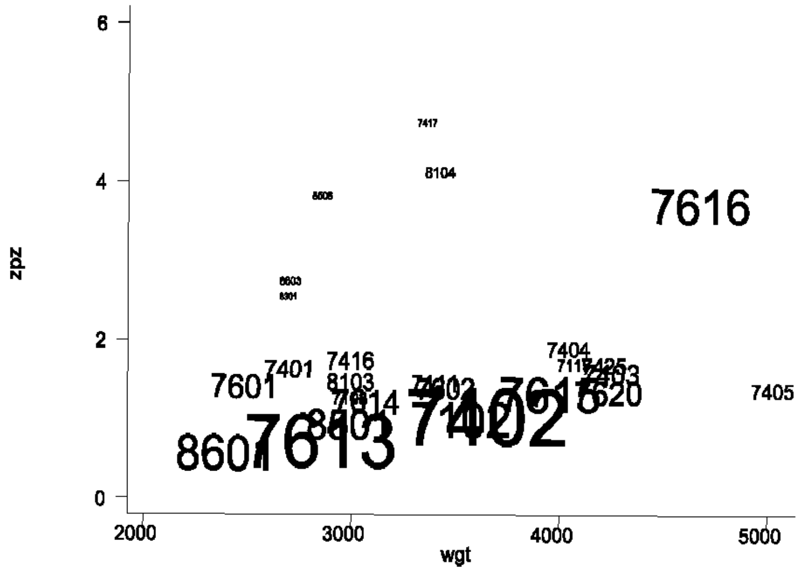

Figure 4.2.4-2 Relative (to comparable car-car collisions) car driver fatality risk in front-front collisions with pickup trucks, versus weight of the pickup truck. The numbers representing the data points are Kahane's group codes for the pickup trucks, their sizes are proportional to their statistical weights.

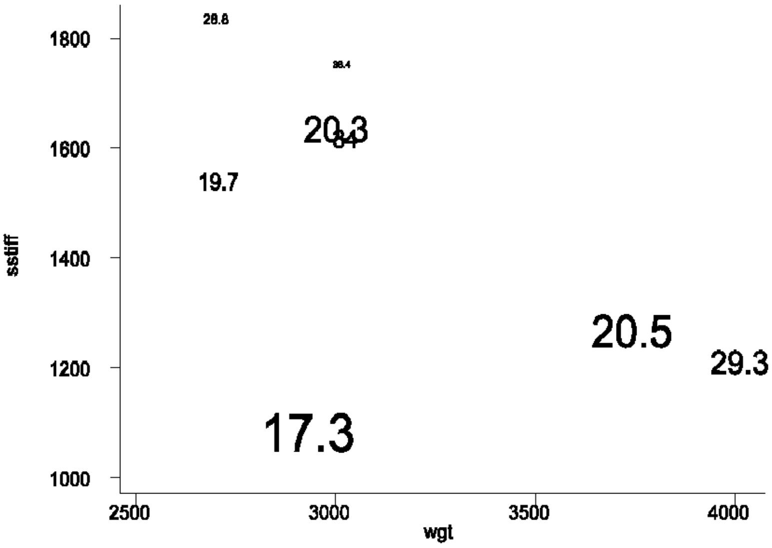

Figure 4.2.4-3 Car driver fatality risk (per 1,000 involvements) in front-front collisions with pickup trucks versus static stiffness and weight of the pickup truck. The numbers representing the data points are the risks, their sizes are proportional to their statistical weights.

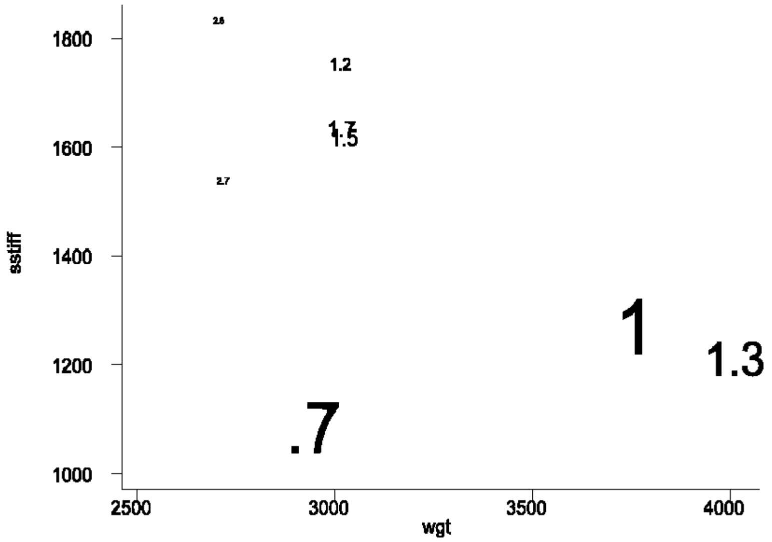

Figure 4.2.4-4 Relative (to comparable car-car collisions) car driver fatality risk in front-front collisions with a pickup truck, versus static stiffness and weight of the pickup truck. The numbers representing the data points are the risks, their sizes are proportional to their statistical weights.

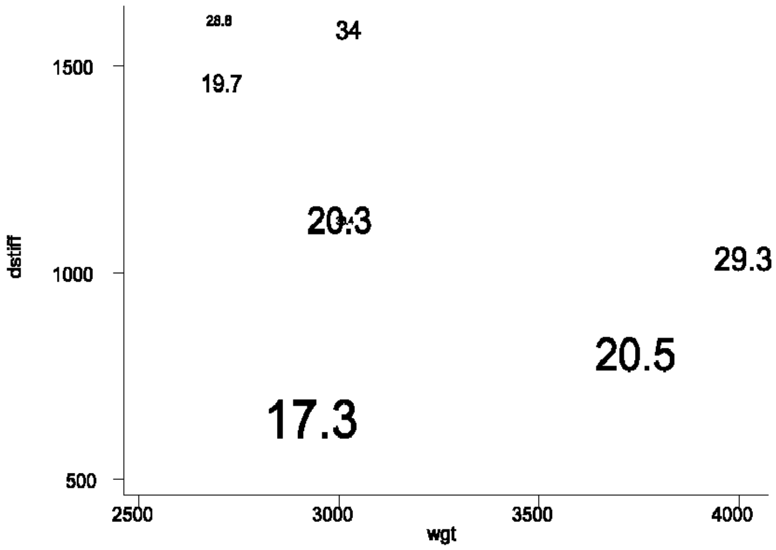

Figure 4.2.4-5 Car driver fatality risk (per 1,000 involvements) in front-front collisions with pickup trucks versus dynamic stiffness and weight of the pickup truck. The numbers representing the data points are the risks, their sizes are proportional to their statistical weights.

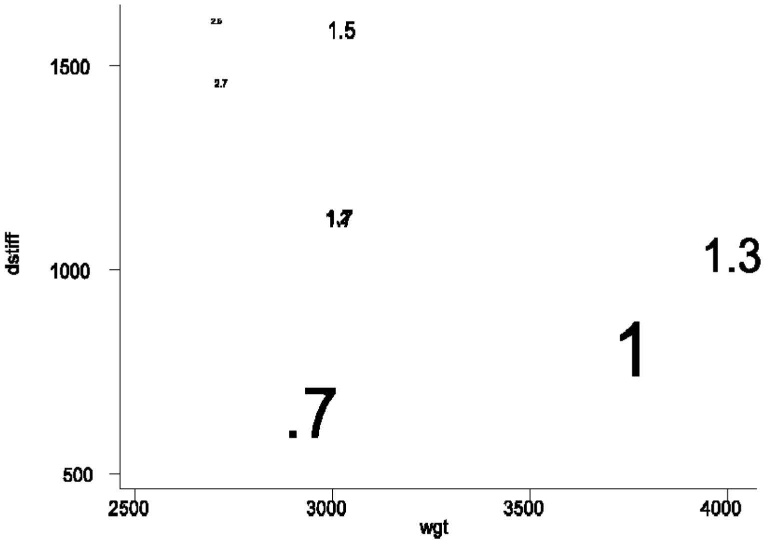

Figure 4.2.4-6 Relative (to comparable car-car collisions) car driver fatality risk in front-front collisions with a pickup truck, versus dynamic stiffness and weight of the pickup truck. The numbers representing the data points are the risks, their sizes are proportional to their statistical weights.

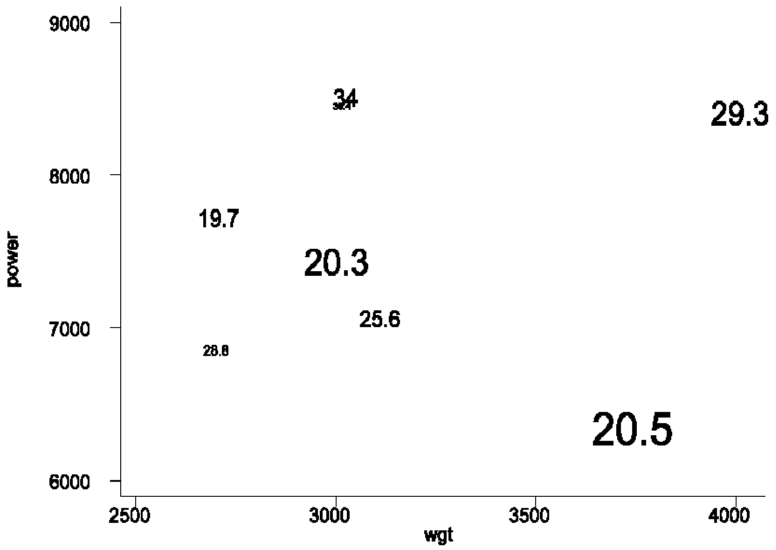

Figure 4.2.4-7 Car driver fatality risk (per 1,000 involvements) in front-front collisions with pickup trucks versus peak power and weight of the pickup truck. The numbers representing the data points are the risks, their sizes are proportional to their statistical weights.

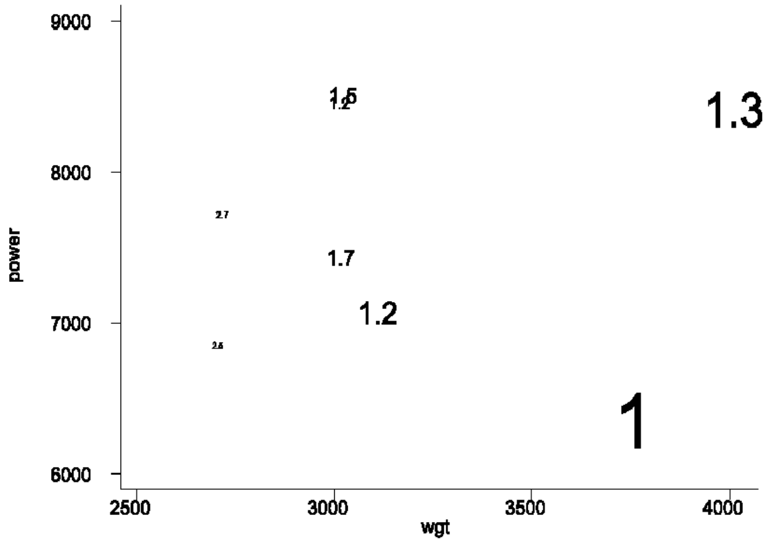

Figure 4.2.4-8 Car driver fatality risk (per 1,000 involvements) in front-front collisions with pickup trucks versus peak power and weight of the pickup truck. The numbers representing the data points are the risks, their sizes are proportional to their statistical weights.

4.3 Vans

4.3.1 All Collisions

Figure 3.2-7 where we made gross comparisons between car-car and car-van collisions for minivans and for larger vans showed an interesting pattern. Where the weight ranges for minivans and large vans overlapped, the relative risks for both types of vans declined with weight, but those for large vans were much higher. Pickup trucks and SUVs did not show such a pattern.

Figure 4.3.1-1 shows the car-driver fatality risks in collisions with vans by Kahane group. Minivans are identified by a "5", large vans by "6". To show the difference between them more clearly, separate regression lines are fitted to these points. For each type of van, the risk declines slightly with weight of the van, but the risks in collisions with large vans are much higher. Figure 4.3.1-2 shows relative (to comparable car-car collisions) risks in a similar manner. The general pattern is similar, but the slopes of the lines are much steeper.

These patterns suggest that there is a strong difference between the two classes of vans. An obvious candidate is the critical “height” of the vehicle. Figure 4.3.1-3 shows the average height of the force versus vehicle weight, again separating the two classes of vans. A similar graph for the height of the center of gravity is not shown, because for the large vans, only one value is known. In Figure 4.3.1-3, the points for the minivans are all below those for the large vans, but the separation is not strong. If one imagines a regression line through the points "5", and one through those marked "6", one gets a pattern very roughly similar to Figure 4.3.1-1.

This was analyzed more thoroughly. Figure 4.3.1-4 shows the average height of force versus van weight, and the car driver fatality risk. One can distinguish three groups of AHOF: minivans under 450 mm; minivans around 500 mm; and large vans. Within each group the fatality risk seems to vary little with weight. To check this more thoroughly, for each group a regression of risk against weight was run. Figure 4.3.1-5 shows the regression lines. The differences between the regression lines reflect potential effects of the differences in AHOF. To compare them quantitatively, the modelled values for 3,500 lb, shown in Table 4.3.1-1 were calculated. The same was done for the relative risks in Figures 4.3.1-6 and 7. Table 4.3.1-1 also shows the resulting differences of relative risks.

The risk difference between the highest and lowest groups is 2.32-1.72=0.60. The average AHOF for the lowest group is 42 cm, and for the highest group 54 cm. If one assumes a linear relation between risk and AHOF (but the three values indicate a greater increase per cm of AHOF between the second and third group than between the first and second, but their errors are very large), the risk increase per 10 cm difference is AHOF is 0.7. With an average risk of about 2, this is a 35% increase.

If we fit regression models to the data, not distinguishing groups by AHOF, we obtain the coefficients shown in Table 4.3.1-3. The coefficient for AHOF is slightly above 0.07, whether vehicle weight is included in the model or not. This agrees with the estimates of 0.7 per 10 cm difference in AHOF found above.

If one uses relative risks, one notices that the coefficients of the regression models change very much if van weight is not included in the model. This may indicate that the relative risks, largely based on an extrapolation of the risk model for car-car collisions, are less robust than the absolute risks. If one ignores the models for relative risks which do not include van weight, one obtains relative changes of 0.36 and 0.39 for a 10 cm change of AHOF, respectively, from Tables 4.3.1-1 and 2. With an average relative risk of about 1.5, the changes in relative risk range from about 15 to 25% per 10 cm change in the van's critical "height".

We also examined other factors. Only dynamic stiffness and power showed a consistent pattern. However, the coefficient of dynamic stiffness was significant only for absolute risks at +1.00 (.50) for dynamic stiffness in mN/m. The coefficient for peak power, -.12 (.05), for power in mN• m/s, was significant only for relative risks. Graphs showed no clear relations.

Table 4.3.1-1 Modelled car driver fatality risks in collisions with vans, for vans of 3,500 lb weight, for three ranges of AHOF. Non-standard errors are in parentheses. An (x) indicates that the non-standard error could not be calculated.

AHOF range (cm)	absolute risk (per 1,000 involvements)		relative risk (to car-car collisions)	
<45	1.72	(x)	1.13	(x)
45 - 51	1.94	(.22)	1.38	(.13)
>51	2.32	(.69)	1.56	(.11)

Table 4.3.1-2 Regression coefficients of models for car driver fatality risks in collisions between cars and vans. Non-standard errors are in parentheses.

variable	absolute risk (per 1,000 involvements)				relative risk (to car-car collisions)			
	model 1		model 2		model 1		model 2	
AHOF (cm)	.071	(0.044)	0.074	(0.038)	.039	(.026)	.001	(.022)
weight (1,000 lb)	.065	(0.360)			-.420	(.20)		
constant	-1.670	(2.01)	-1.58	(1.85)	.880	(.95)	1.12	(1.11)

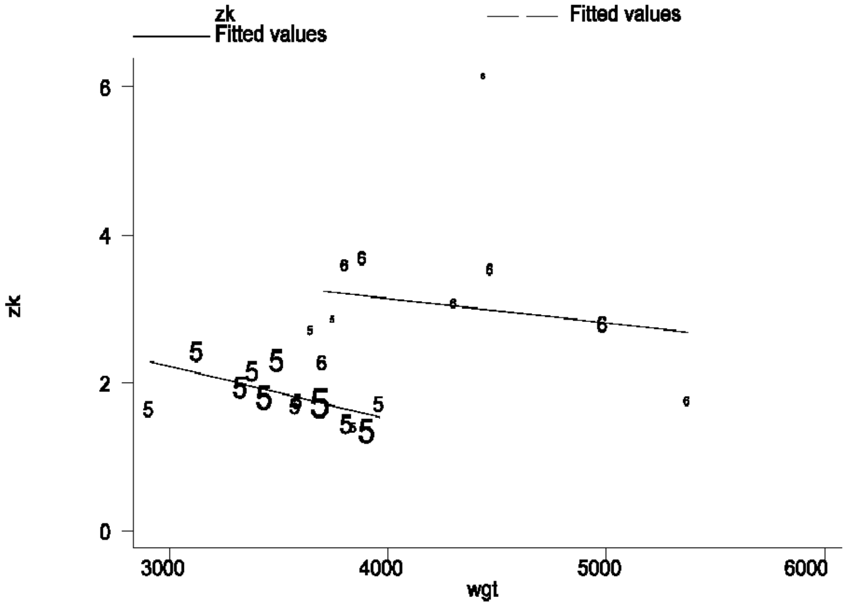

Figure 4.3.1-1 Car driver fatality risk (per 1,000 involvements) in collisions with vans, versus weight of van. Points for minivans are shown as "5", points for large vans as "6". Their sizes are proportional to their statistical weights. The lines are regression lines fitted to the points.

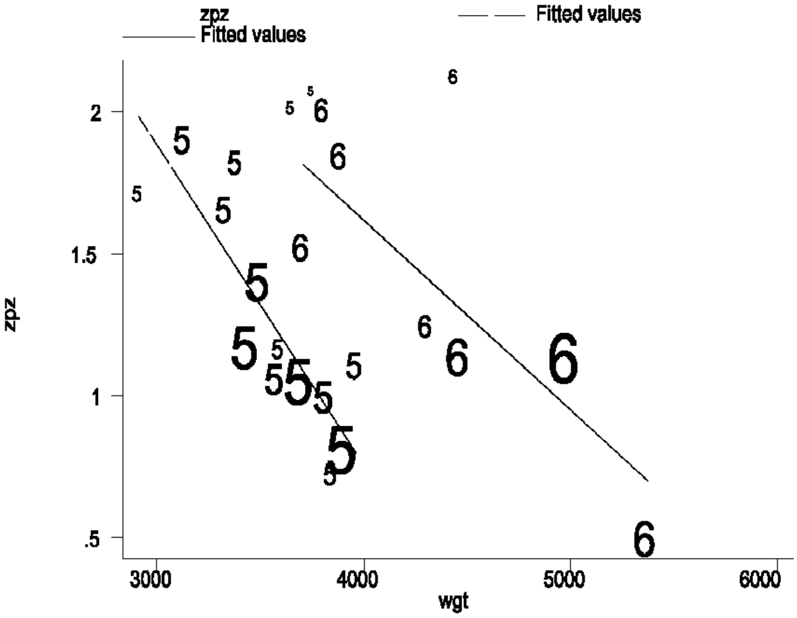

Figure 4.3.1-2 Relative (to comparable car-car collisions) car driver fatality risk in collisions with vans, versus weight of van. Points for minivans are shown as "5", points for large vans as "6". Their sizes are proportional to their statistical weights. The lines are regression lines fitted to the points.

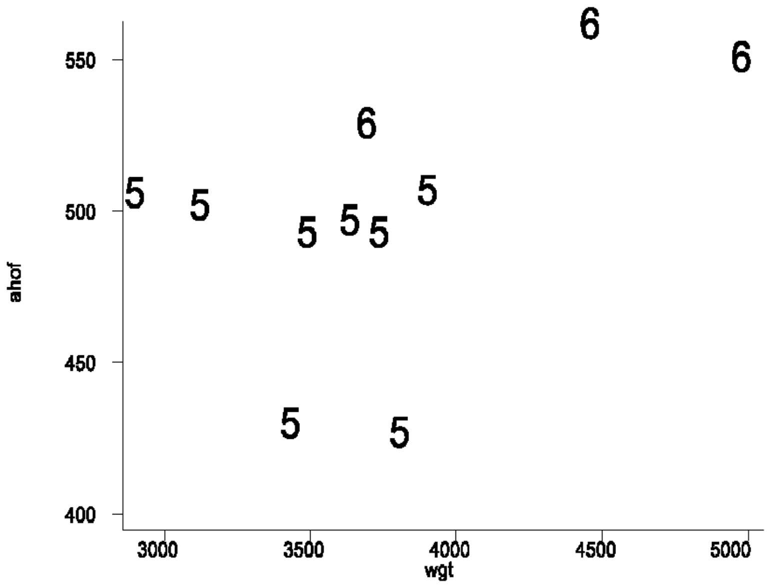

Figure 4.3.1-3 Height of the average force for vans versus van weight. Points for minivans are shown as "5", points for large vans as "6".

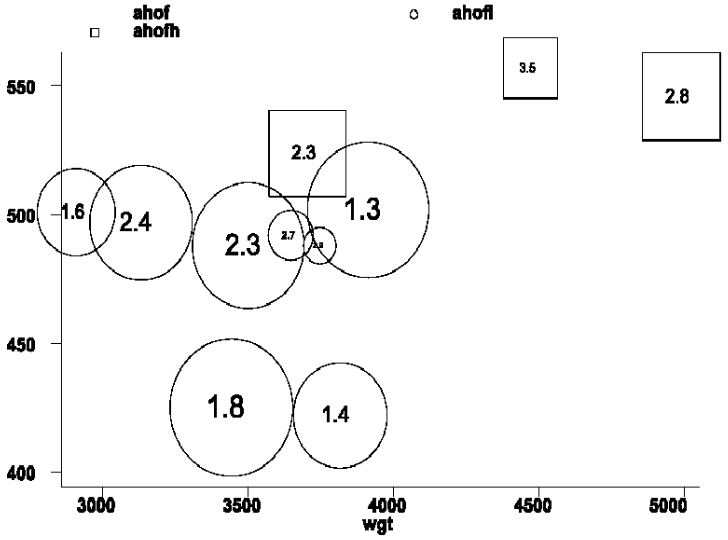

Figure 4.3.1-4 Average height of force versus weight of van. The numbers representing the points are the car driver fatality risks in car-van collisions (per 1,000 involvements). Points for minivans are “circled”, points for large vans”boxed”. The sizes of the symbols are proportional to their statistical weights.

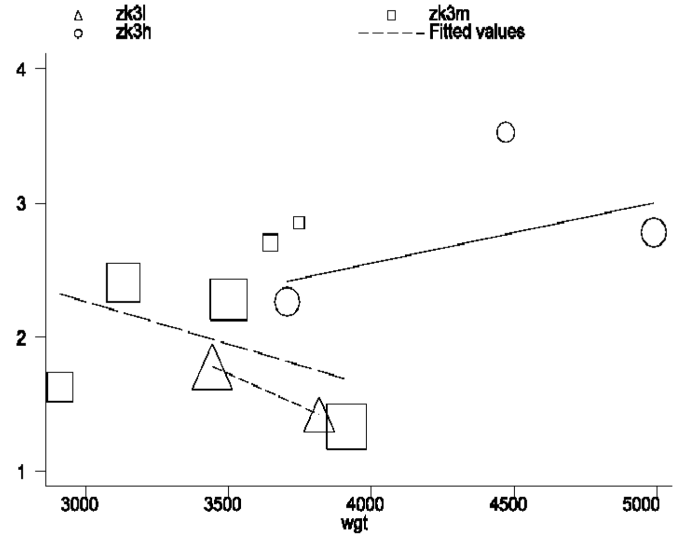

Figure 4.3.1-5 Car driver fatality risk (per 1,000 collisions) in car van collisions versus weight of van, for three groups of vans: with AHOF<450mm, AHOF 450 to 510 mm, and AHOF >510 mm. These groups are represented by triangles, squares, and circles, respectively. The sizes of the symbols are proportional to the statistical weights of the points. The lines are regression lines versus weight for the three groups.

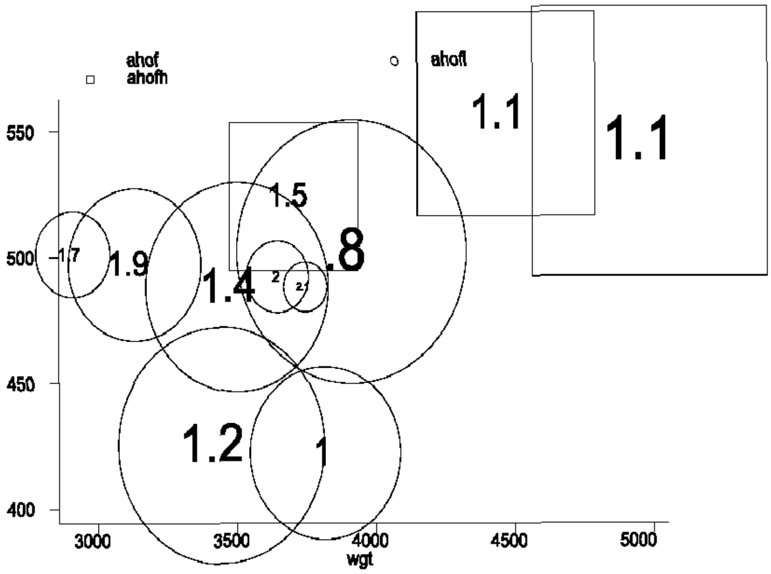

Figure 4.3.1-6 Average height of force versus weight of van. The numbers representing the points are the relative (to car-car collisions) car driver fatality risks in car-van collisions. Points for minivans are "circled", points for large vans"boxed". The sizes of the symbols are proportional to their statistical weights.

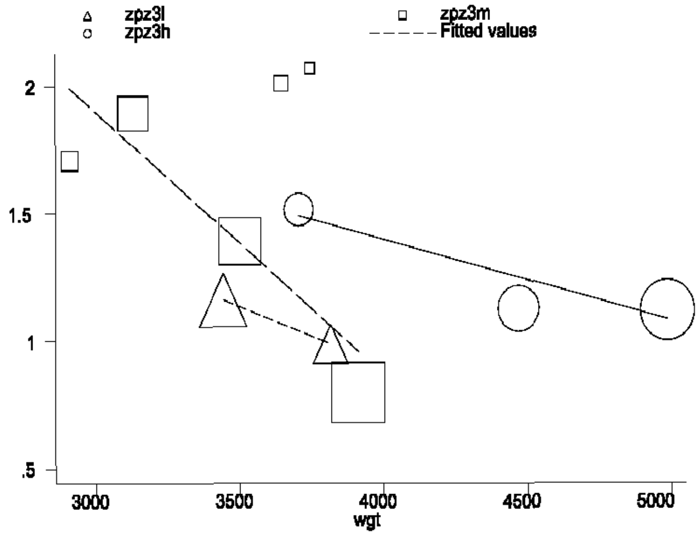

Figure 4.3.1-7 Relative (to car-car collisions) car driver fatality risk in car van collisions versus weight of van, for three groups of vans: with AHOF< 450 mm, AHOF 450 to 510 mm, and AHOF > 510 mm. These groups are represented by triangles, squares, and circles, respectively. The sizes of the symbols are proportional to the statistical weights of the points. The lines are regression lines versus weight for the three groups.

4.3.2 Left Side Impacts by Vans

Because of the much lower number of collisions where the front of a van impacted the left side of the car, fewer van groups had sufficient case numbers to be used for studying this collision configuration than for all car-van collisions.

Figures 4.3.2-1 and 2 show, similar to Figures 4.3.1-1 and 2, the absolute and the relative car driver fatality risk versus van weight, by van class. For the absolute risks, there is also a large offset where the weight ranges overlap, but the slopes have opposite signs. For the relative risk they are quite different, for all collisions, there are two roughly parallel lines with downward slope; for the side impacts there are two lines with very small — opposite — slopes, and little offset.

We proceeded as in section 4.3.1 and calculated regressions of absolute and relative risks versus van weight, separately for three groups of AHOF. The results are shown in Figures 4.3.2-3 and 4, which correspond to Figures 4.3.1-5 and 7. Here however, the regression lines through the two points in the lowest group of AHOF have extremely unlikely slopes, and the extrapolation of the lines for the highest group of AHOF gives for 3,500 lb lower values of the absolute and of the relative risks than for the middle group. Thus, this approach allowed no plausible conclusion on the effect of AHOF.

Table 4.3.2-1 shows consistent coefficients for absolute risk, which correspond to a difference of 2.4 or 2.9 per 10 cm. That is 3 to 4 times as much as found in section 4.3.1. Even if one uses percentage change against an average risk of 5, the increases of 50 or 60% are higher than the 35% found in section 4.3.1.

Other factors showed no consistent relations to the risks.

Table 4.3.2-1 Regression coefficients of models for car driver fatality risks in collisions with the front of a van striking the left side of a car. Non-standard errors are in parentheses.

variable	absolute risk (per 1,000 involvements)				relative risk (to car-car collisions)			
	model 1		model 2		model 1		model 2	
AHOF (cm)	0.24	(0.16)	0.29	(0.15)	.075	(0.072)	.002	(0.06)
weight (1,000 lb)	1.75	(2.03)			-.70	(0.50)		
constant	-11.9	(8.4)	-8.1	(7.0)	.83	(2.65)	1.7	(2.8)

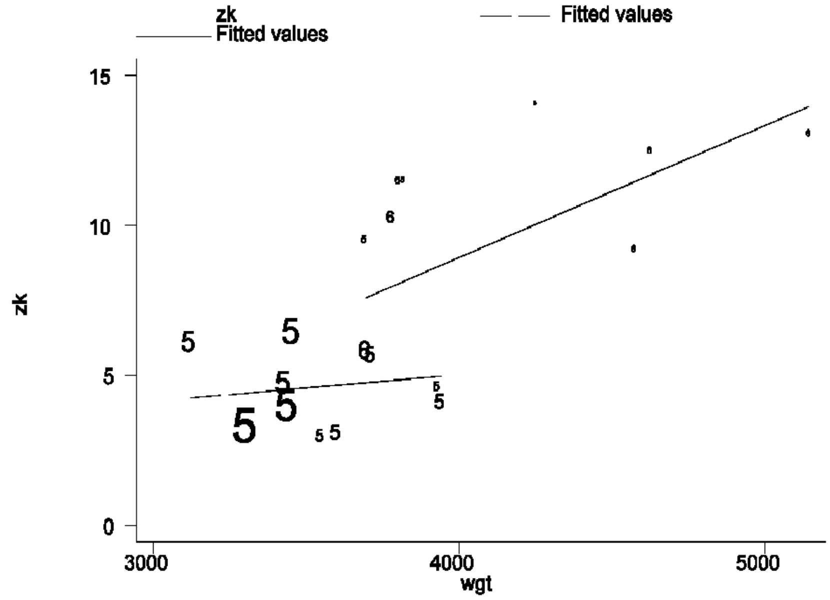

Figure 4.3.2-1 Car driver fatality risk (per 1,000 involvements) versus weight of the van in collisions where the front of the van struck the left side of the car. Points for minivans are shown as "5", points for large vans as "6". Their sizes are proportional to their statistical weights. The lines are regression lines fitted to the points.

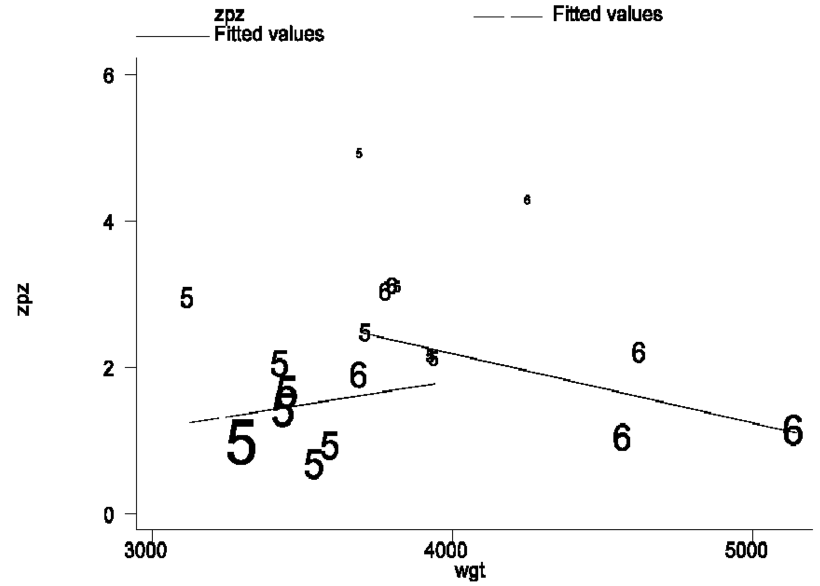

Figure 4.3.2-2 Relative (to car-car collisions) car driver fatality risk versus weight of the van in collisions where the front of the van struck the left side of the car. Points for minivans are shown as "5", points for large vans as "6". Their sizes are proportional to their statistical weights. The lines are regression lines fitted to the points.

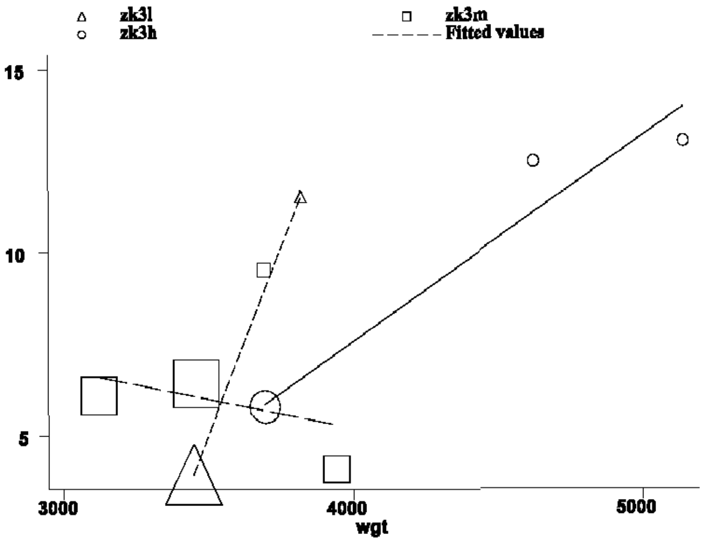

Figure 4.3.2-3 Car driver fatality risk (per 1,000 collisions) versus weight of van, in collisions where the front of the van struck the left side of the car, for three group of vans: with AHOF <450 mm, AHOF =450 to 510 mm, and AHOF >510 mm. These groups are represented by triangles, squares, and circles, respectively. The sizes of the symbols are proportional to the statistical weights of the points. The lines are regression lines versus weight for the three groups.

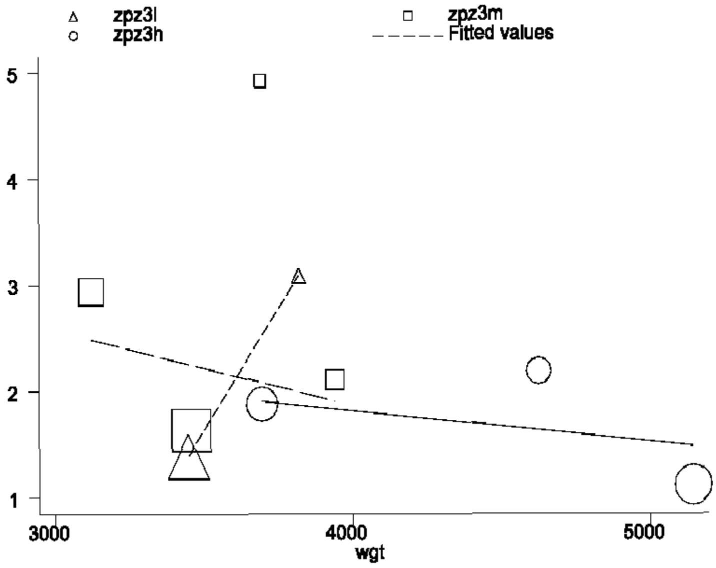

Figure 4.3.2-4 Relative (to car-car collisions) car driver fatality risk versus weight of van, in collisions where the front of the van struck the left side of the car, for three group of vans: with AHOF <450 mm, AHOF =450 to 510 mm, and AHOF >510 mm. These groups are represented by triangles, squares, and circles, respectively. The sizes of the symbols are proportional to the statistical weights of the points. The lines are regression lines versus weight for the three groups.

4.3.3 Front-Front Collisions

For this collision configuration, no consistent relation between the car driver fatality risk of the van was apparent (Figures 4.3.3-3 and 4). Regressions between the risks and AHOF (model 2), even when van weight was included (model 1), showed no “significant”, not even approaching “significance”, coefficient. This does not mean that AHOF might not have an effect; it might be just too small to be detectable in the relatively small numbers of front-front collisions.

However, we noted that the peak power showed relations with the risk, either “significant”, or approaching it. Table 4.3.3-1 shows the coefficients. The negative coefficients of power is counterintuitive.

Table 4.3.3-1 Regression coefficients of models for car driver fatality risks in front-front collisions with vans. Non-standard errors are in parentheses.

variable	absolute risk (per 1,000 involvements)				relative risk (to car-car collisions)			
	model 1		model 2		model 1		model 2	
power (mN• m/s)	-1.9	(1.1)	-1.6	(1.0)	-0.24	(0.12)	-0.19	(0.13)
weight (1,000 lb)	2.7	(3.8)			0.75	(.50)		
constant	21	(14)	29	(8)	0.23	(1.86)	2.57	(1.11)

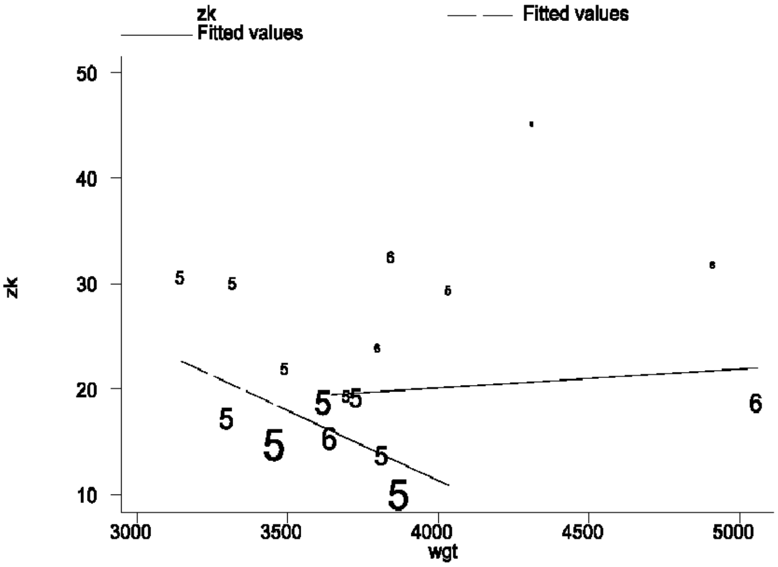

Figure 4.3.3-1 Car driver fatality risk (per 1,000 involvements) in front-front collisions with a van versus weight of the van. Points for minivans are shown as "5", points for large vans as "6". Their sizes are proportional to their statistical weights. The lines are regression lines fitted to the points.

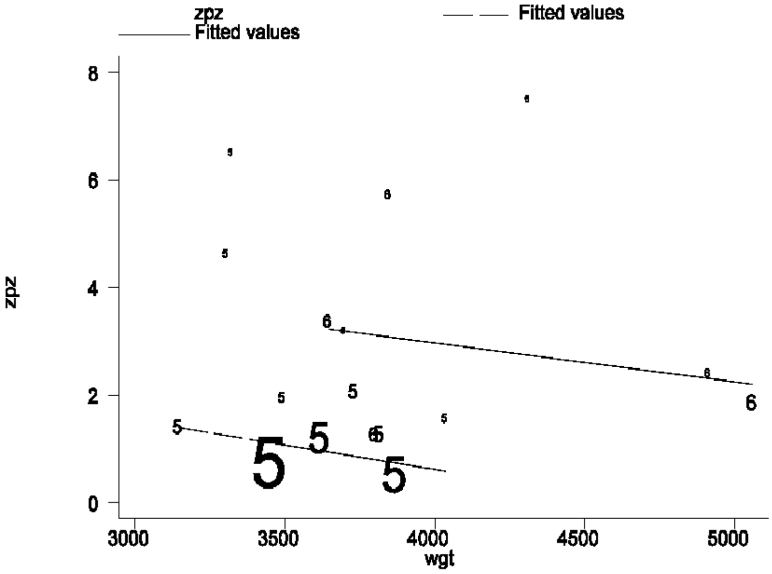

Figure 4.3.3-2 Relative (to car-car collisions) car driver fatality risks in front-front collisions with a van versus weight of the van. Points for minivans are shown as "5", points for large vans as "6". Their sizes are proportional to their statistical weights. The lines are regression lines fitted to the points.

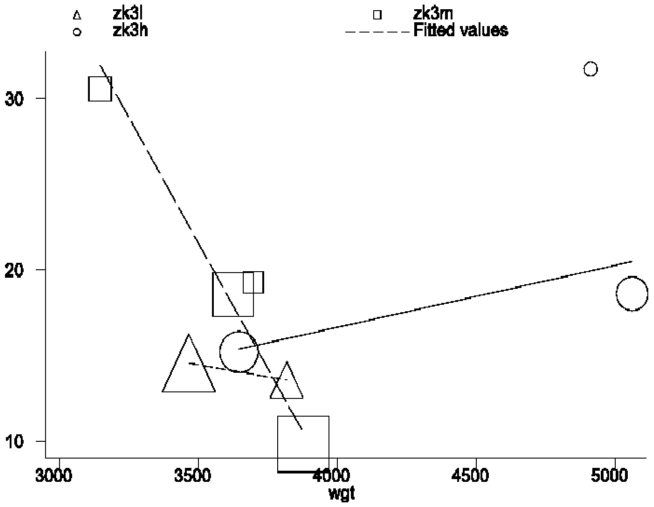

Figure 4.3.3-3 Car driver fatality risk (per 1,000 involvements) in front-front collisions with a van versus weight of van, for three groups of vans: with AHOF <450 mm, AHOF = 450 to 510 mm, and AHOF > 510 mm. These groups are represented by triangles, squares, and circles, respectively. The sizes of the symbols are proportional to the statistical weights of the points. The lines are regression lines versus weight for the three groups.

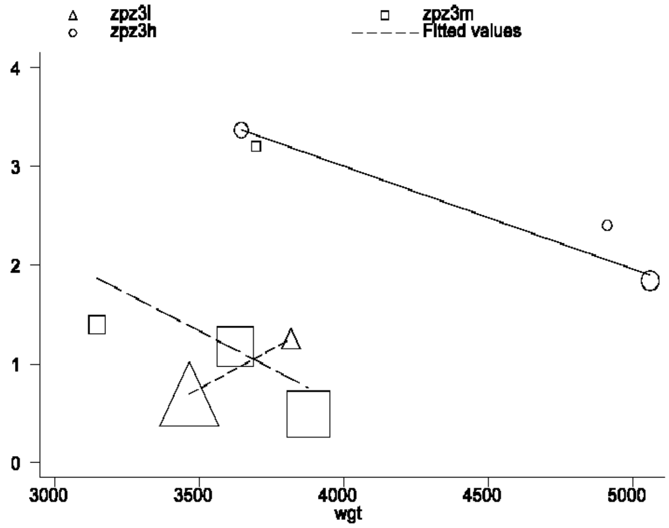

Figure 4.3.3-4 Relative (to car-car collisions) car driver fatality risks in front-front collisions with a van versus weight of van, for three groups of vans: with AHOF <450 mm, AHOF = 450 to 510 mm, and AHOF > 510 mm. These groups are represented by triangles, squares, and circles, respectively. The sizes of the symbols are proportional to the statistical weights of the points. The lines are regression lines versus weight for the three groups.

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions Regarding the Approach

Out of several possibilities we selected an approach to develop statistical models for the car driver fatality risk in car-car collisions as a baseline with which to compare car driver fatality risks in car-LTV collisions.

Initially, we tried to develop models that included both vehicles' weights, both drivers' ages, both drivers' sexes, and the speed limit. We found it too laborious to develop such models within the scope of the contract, but we later completed development of one of these models outside of the scope of the contract. It is presented in Appendix C. That model gave an excellent representation of the actual risk over the range of vehicle weight, driver ages, and speed limit for which it was developed, and also with regard to the drivers' sexes.

The models we actually developed for use in this work used only the characteristics of the "other" vehicle and its driver, and the speed limit. Ignoring the characteristics of the case vehicle and its driver may increase the uncertainty of the model parameters, and possibly introduce biases. These simple models represented the actual risk comparably well as the more comprehensive model presented in Appendix C.

However, most cars are in the weight range below 3,500 lb, relatively few are in the range between 3,500 and 4,000 lb, and only very few have weights above 4,000 lb. Compact pickup trucks, compact SUVs, and minivans weigh up to between 3,500 and about 4,000 lb. Thus, the models developed for car-car collisions should form a solid baseline for estimating the aggressivity of these types of LTVs.

Full size pickup trucks, full size SUVs, and large vans typically weigh more than 4,000 lb, and only in some cases slightly less. This means that their aggressivity metric is estimated by extrapolating the models for car-car collisions into a weight range where their agreement with reality can not, or at least not very precisely, be checked. Thus, the aggressivity metrics for full size pickup trucks, full size SUVs, and large vans depend critically on the validity of the extrapolation. Even from a purely mathematical point of view, extrapolation is very uncertain, as the errors of extrapolated values quickly "blow up" if one exceeds the range on which the model is based. In our case, the matter is even more complicated, since the majority of the cars in car-car collisions had weights below 3,000 lb. The part of the risk-weight relation which is critical for the extrapolation was strongly influenced by the much fewer cases in the 3,000 to 3,500 lb range, and the even fewer cases in the 3,500 lb and higher range. With the few cases in that range, the effect of different variables can no longer be reliably separated– even if it seems to be so if one relies on the estimated error– and slight modifications of the model, compatible with the available data, can result in different extrapolations. Much more sophisticated work than was possible within the scope of the contract is necessary to adequately deal with this question.

Consequently, we believe that our aggressivity estimates for LTVs up to about 4,000 lb of weight rely on solid bases of models for car-car collisions. Aggressivity estimates for heavier LTVs, however, critically rely on extrapolation of the models and may be much less reliable.

5.2 Estimates of Aggressivity

Tables 5.2-1 through 3 summarize the overall findings on the aggressivity of LTVs (and also of different car classes). Table 5.2-1 shows absolute car driver fatality risks (per 1,000 involvements) by type and weight of the other vehicle in the collision.

The average fatality risk in a car-car collision is 1.0 (it happens to be 1.0 per 1,000 involvements, it is not a “standardized” or “normalized” value). If the other vehicle is a car weighing less than 3,000 lb, the risk is only 0.8 (the average weight of the cars under 3,000 lb is 2,600 lb). For cars between 3,000 and 4,000 lb (with an average weight of 3,400 lb) the risk is 1.4; and for cars above 4,000 lb (with an average weight of 4,800 lb) it is also 1.4. These are actual risks, confounded by other factors, such as more younger drivers and women for the lighter, more older drivers and men for the heavier cars.

If the other vehicle is a pickup truck or a SUV, the risk to the car driver is roughly three times as high as in a collision with another car. Their heavier weight (averaging 3,500 and 3,700 lb, compared with 2,800 lb for cars) accounts for much of the difference. The right side of the table shows more detail by separating the smaller and larger LTVs (roughly corresponding to those weighing less than 4,000 and those weighing more). For the heavier LTVs, the risk to the car occupants is three to four times as high as in a collision with an average (2,800 lb) car. It is also much higher than in collisions with the heaviest cars, for instance 3.3/1.4=2.4 times as high in collisions with a large pickup, though its average weight of 4,100 is less than that of the heaviest cars, which are 4,300 lb. Considering the magnitude of the non-standard errors, one can say that the risk in collisions with large LTVs is approximately 3.5/1.4=2.5 times higher than in collisions with large cars, though their weights are comparable.

Table 5.2-1 Car driver fatality risk (per 1,000 involvements) in collisions with other car, or LTVs, by type of other vehicle and its weight range. Each entry contains the estimated risk, its non-standard error in parentheses, and the average weight of the other vehicle.

	weight			
vehicle type	all weights	<=3,000 lb	3,000 - 4,000 lb	> 4,000 lb
car	1.0 (.1) 2,800	.8 (.1) 2,600	1.4 (.1) 3,400	1.4 (.2) 4,300
pickup truck	3.3 (.3) 3,500	2.8 (.3) 3,000		3.8 (.4) 4,100
SUV	2.6 (.3) 3,700		2.5 (.3) 3,500	3.2 (.6) 4,700
van	2.3 (.2) 3,700		1.9 (.2) 3,500	3.2 (.3) 4,300

For the lighter SUVs and vans (in the 3,000 to 4,000 lb range) one can say that the risk to the car driver in a collision is approximately 2.1/1.4=1.5 times higher than in a collisions with a car in the same weight range, though their average weights are practically the same.

For compact pickup trucks, the situation is slightly different. Their average weight of 3,000 lb is between that of the light cars, 2,600 lb, and that of the mid-weight cars, 3,400. If one compares the average risk for them, 1.1, with that for the compact pickup trucks, 2.8, one finds that the latter is 2.8/1.1=2.5 times higher.

Table 5.2-2 Modelled fatality risk (per 1,000 involvements) for a car driver in a car-car, or car-LTV collision, if the other vehicle had been replaced by a comparable car, by type of other vehicle and its weight class. Each entry contains the modelled risk, and the average weight of the other vehicle.

	weight							
vehicle type	all weights		<=3,000 lb		3,000 - 4,000 lb		> 4,000 lb	
car	1.0	2,800	.8	2,600	1.4	3,400	2.1	4,300
pickup truck	2.1	3,500	1.6	3,000			2.7	4,100
SUV	1.8	3,700			1.6	3,500	2.7	4,700
van	1.7	3,700			1.5	3,500	2.3	4,300

These comparisons “controlled” for vehicle weight by a coarse weight classification. However, other factors such as speed limit and driver age can have much stronger effects on the fatality risk than vehicle weight. Table 5.2-2 provides a basis for “controlling” for the effect of the other factors. It shows the risks which a car driver would have faced in a collision with another vehicle, if the other vehicle had been replaced by a car, but keeping all variables unchanged. For instance, the risk for a driver of an “average” car is 1.4 if colliding with a car in the 3,000 to 4,000 lb range, averaging 3,400 lb. If he had collided with a car of the same weight, but with drivers and at a speed limit as in the collisions with SUVs, the risk would had been 1.6. This means that difference in drivers and driving environment alone would make collisions with compact SUVs 15% more dangerous than collisions with cars between 3,000 and 4,000 lb. Similarly, collisions with large SUVs are about 30% — (2.7/2.1-1)•100 — more dangerous than collisions with cars heavier than 4,000 lb. One notices that compared with the difference shown in Table 5.2-1, those in Table 5.2-2 are relatively small.

Table 5.2-3 shows the “aggressivity” of the various groups of vehicles, expressing it as the ratio of actual fatality risks to those expected due to differences in vehicle weight, driver characteristics, and speed limit. For cars, we find what we expect for weights up to 4,000 lb. The ratios for cars of low and middle weight are 1, because the modelled risks are based on the actual risks, and the model fits the data well.

Table 5.2-3 Relative (to comparable car-car collisions) car driver fatality risks in collisions with other car, or LTVs, by type and weight class of other vehicle. Each entry contains the relative risk, its non-standard error in parentheses, and the average weight of the other vehicle.

		weight		
vehicle type	all weights	<=3,000 lb	3,000 - 4,000 lb	> 4,000 lb
car	1.0 (.1) 2,800	1.0 (.1) 2,600	1.0 (.1) 3,400	.6 (.1) 4,300
pickup truck	1.6 (.2) 3,500	1.8 (.2) 3,000		1.4 (.2) 4,100
SUV	1.4 (.2) 3,700		1.6 (.2) 3,600	1.2 (.2) 4,700
van	1.4 (.1) 3,700		1.3 (.1) 3,500	1.4 (.1) 4,300

For heavy cars, however, the ratio is only 0.6, showing that the model overpredicts the expected risks dramatically. The non-standard error is so small that the difference against 1 is extremely unlikely due to random errors. This means that the extrapolation of the model to weights above 4,000 lb, where there are few car-car collisions, is speculative and unreliable. This also means that all the values in the rightmost column, which are based on the extrapolated part of the model, are unreliable. Therefore, we can not trust the estimates of aggressivity for standard pickup trucks, standard SUVs, and large vans, as increasing the fatality risk for car drivers by 40, 20, and 40%, respectively. However, we may attempt a heuristic adjustment. Since the value for collisions with heavy cars should be 1 instead of 0.6, the risk for heavy cars was overestimated by 50% — obtained from 2.1/1.4 —. If one is willing to make an adjustment for this, one obtains aggressivity factors of 2.7 for standard pickup trucks, 1.8 for standard SUVs, and 2.1 for large vans. These estimates are, of course, speculative. Reliable are, however, the estimates for compact pickup trucks, compact SUVs, and minivans of 1.8, 1.6, and 1.3, respectively. With the estimated non-standard errors, the difference between 1.8 and 1.6 is far from “significant”, and even the difference between 1.3 and 1.6 is not “significant”.

5.3 Relations Between Risk and LTV Characteristics

Relations between LTV characteristics and the car driver fatality risk in collisions were studied separately for SUVs, pickup trucks, and vans, and for each of them for all collisions with cars, collisions where the front of the LTV struck the left side of the car, and front-front collisions. Table 5.3-1 gives a simplified overview of the findings. AHOF appears as a strong, or a suggestive factor in all “all” collisions, and in the front-left collisions. A related measure, the height of the center of gravity from the ground, appears once. The impulses on the four rows of sensors appear also. Static and/or dynamic stiffness appear several times, but not for SUVs. The peak power appears four times, but has the “wrong” negative sign in three of these cases.

Quantitative estimates of the relations vary widely. Simple estimates show that for SUVs, fatality risks increase by 38% to 47% per 10 cm increase in AHOF, assuming a linear relation. Closer examination of the relation suggested that there might be a “threshold” of about 60 cm, below which the risk varies little with AHOF, but above which it varies strongly. One estimate suggests that up to a weight of 4,300 lb, the risk increases by 23% per 10 cm increase in AHOF, but more than doubles per 10 cm increase in AHOF for heavier SUVs. Another estimate gives an increase of 23% per 10 cm for SUVs under 3,800 lb, but 72% for SUVs above that weight.

For pickup trucks, we get a suggestion of a relation between risk and AHOF, but only if vehicles with less reliable test data are included in the analyses. They are too uncertain to allow any quantitative estimates.

For vans, we find an increase of the risk by about 35% for a difference of 10 cm in AHOF, and 15-25% for the relative risk. The 35% increase approaches that found for SUVs.

Other measures of a critical “height” of the LTV are the distributions of the impulses on the 4 rows of sensors, and the height of the center of gravity from the ground.

For SUVs, a simple relation appears, where the distribution of the impulse over the upper 3 rows of sensors seems to make no difference in the risk, but increasing the impulse on the lowest row decreases the risk. Whether this is an actual effect, or whether it just reflects a difference in effect between forces acting low and acting high on the vehicle could not be determined with the available data.

The height of the center of gravity from the ground appears as a factor only in collisions with SUVs. The overall relation with the risk is similar to that for AHOF; an increase of 26 to 38% per 10 cm difference in CGFG. However, a difference is that the greater change holds for SUVs lighter than 3,500 lb, and the smaller for the heavier ones. This should be interpreted with caution; there were no SUVs heavier than 4,500 lb with known CGFG.

Static and dynamic stiffness had “significant” relations with the risk in collisions with pickups, in collisions with vans only dynamic stiffness. Peak power had a counterintuitive relation, with a negative sign, with the risk in collisions with vans.

In front-left collisions, AHOF showed relations with the risk. Overall the risk change was between 30 and 40% per 10 cm change of AHOF. For AHOF under 55 cm, it was 40%, for AHOF over 55 cm, about 15%. This decrease of change of risk with increasing AHOF contradicts the finding for all collisions. For relative risk, the changes are smaller, between 7 and 18% per 10 cm difference in AHOF.

For pickup trucks, trends of increasing risk with AHOF were noted, but none were “significant”.

For vans, the risk increased by 50 to 60% for 10 cm difference in AHOF. Front-front collisions showed, presumably because of the low case numbers, few patterns. No measure of height showed a clear relation with risk.

Peak power seemed to be related to the risk for all LTV types. For SUVs and Vans, the relations were “significant”, but had the “wrong” sign: an increase reduced the fatality risk. Only for pickup trucks peak power showed the expected positive relation with the risk. Static and dynamic stiffness showed the expected relations with risk for pickup trucks.

Table 5.3-1 LTV characteristics found to be related to car driver fatality risk in collisions between cars and LTVs. A question mark indicates suggestions of relations. (-) indicates a negative relation.

LTV type	collision type		
	all	front-left	front-front
SUV	AHOF CGFG Row 1 (-) Row 4	AHOF	peak power (-)
pickup truck	Row 4 (-) stiffness AHOF ?	AHOF	stiffness peak power
van	AHOF dynamic stiffness peak power	AHOF	peak power (-)

5.4 Recommendations Concerning Data

We found that more information is needed to identify characteristics contributing to LTV aggressivity. The average height of force was found to be an important characteristic. However, because it is calculated from forces on four rows of fairly wide sensors, its precision is necessarily limited. As a conceptually related measure we also used the height of the center of gravity from the ground. It is conceptually less satisfying, but more easily and more precisely available. It would be desirable to obtain such measures for a larger number of LTV groups. Even more important would be to obtain the heights, and possibly other measurements of frame rails, bumper supports, bumpers, and possibly other structural elements for a larger number of LTV groups.

Reliable characteristics were available only for a relatively small number of LTV groups. This limited the power of the analyses which were performed. We suspect that using larger numbers of LTV groups, even if the values of their characteristics are less precise, may reveal relations which we could not recognize in this work. The best approach seems to be to rank the crash tests in terms of their reliability: those judged to be most reliable; those which are complete, but less reliable; those where some measurements are reliable, but others missing or unreliable (identifying them); and those considered unreliable.

The basis of our LTV classifications was Kahane's vehicle groups, defined according to their "platform". While this is a physically valid and very useful classification for our purposes it can be improved in some cases. For instance, it sometimes puts 2 and 4 door versions of the same vehicle into different groups. In other cases, the frontal structure of a pickup truck and of a SUV may be very similar. In such cases, for the study of frontal impacts by LTVs it seems promising to define larger groups which combine LTVs of essentially the same front structure. If crash test data for only one of them would be available, one could impute to the other and gain precision by using a larger number of collisions. If crash test data for several of them were available, one would also gain precision by averaging the crash test results.

As confounding factors, we used driver age, driver sex, and the speed limits. Other driver factors may also have effects on the apparent aggressivity of LTVs, e.g. alcohol use, and the socioeconomic status of the driver. Alcohol information in FARS and even more in GES is neither complete nor reliable. However, imputed values are available. One has to find ways to use it, without biasing the results obtained. Especially important would be to find credible ways to use only the more reliable alcohol information in FARS, but ignore that in GES.

There are two potential indicators for socioeconomic status, vehicle age, which is available in FARS and GES, and vehicle price. The latter is available but to collect it is time consuming. It is desirable to collect that information into an easily accessible data base.

5.5 Recommendation Regarding the Analytical Approach

This study approached the problem in two steps. In the first step, models for car-car collisions were developed. Actual risks in car-LTV collisions were compared with those predicted by models for comparable car-car collisions. The ratios of the actual to the predicted risks were studied in relation to LTV characteristics to determine which ones showed significant relations.

The first step turned out not to be completely successful. The data base contained relatively few collisions involving cars with weights over 3,500 lb, and very few with weights over 4,000 lb. We obtained models which represented the risks in car-car collisions very well up to weights of about 4,000 lb, but underestimated them for higher weights (and there were too few cases to credibly modify the models so that those cases were fit better). Comparing risks in car-car collisions with car-LTV collisions also suggested that the car-car model could not be credibly extrapolated to weights over 4,000 lb.

The main reasons for using car-car collisions as a basis for comparisons are that they allow to estimate how much more aggressive LTVs are than cars, which is important for policy decisions, and that the large number of car-car collisions allows estimating a reliable model, so that the effect of factors confounding the apparent aggressivity of LTVs could be more reliably adjusted for.

If one were interested only in adjusting for confounding factors, one could have used a different approach. One could have ignored car-car collisions, and developed models for only the collisions of cars with LTVs of the different classes. Selecting certain “standard” values, e.g. 30 years old male drivers, and speed limits of 55 mph, one would would have obtained standardized risks for the different LTV groups, and then relate the standardized risks to the LTV characteristics. The main disadvantage of this approach is that the number of car-LTV collisions is so much smaller than the number of car-car collisions, that the effect of the confounding factors could be only imprecisely estimated, and therefore the standardized values be less precise. Another disadvantage is that different relative risks may be obtained for different sets of “standard” confounding factors.

A third approach is to use car-car, and car-LTV collisions in one model that includes terms for LTV characteristics, and possibly interactions between vehicle type and confounding factors. The great disadvantage of this approach is that model fitting is very laborious, and that very complex models seemed to result. Therefore, we recommend that these approaches be more thoroughly compared and one selected that does not rely on extrapolating a model beyond the range on which it is calibrated, but which will use as much of the available data as possible, and not lead to very complicated models.

Another point concerns the second step, which involves fitting models for the relative risks in car-LTV collisions in relation to the LTV characteristics. Since the statistical precision of the estimated absolute and relative risks varies greatly, we used weighted regression for models. Weights were obtained from errors estimated considering the complex survey structure of GES (and an ad hoc device to introduce binomial variability into the FARS data). There were some surprises, as some car groups had high weights, even though they were based on relatively few cases. The reverse was not observed; risk estimates based on large case numbers tended also to have high statistical weights. Points based on few cases, but with high statistical weight caused some concern when we noticed that down-weighting them could have a strong effect on some regression coefficients. Therefore, we recommend to more thoroughly study the question of appropriate weighting in the second step.

In this study, three types of collisions were studied: all planar collisions; front (LTV) to left side (car); and front-front collisions. Models for all collisions combine very different collisions configurations in which different physical process cause injury and death. Therefore, they are also influenced by the relative frequencies of the different collision types. Differences between models for different SUVs can therefore result from differences in the frequencies of collision types, and not only from differences in their physical characteristics. Nevertheless, it is worthwhile to study “all” collisions, to obtain an overall picture on the effects of LTVs on deaths in collisions. In front-side collisions, and in front-front collisions, differences in collisions configuration have smaller confounding effects, and the models should more closely reflect the physical effects of the vehicle characteristics included. However, the case numbers are much smaller. Therefore, only much smaller (in terms of the numbers of coefficients) models could be developed.

Therefore, we also recommend that an intermediate level of disaggregation be studied. One group, combining all collisions where the front of the LTV strikes the car anywhere; and the other, where a car strikes with its front an LTV anywhere but in the front. The first has the advantage that the forces that the front of the LTV exerts on the car should be more similar to the forces it exerts on the barrier in a test, than in all collisions. Also, it would allow us to aggregate LTVs with similar front ends (see section 5.4). The other group of cases combines collisions where the "height" of the LTV may play a major role, somewhat similar as in an underride. In this situation, purely static characteristics, such as the height of the rocker panel, or the height of the center of gravity may be more important than dynamic features, such as AHOF.

5.6 Recommendations on Statistical Work

This study used an inhomogenous data base which is a combination of FARS and GES. It depended critically on developing a mathematical model for the probability of death as a function of several variables. Making "point" estimates of the coefficients of such models poses no serious problems, though it can be complicated. Estimating errors of the estimated coefficients is not only practically, but also conceptually difficult. For such modelling, one has to assume that the FARS cases, and the population from which GES samples are taken, are random variables. Each "potential" accident has a probability with which it occurs; only those which occur are known. In addition, there are the sampling errors of GES. It is desirable to have techniques that allow this to be handled in a routine manner.

It is also desirable to allow separation of the effects of the random variability of the crash counts, and the sampling variability due to the sampling of the GES cases, from the sampling errors resulting from the selection of the PSUs and police jurisdictions (PJs) in GES. Since the selection of PSUs has remained constant over a long time, and PJs are also selected for longer time periods, these error components are approximately constant over time. Thus, they should be ignored in year-to-year comparisons, or trend analyses over short time periods.

The relations between fatality risk, car weight, and driver age are highly nonlinear. Most vehicles fall into a fairly narrow weight range, whereas the major changes of risk with weight occur outside of this range. Similarly, the number of cases is decreasing with increasing driver age, but the risk is dramatically increasing at the highest ages. Standard estimating procedures give greatest weight to the ranges with most cases, even though a practically negligible worsening of the fit in this range may allow a dramatically better fit outside it. It would be desirable to have simple procedures which allow such trade-offs.

To represent the highly nonlinear relations we found, we used "kinky" relations, including terms of the form $(x - a) \cdot (x > a)$. Standard routines calculate errors for the coefficients of such terms, but it is not clear how they should be tested, because they are largely, possibly entirely, based on only part of the cases, sometimes a small part. This should be studied.

Some “errors” are correlated. For instance, a certain make/model may differ in crashworthiness from others of comparable weights. Thus, an error component by make-model should be considered. This could be done by adding a term for each make-model, but then it would no longer be possible to estimate a relation with car weight, except in a second level analysis of the “error” terms. A strategy to deal with this issue is needed.

“Influential observations” are of interest, especially at very low or high vehicle weights, or high driver ages, where there are only few cases. Techniques to deal with individual observations are available. In our context, however, situations arose where certain make/models, or a PSU constituted “influential groups”. Techniques to identify such groups are desirable.

APPENDIX A DATA

The data base were the 1991-99 FARS and GES files. The Volpe National Transportation Systems Center (VNTSC) prepared special files for this work. The file included collisions between two vehicles, cars or LTVs, not towing a trailer, excluding those where a vehicle was not in transport, or the manner of collision unknown.

VNTSC decoded the Vehicle Identification Number (VIN) and derived from it, for vehicles of model years 1985 and later, two codes developed by Dr. C. Kahane and Marie Walz of NHTSA; a four-digit “car group” code (also for LTVs), which reflects the platform on which the vehicles are built, and a four-digit make/model code. Also, vehicle weights corresponding to these codes were assigned. Where these weights were missing, we imputed them by either assigning the average weight for the same make/model over all model years, or the average weight for the car group.

As "case" vehicles, vehicles of model years 1985 and later were used, first because of the availability of the Kahane codes, and vehicle weights, second, because the more recent vehicles are of greater interest than older ones which will soon drop out of the vehicle population.

FARS contains all fatal crashes in the USA. GES is a sample of all police reported crashes; if expanded, it includes also all fatal crashes. Therefore, a simple combination of FARS and GES would double the number of fatal crashes. To avoid this, fatal crashes were dropped from the GES files when combining them with FARS.

GES is a complex sample. The country is divided into four geographic regions, and three types of land use, which combine to 12 strata (there is a further complication: for two self-representing PSUs [primary sampling units], additional strata are created). Within each stratum, a number of PSUs are randomly selected. They are indicated in Table A-1 by their number, or an “x”. This pattern has remained constant over the study period 1991-99. Within each PSU, either a sample of all crashes is taken, or first a sample of police jurisdictions (PJs) is taken, and then within each PJ crashes are sampled. The selection of most PJs has also remained constant over time, but some have been replaced by others in later years. At the last level of sampling, crashes are stratified by crash type into four strata, and within each of them police crash reports are sampled.

Table A-1 GES strata and PSUs. Regions, types, and the strata resulting from their cross-classification. Numbers show the PSUs used in this study. “x” indicates PSUs not used. States are shown for illustration; they enter the GES sampling plan only by defining regions.

		type		
region	state*	central city	suburban	other
Northeast	MA		x x	
	NJ			x
	NY	x x x	x x x	x
	PA	x	x x x	
Midwest	IL	72**	91	
	IN		x	
	IA			93
	MI	32	10 12 33	11 13
	MD		92	
	NE	74		
	OH	x	x	x
	WI		71	
South	AL		47	48
	FL	41	42	61
	KY			28
	MD		9	
	NC			43 44
	OK	64		
	TN		45 46	
	TX	49 63	50 62	51
	VA		x	
West	AZ		77	76 78
	CA	x	x x x	
	CO		75 94	
	NM		95	
	WA	82	81	

*States are shown for information only. They are not part of the sampling plan.
**Chicago is self-representing and treated as a separate stratum.

For this study, the VIN is a critical data item. FARS shows the VIN for nearly all cars and LTVs. In GES, the VIN is systematically missing; within a PSU, either VINs are given for the vast majority or even nearly all cases, or for none or only few. In the Northeast, VINs were missing in nearly all PSUs. Therefore, we dropped the GES cases from the Northeast region, and the FARS cases from the corresponding states from the data base; indicating this by “x” for the PSUs in Table A-1.

In the South, only one PSU, indicated by an “x” had too few VINs. It affects only the South - suburban stratum. GES cases from this PSU were omitted, and the weights (expansion factors) for the remaining 7 PSUs increased by a factor 8/7. This gives statistically valid estimates of police reported crashes in this stratum. The situation was similar in the three strata representing the Midwest. Here, in each of the strata 1/4 of the PSUs had missing VINs.

Therefore, the GES cases from these PSUs were dropped, and the weights for the other PSUs increased by a factor of 4/3.

In two of the Western strata, PSUs had missing data, all from California. One could have proceeded as in the South and Midwest, and obtained statistically valid estimates. However, California accounts for a high proportion of the crashes in the West, but it differs in many respects from the other Western states. Therefore, making estimates for the entire West only from the other states would probably have introduced strong biases.

Therefore, a new region was defined for the West excluding California. To make estimates for this new region, we obtained from NHTSA crash numbers for the corresponding strata, and for California within these strata, and adjusted the GES weights accordingly.

To make error estimates, any statistical program requires at least two PSUs in each stratum. The stratum WxCA-central-city contained only one PSU, 82. To circumvent this difficulty, we created two artificial PSUs by randomly separating the PJs in PSU 82 into two groups.

Our analyses used driver age and sex, car weight, and speed limit as independent variables. In FARS, values were rarely missing or unknown. In GES, this occurred more often[1]. These cases were simply omitted. This resulted in a systematic overestimation of fatality risks. Whether it biases the estimates of aggressivity, or the underlying mathematical models could have been determined only by very extensive analyses.

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[1] Dr. Daniel Blower of UMTRI noted that speed limit is missing in certain PSUs. In our data set, it is missing in Chicago.

APPENDIX B ERRORS

The data and the results are subject to several kinds of errors:

- “gross errors” in data acquisition and coding
- missing information
- sampling errors in GES
- the random variability of the actual crash counts

Gross errors occur if crashes which are supposed to be reported are not; crashes which are not to be reported are included in the data files; or if information on the report form is wrong, e.g. age of the driver, speed limit, etc. Errors occur also in coding. In FARS, extensive quality control reduces such errors, in GES such checks are less thorough. Researchers usually ignore such errors, hoping that they will implicitly be included in the error estimates produced by the analytical techniques. In this study, this was also done. However, this assumption is not conceptually sound. The standard analytical techniques can capture only errors in the dependent variable. A rigorous treatment of errors in the independent variables requires much more thorough study.

In FARS, missing information is relatively rare; in GES it occurs frequently. Therefore, GES provides “imputed” values for many data items when the information is missing. They allow to make unbiased estimates of simple totals or means. However, it depends strongly on the details of the imputation and any patterns among the missing data whether this holds also for functional relations based on imputed values. Therefore, cases with critical information missing were omitted in this work. This results in an upward bias of the fatality risks estimated. Whether such biases show a pattern across crash types can not be assessed.

Most complex is the sampling error. The GES sampling plan consists of a stratification based on a cross-classification of geographical regions and land use, a first level of clusters, the PSUs, (one or several counties), a second level of clusters, (police jurisdiction within the PSUs,) and within the PSUs simple random sampling within four strata determined by crash type. Though these last strata are used in practice at the lowest sampling level, they are conceptually at the highest level.

The standard definition of the sampling error in such a complex sampling plan is that it reflects the variance among the results one would obtain if one took many different samples, following the same sampling plan, from the same population, e.g. all crashes in the entire US in one year. In our GES data base, the situation is slightly different. The overall sampling plan has remained constant over the period covered. The selection of the first level clusters has also remained constant over the period, and most of the selection of the second level cluster has also remained constant; only in recent years have in some PSUs different police jurisdiction been selected. That means that the contribution to the errors made by the choice of the PSUs, and most of that made by the choice of the police jurisdiction has remained constant.

Therefore, one can consider it as being more akin to a bias than to a random error. The only truly randomly varying element in our data base is the selection of the individual cases. This distinction could be important, because the error contributed by the selection of PSUs and PJs will not be reduced if GES data are accumulated over longer time periods; only the errors introduced by random sampling at the last stage will be reduced.

During a certain time period in one area, traffic crashes defined by a specific reporting criterion are a fixed number and as such not subject to statistical analyses. However, for research purposed they are considered realizations of random variables. Only this allows to answer questions such as whether a change from one year to another is "real", or whether an apparent relation between deaths and a certain variable is "real" or just due to chance. A common assumption is that the number of accidents of a certain type – be it defined as a broad class, or a very narrow one by the values of several pre-crash factor – is a Poisson-distributed random variable; sometimes more complex distributions are assumed. Thus, nationwide counts of GES cases– all or only of certain types– as well as of FARS cases are to be treated as random numbers.

In the case of FARS, it is easy to deal with this issue, assuming that each FARS case is a realization of a binomially-distributed random variable which has a value of 0 or 1 – only cases with 1 appearing in the FARS file – and a certain expected value p allows straightforward statistical analyses.

In the case of GES, the situation is more complex. Again, one can assume that each crash is a random variable with value 0 or 1 (in this case, zero meaning that no crash occurs, 1 that a crash occurs; only the latter cases appearing in the GES files), with an expected value p. This means that if there are x crashes of a certain type, x is an estimate of the expected number m, and as a Poisson variable has the variance m, estimated by x.

The number x is not known, but GES gives an estimate $\hat{x}$. NHTSA publishes approximate estimates of the sampling error of $\hat{x}$. Under the Poisson assumption, $\hat{x}$ is an estimate of the variance of the random variable x. Comparing the Poisson variance with the sampling error, we find that the "error" resulting from the Poisson-variance is 8% of the sampling error for a count estimated to be 1,000, 1% for a count estimated to be 1,000,000. This means that for GES counts the random variability may be neglected relative to the sampling error. This was done in this study. However, this may not be true in some of the more complex analyses. If some relations are not, or only little affected by the "bias" component of the sampling error, and primarily by the case selection component, the random variability could contribute a higher percentage.

If one combines FARS and GES data into one file, how can one reconcile the different approaches to estimating errors? First a new, additional PSU stratum was created, which included all FARS cases. Since FARS cases have no PSU, they were randomly assigned to a number of newly created PSUs, ranging from 2 to 100. The statistical program used estimated errors from the differences of the estimates for the PSUs within each PSU stratum. In this case, this roughly approximated making estimates from the FARS data as if the cases had been binomially distributed. With an increasing number of these fictitious PSUs from 2 to 100, the “error” calculated for the estimates increased initially rapidly, then more slowly, and finally remained practically constant. For the actual analyses, 10 fictitious PSUs were used; the effect of using more was negligible.

The software used, STATA, allows to estimate sampling errors considering the stratification, and the first level clustering; it does not provide for the effect of the second-level clustering at the PJ level. To explore the effect of this, we also performed some analyses using the PJs as PSUs, thus greatly increasing their number. The effect on the error estimates was negligible. Therefore, we used the STATA program, using the actual GES PSUs, ignoring the second level clustering, and randomly assigning the FARS cases to 10 fictitious PSUs.

Initially we had planned to use bootstrapping to make error estimates which allowed to incorporate all sampling stages of GES, to separate the effects of the GES quasi-bias from the random effect, and to consider the random nature not only of the FARS, but also of the GES cases. Though we found this conceptually feasible, the computational effect turned out to be prohibitive.

APPENDIX C AN EXTENSIVE MODEL FOR CAR-CAR COLLISIONS

The preliminary analyses had determined that the following factors had appreciable effects on the car driver fatality risk in car-car collisions: the weight of both cars; the ages of both drivers; the sexes of both drivers; and the speed limit at the location of the collision. There are other factors which also have appreciable effects, but the relevant information was either not available, incomplete, or considered unreliable.

The initial plan was to develop fatality risk models including all these seven variables. This turned out to be impractical, and the models were limited to using only the factors relating to the “other” vehicles, the aggressivity of which should be studied.

However, such a model was developed outside of the scope of this contract for presentation at the Transportation Research Board meeting in Washington D.C. on January 16, 2002. Since it provides information on the effects of both vehicles’ weights in a collision, it is presented here.

This model was developed the same way as the simpler ones used in this study. First, the simple effects of all of the factors were estimated. Then, the fit of this simple model was examined. It was assessed whether the simple relations with respect to each factor were adequately representing the data, or whether more complex relations were needed. Then, with an improved model, we searched for interactions and determined their form. This was repeated several times. Finally, we tried to “fine-tune” the model, to fit smaller but systematic deviations by interaction terms, sometimes of three factors.

Table C-1 shows the coefficients of the model obtained. The first three coefficients deal with the speed limit. There is a practically exponential increase of the risk with the speed limit up to 50 miles per hour. For 55 mph, the risk is much higher than this trend (by a factor of about three!), but for higher speed limits it is only one and a half times as high. The next group of three coefficients applies to the weight of the case vehicle. Its coefficient is largest (in absolute terms) for the lowest speed limit, smaller for 55 mph, and much smaller for the higher speed limits. In fact, the latter is less than its standard error, but we retained it because it fits a downward trend with the speed limit fairly well. Basically this means that the “protective” effect of a heavy car is greatest at lower speeds, and very small, if not actually nil at the highest speed limit.

The next three coefficients apply to the weight of the “other car. Again, the coefficient for the lowest speed limit is the largest, that for the 55 mph smaller, and that for the highest speed limits even smaller. However, it is not “significantly” different from that for the speed limit of 55 mph, and it is very significantly different from 0. That means that car weight mostly retains it “aggressive” property at the highest speed limits, whereas its “protective” property nearly disappears.

The sex of the driver has a very strong effect. The fatality risk for a female driver is much lower than for a male driver, and if the “other” driver is a woman, the risk for the driver of the case vehicle is even more reduced. Women appear to be less aggressive drivers than men.

Table C-1 Coefficients of model for car driver fatality risk in car-car collisions. “A” refers to the car the driver is considered in, “B” to the other car. Car “A” has no air bag and is of model year 1985 or later.

variable	coefficient	non-standard error
(splimit-50)/10	.95	.08
(splimit=55)	1.09	.23
(splimit>55)	.39	.21
log(wgtA/2800) • •(splimit<55)	-2.03	.16
log(wgtA/2800) • •(splimit=55)	-1.50	.14
log(wgtA/2800) • •(splimit>55)	-.41	.51
log(wgtB/2800) • •(splimit<55)	2.26	.16
log(wgtB/2800) • •(splimit=55)	1.81	.18
log(wgtB/2800) • •(splimit>55)	1.57	.42
female A	.38	.05
female B	-.58	.04
(ageA-30)/10	1.59	.02
(ageA-60) • •(ageA>60) • •maleA/10	.66	.09
(ageA-40) • •(ageA>40) • •femaleA/10	.33	.04
(ageB-30) • •maleB/10	-.07	.02
(ageA-60) • •(splimit-55)/100	-.06	.01
(ageB-60) • •(splimit-55)/100	.08	.01
(ageA-50) • •(ageA>50) • •(wgtA>2800)/10	-.12	.03
(ageA-50) • •(ageA>50) • •(splimit>55)/10	.39	.11
(calyear-1990)/10	-.33	.13
constant	-6.40	.22

The next three terms apply to the age of the driver of the case vehicle. The first term applies to all drivers. It represents a practically exponential increase of the risk with age. The second term applies to male drivers. In addition to the overall exponential trend with age, the risk increases even more at ages above 60. The third term is for female drivers, where the coefficient for higher ages is only half as large as for men (.33 versus .66), but the additional increase in risk begins already with age 40 instead of 60 as for men.

Another age term applies to the age of the "other" driver. It applies only to men and indicates that the "aggressivity" of men declines with age after age 30. There are two interaction terms between the ages of the two drivers and the speed limit. The first shows that for older drivers at higher speed limits the risk is lower than that resulting from combining the age and speed effects. The other shows that for older drivers at higher speed limits their aggressivity is higher than given by the simple age and speed terms.

The next two terms are age effects for the driver of the case car. The first shows that for older drivers in heavier than average cars the risk is lower than expressed by the main effects of age and car weight. The second shows that for older drivers at high speed limits the risk is larger than given by the main effects of age and speed limit. This interaction partially counteracts the interaction between age and speed limit which applies to all ages and speed limits.

Finally, there is a term for the calendar year; this risk declines annually by about 3%, for reasons beyond changes in the factors included in this model. One may speculate that phasing out of earlier model year cars which are less crash worthy, and increasing use of safety belts contribute to this effect.

The first 15 terms of the model are easily interpretable and plausible. Some of the more complex of them just approximate non-linear relations. The three interaction terms are much more difficult to interpret. All of them are highly significant by conventional standards. That does not mean that they are "real". The term which applies only to older drivers at high speed limits, e.g., is based on far fewer cases than the other terms, and may be less reliable than it appears from its non-standard error.

Figures C-1 through 12 show how the data are represented by the model. Figure C-1 shows the overall agreement between actual and modelled risks. It is excellent. However, despite a good overall agreement, a model may have systematic errors with regard to certain factors. Therefore, Figures C-2 through 12 show actual and modelled risks versus certain factors, sometimes also for different subsets of the data. Overall, the agreement is good. It is best with regard to the age of the driver of the case vehicle, followed by the speed limit, and the weight of the "other" vehicle. The differences are largest in the plots versus the weight of the case vehicle. They seem to be primarily random, but small systematic deviations can not be excluded. When the cases were grouped differently, the deviations showed sometimes very different patterns. When looking at Figures C-2 through 12, one must keep in mind that the solid line does not represent the “pure” effect of the factor represented by the abscissa of the graph, but that it includes the effects of all other confounding factors. To obtain the “pure” effect, one has to use the coefficients in Table C-1.

Of specific interest is how the risk depends on the weights of the two cars. Keeping all the other factors constant, the relation is:

risk1=(a• (w1 • •b)• (w2 • •c)/(1 + a• (w1 • •b)• (w2 • •c))

where w1 and w2 are the weights of the two cars. The term in the denominator does not differ much from 1, therefore, the numerator alone is a good approximation. Table C-2 shows the coefficients b and c for collisions involving two male drivers 30 years of age, at speed limits of under 55 mph, 55 mph, and higher than 55 mph. Figures C-13 through 15 show the risk in one car as functions of the weights of both cars, normalized so that the risk in a 2,800 lb car is 1. The long dashed line shows the risk as a function of the weight of the studied driver’s car, the solid line as function of the weight of the “other” car. For speed limits up to 55 mph, the risk declines for low weights faster, for high weights more slowly with the weight of the driver’s car; for speed limits over 55 mph, it declines only little over the entire range (not “significantly’ different from a horizontal line). As a function of the weight of the “other” car (solid line), the risk increases consistently with weight, for speed limits under 55 mph, noticeably faster than linearly, for speed limits of 55 slightly faster than linearly and for higher speed limits practically linearly.

One can compare these empirical relations with others derived from physical arguments. Joksch[2] found that for a car driver the fatality risk in a crash increased approximately with the fourth power of delta-V. If two cars of weights w1 and w2 approach each other from opposite directions with speeds v1 and v2, driver 1 experiences a delta-V of:

(v1 + v2)• w2/(w1 + w2)

(If the cars do not approach each other from opposite directions, the situation is significantly more complicated.) Thus, the fatality risk would be proportional to:

[(v1 + v2)• w2/(w1 + w2)] • •4

This risk, a function of w1 and w2 is also, again normalized to 1 for weights of 2,800 lb., shown in Figures C-13 and 14 (since it does not vary with the speed limit, the relations in Figures C-13 and 14 are the same, and it is not shown in Figure C-15). The short broken line with dots shows how it depends on the weight of the driver’s car, the long broken line with dots how it depends on the weight of the “other” car.

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[2] Joksch, H. C. Velocity Change and Fatality Risk in a Crash – A Rule of Thumb. Accident Analysis & Prevention, <u>25</u>, pp. 103-104, 1993.

Though there are some systematic differences, this model agrees overall with the empirical relations for speed limits up to 55 mph. Only for higher speed limits than 55 mph (the curves for the physical model are not shown; they are the same as in Figures C-13 and 14) do the models not agree. This suggests that the weight terms in the empirical model reflect not only the inertial effects of mass, but also effects of other vehicle characteristics which are related to weight. Figures C-13 through C-14 provide also some insights into the effect of weight differences on the total number of driver deaths in car-car collisions.

If two cars of 2,800 lb. collide, the expected number of deaths in both cars is, because of the normalization, 2. If, e.g., a car of 2,800 lb. collides with a car of 3,500 lb., the lower curve in the figures shows the risk in the 3,500 lb. car, the higher curve that in the 2,800 lb. car. The total number of expected deaths in this collision is the sum of the two risks. Their sums are also shown in Figures C-13 through C-15. Those resulting from the physical model are shown by dotted lines, those resulting from the empirical model by broken lines. For speed limits up to 55 mph, total driver deaths increase non-linearly with the absolute weight difference. For the physical model, total deaths are minimal if both weights are 2,800 lb. The empirical model shows minima at slightly lower weights for one of the cars. Whether that is within the uncertainties of this model, or whether it reflects an aggressivity of heavier cars which goes beyond the inertial effect of mass was not studied. For high speed limits, Figure C-15, this phenomenon is even stronger. The number of deaths has no minimum, it increases with the weight of the other car. This seems to support the hypothesis that heavier cars are aggressive beyond the inertial effect of mass. However, one should be cautious with conclusions because there are relatively few fatal collisions in this speed range. In sum, this model suggests for all speed ranges that the protective effect of additional weight becomes weaker once 3,000 lb. are exceeded, and even weaker if 3,500 lb. are exceeded; the empirical model suggests an even weaker increase than the physical model. If this trend continues, the often much higher weight of LTVs should offer very little additional protection.

On the other hand, the aggressive property of car weight holds consistently over the entire weight and speed range studied. At lower speed limits, the empirical model shows an even higher aggressivity with increasing weight than the physical model. Therefore, one would expect this to hold similarly for LTVs of higher weights. That the analysis in this report showed an apparent leveling off of the aggressivity of LTVs for the highest weights seems to suggest that other vehicle, user or use factors mitigate the expected increase in aggressivity for the highest weights.

Table C-2 Exponents of the car weights in the models for driver fatality risk in car-car collisions. "b" refers to the exponent of the weight of the studied driver's car, "c" to the exponent of the weight of the other car.

Speed Limit (mph)	b	c
< 55	-2.03	2.26
55	-1.50	1.81
> 55	-0.41	1.57

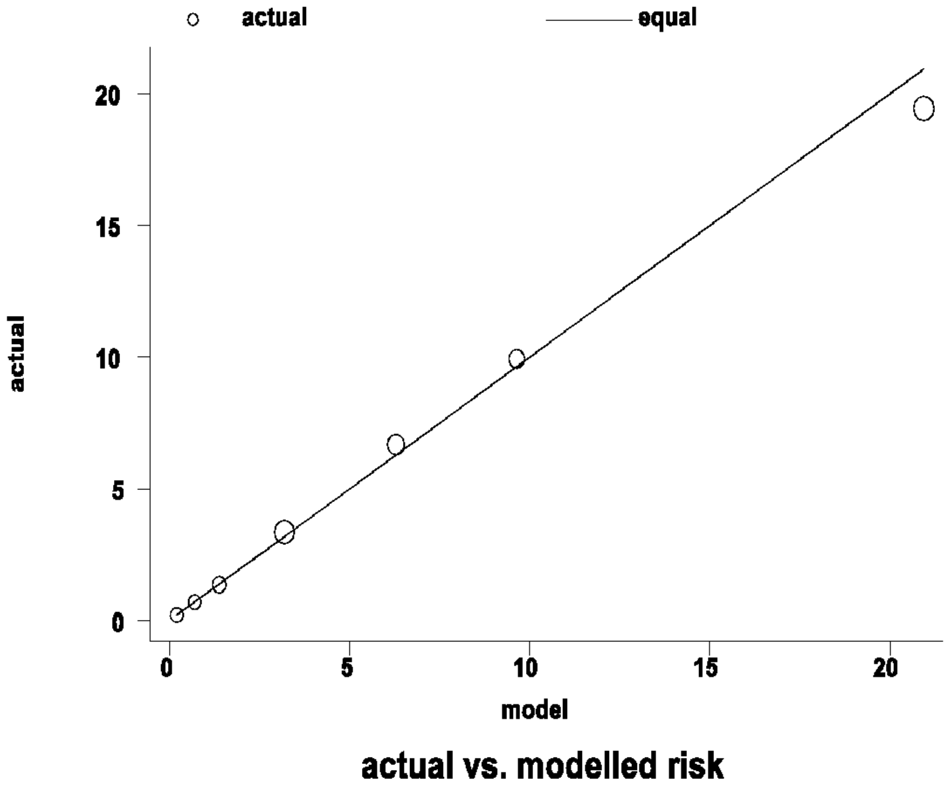


Figure C-1 Actual car driver fatality risk in car-car collisions versus modelled risk (model from Table C-1). Cars of model years 1985 and later, with no airbags. The circles represent the actual risks. Their size is proportional to the number of driver deaths in the case vehicles. The line represents equality of the actual and modelled risk.

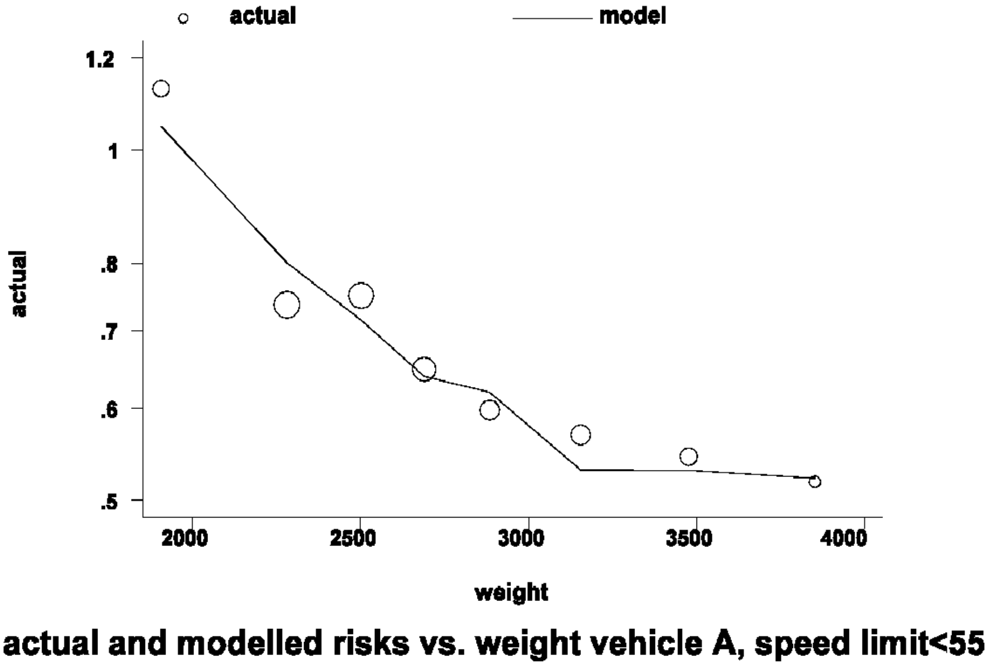
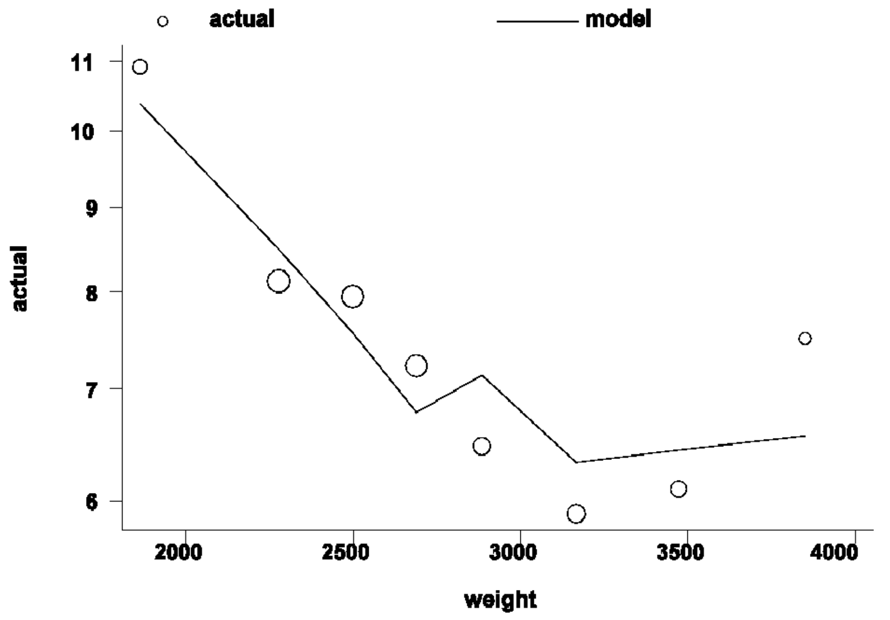
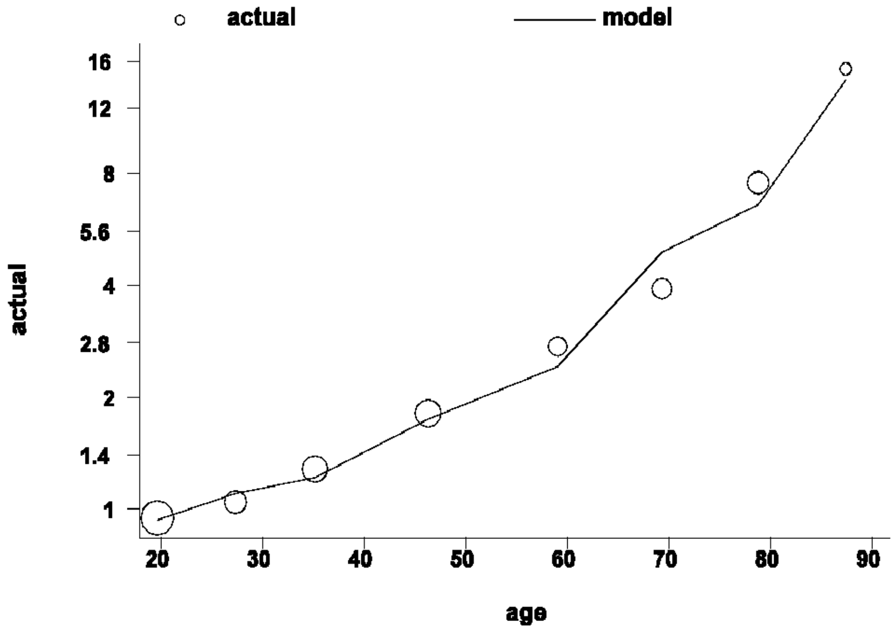


Figure C-2 Actual and modelled driver fatality risk in car-car collisions versus weight of case car. Speed limit under 55 mph. Cars of model years 1985 and later, with no air bags. The circles represent the actual risks. Circle sizes are proportional to the number of driver deaths in the case vehicles. The line represents the modelled risks. Logarithmic scale for risk.



actual and modelled risks vs. weight vehicle A, splimit>=55

Figure C-3 Actual and modelled driver fatality risk in car-car collisions versus weight of case car. Speed limit 55 mph or higher. Cars of model years 1985 and later, with no air bags. The circles represent the actual risks. Circle sizes are proportional to the number of driver deaths in the case vehicles. The line represents the modelled risks. Logarithmic scale for risk.



actual and modelled risks vs. age driver A, vehicle weight<=2800

Figure C-4 Actual and modelled driver fatality risk in car-car collisions versus age of driver of case car. Car weight <=2,800 lb. Cars of model years 1985 and later, with no air bags. The circles represent the actual risks. Circle sizes are proportional to the number of driver deaths in the case vehicles. The line represents the modelled risks. Logarithmic scale for risk.

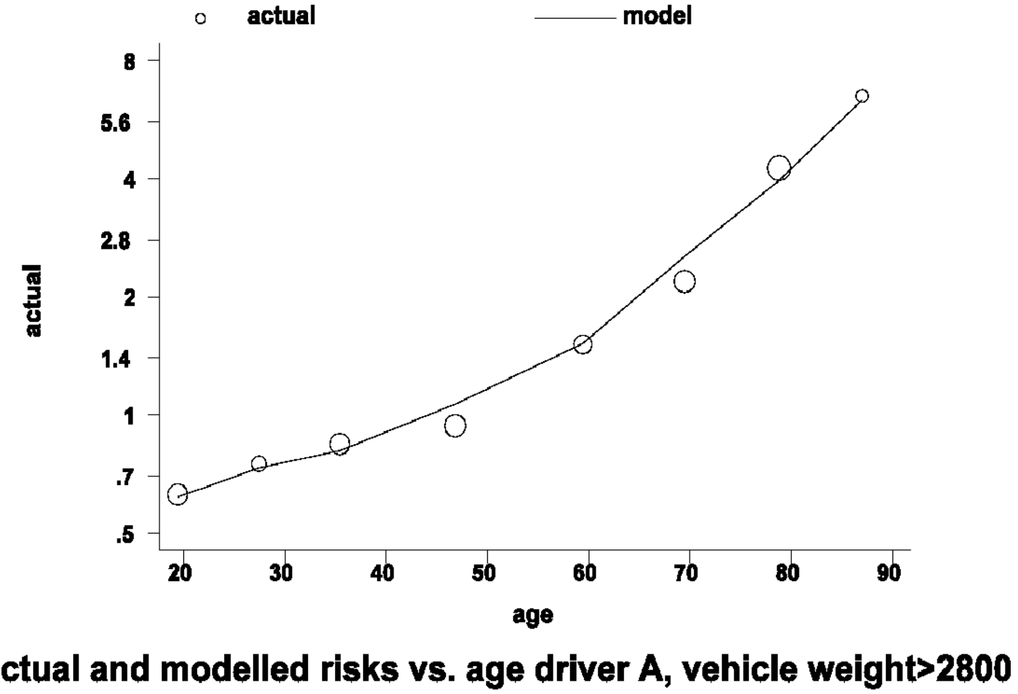


Figure C-5 Actual and modelled driver fatality risk in car-car collisions versus age of driver of case car. Car weight >2,800 lb. Cars of model years 1985 and later, with no air bags. The circles represent the actual risks. Circle sizes are proportional to the number of driver deaths in the case vehicles. The line represents the modelled risks. Logarithmic scale for risk.

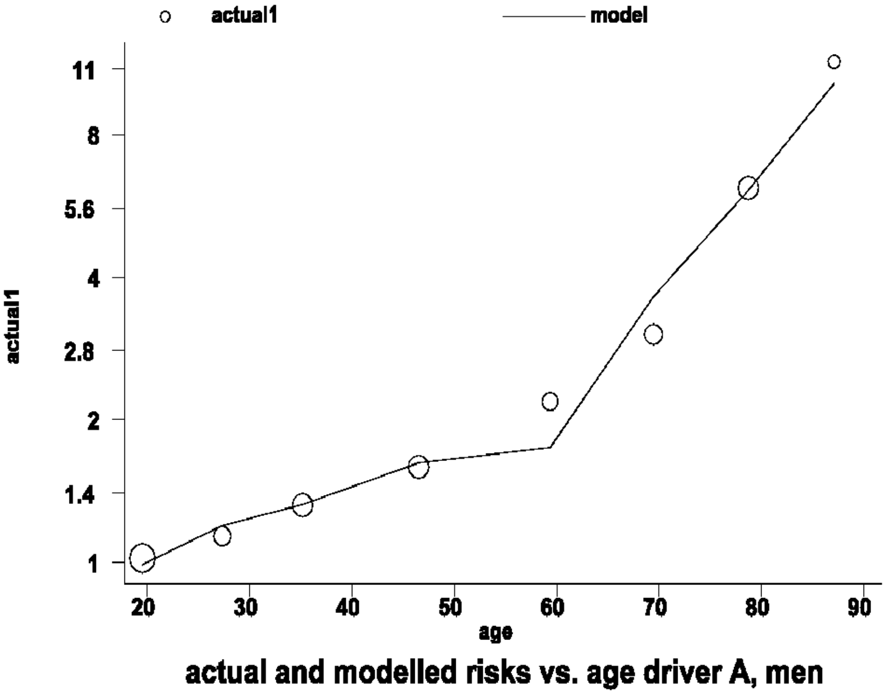


Figure C-6 Actual and modelled driver fatality risk in car-car collisions versus age of drivers of case car, male drivers. Cars of model years 1985 and later, with no air bags. The circles represent the actual risks. Circle sizes are proportional to the number of driver deaths in the case vehicles. The line represents the modelled risks. Logarithmic scale for risk.

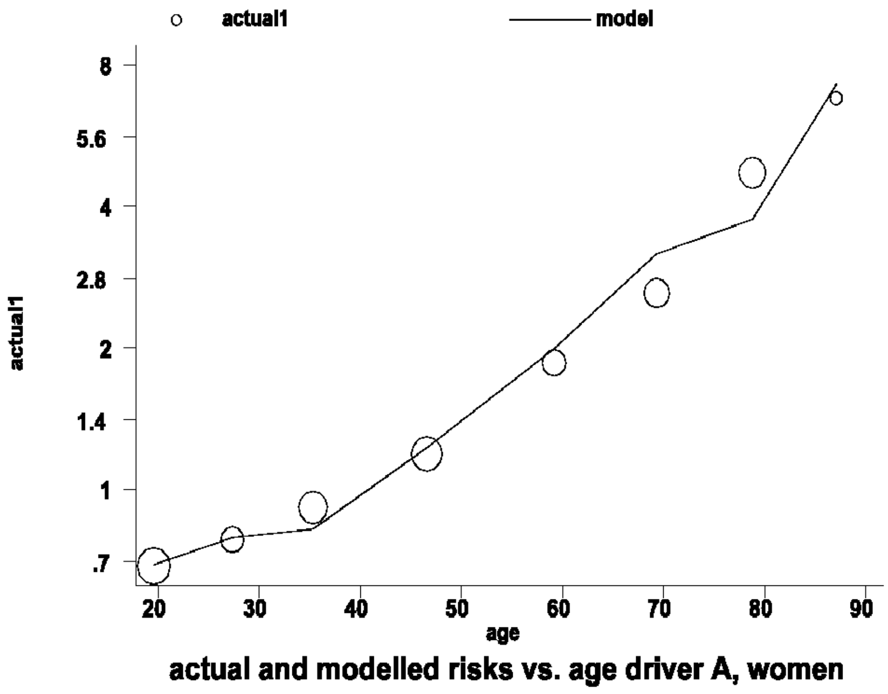


Figure C-7 Actual and modelled driver fatality risk in car-car collisions versus age of drivers of case car, female drivers. Cars of model years 1985 and later, with no air bags. The circles represent the actual risks. Circle sizes are proportional to the number of driver deaths in the case vehicles. The line represents the modelled risks. Logarithmic scale for risk.

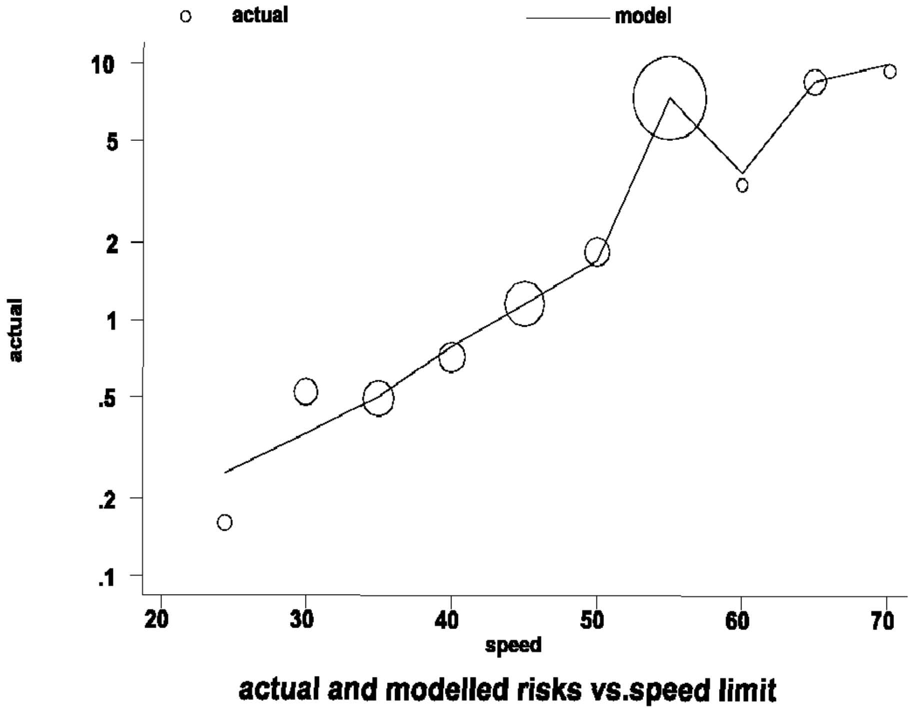
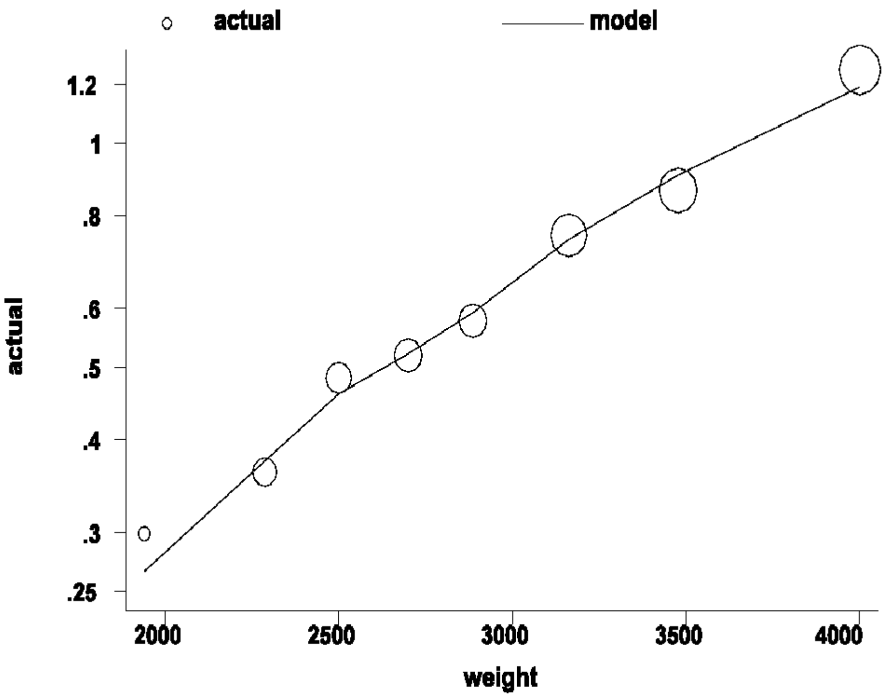


Figure C-8 Actual and modelled driver fatality risk in car-car collisions versus speed limit. Cars of model years 1985 and later, with no air bags. The circles represent the actual risks. Circle sizes are proportional to the number of driver deaths in the case vehicles. The line represents the modelled risks. Logarithmic scale for risk.



actual and modelled risk vs. weight vehicle B, speed limit<55

Figure C-9 Actual and modelled driver fatality risk in car-car collisions versus weight of "other" car. Speed limit under 55 mph. Cars of model years 1985 and later, with no air bags. The circles represent the actual risks. Circle sizes are proportional to the number of driver deaths in the case vehicles. The line represents the modelled risks. Logarithmic scale for risk.

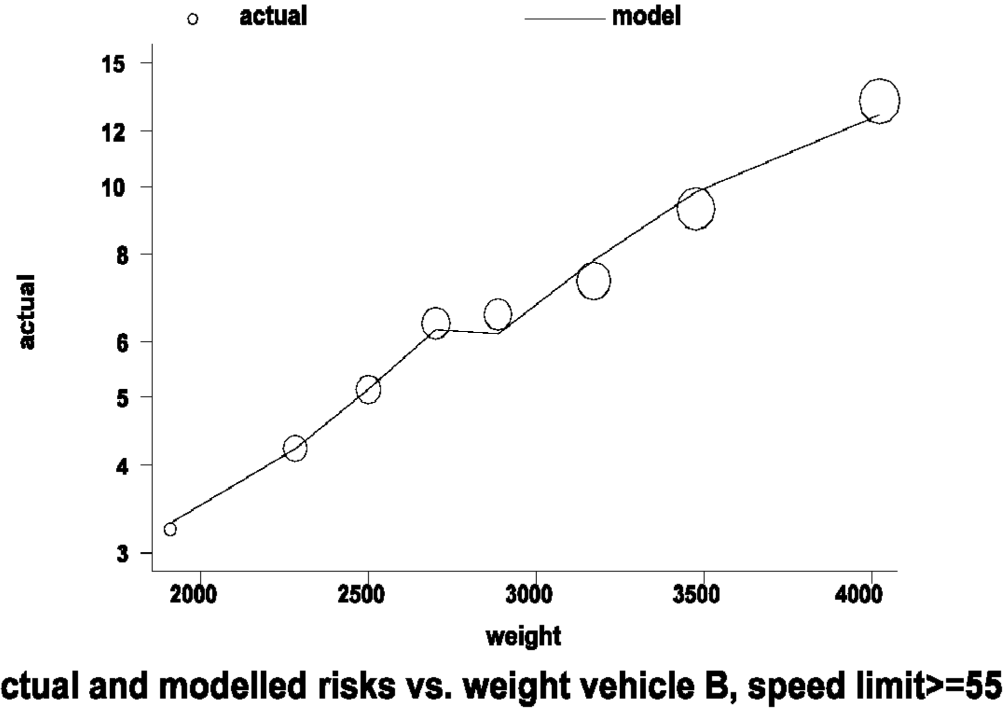


Figure C-10 Actual and modelled driver fatality risk in car-car collisions versus weight of “other” car. Speed limit 55 mph or higher. Cars of model years 1985 and later, with no air bags. The circles represent the actual risks. Circle sizes are proportional to the number of driver deaths in the case vehicles. The line represents the modelled risks. Logarithmic scale for risk.

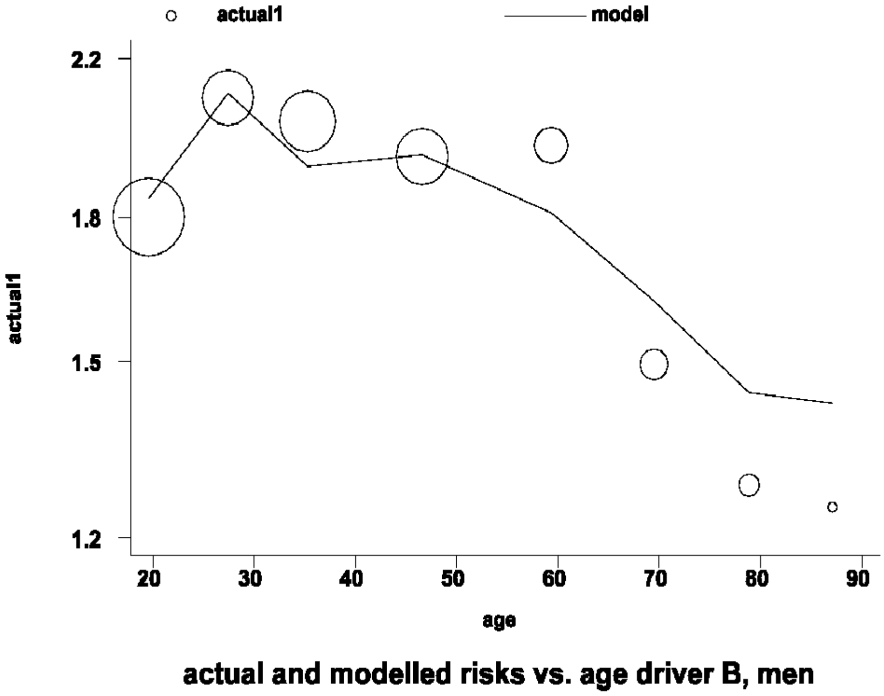
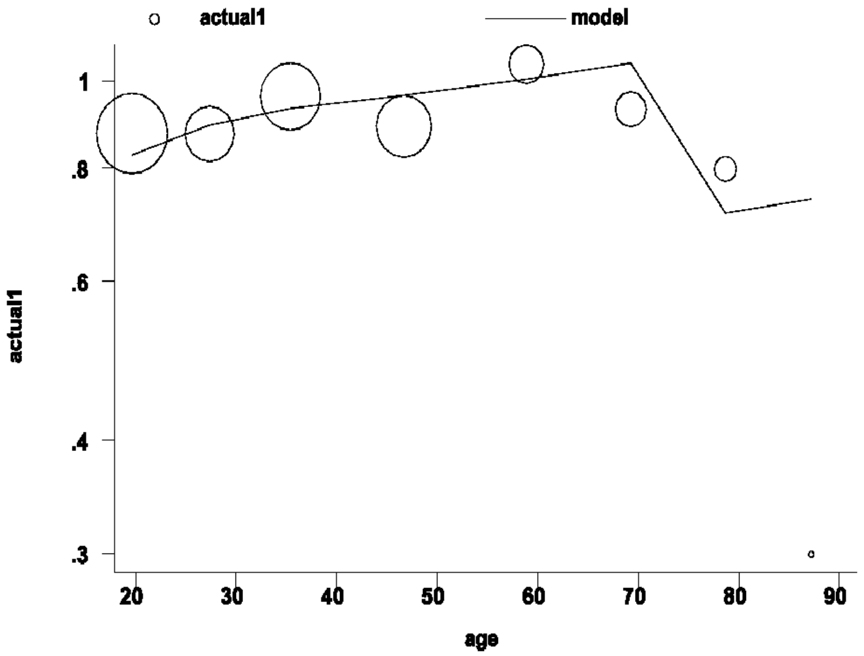
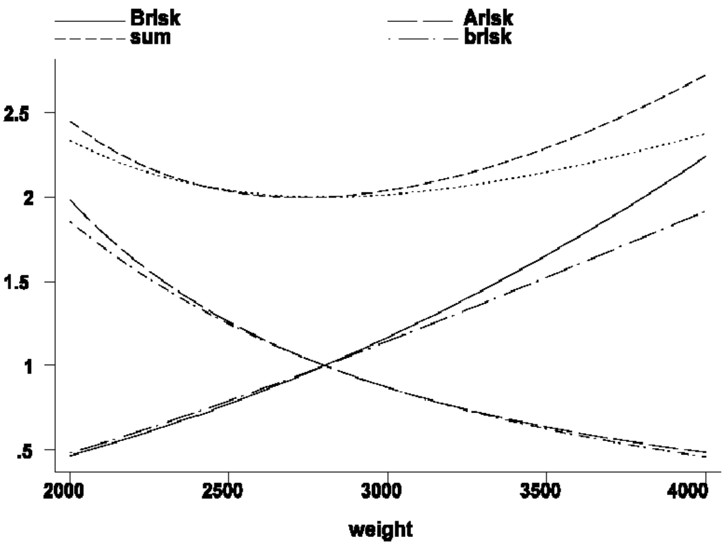


Figure C-11 Actual and modelled driver fatality risk in car-car collisions versus age of driver of "other" car, male drivers. Cars of model years 1985 and later, with no air bags. The circles represent the actual risks. Circle sizes are proportional to the number of driver deaths in the case vehicles. The line represents the modelled risks. Logarithmic scale for risk.



actual and modelled risks vs. age driver B, women

Figure C-12 Actual and modelled driver fatality risk in car-car collisions versus age of driver of "other" car, female drivers. Cars of model years 1985 and later, with no air bags. The circles represent the actual risks. Circle sizes are proportional to the number of driver deaths in the case vehicles. The line represents the modelled risks. Logarithmic scale for risk.



empirical and 4th power risk factors for speed limits <55 mph

Figure C-13 Empirical and hypothetical car driver fatality risks in car-car collisions as function of car weight, normalized to one for collisions between cars of 2,800 lb. Speed limit less than 55 mph.

The solid line shows the fatality risk for the driver of a 2,800 lb. car as a function of the weight of the other car, according to the model in Table C-1. The long broken line shows the fatality risk for a driver in a collision with another car of 2,800 lb., as a function of the weight of his car, also according to the model in Table C-1.

The long broken line with dots shows the fatality risk for a driver of a 2,800 lb. car as a function of the weight of this car, assuming that the fatality risk is proportional to the fourth power of delta-V. The short broken line with dots shows the fatality risk for a driver in a collision with a car of 2,800 lb., as a function of the weight of his car, assuming that the fatality risk is proportional to the fourth power of delta-V.

The short broken line shows the expected total number of driver deaths in a collision between a car of 2,800 lb. and another car, versus weight of the other car, according to the model in Table C-1.

The dotted line shows the expected total number of driver deaths in collisions between a car of 2,800 lb. and another car, versus weight of the other car, assuming that the fatality risk is proportional to the fourth power of delta-V.

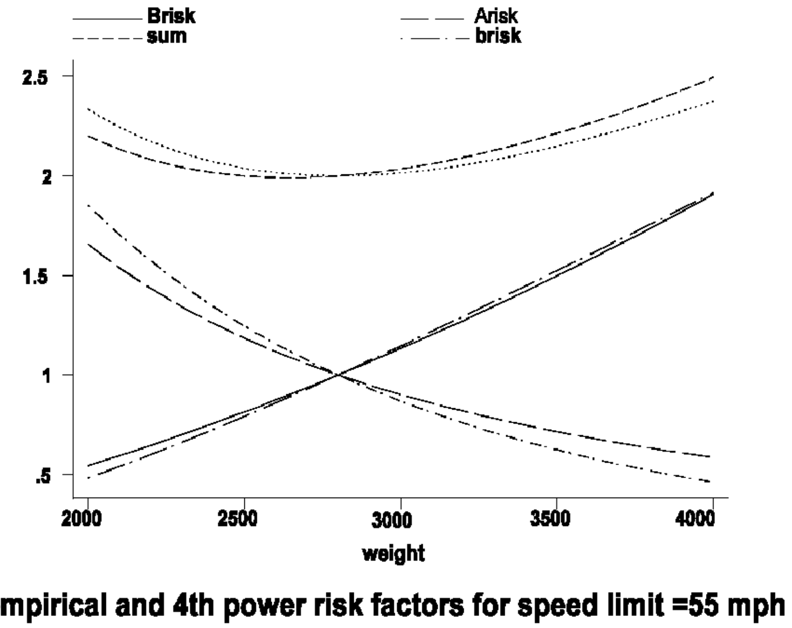


Figure C-14 Empirical and hypothetical car driver fatality risks in car-car collisions as function of car weight, normalized to one for collisions between cars of 2,800 lb. Speed limit 55 mph.

The solid line shows the fatality risk for the driver of a 2,800 lb. car as a function of the weight of the other car, according to the model in Table C-1. The long broken line shows the fatality risk for a driver in a collision with another car of 2,800 lb., as a function of the weight of his car, also according to the model in Table C-1.

The long broken line with dots shows the fatality risk for a driver of a 2,800 lb. car as a function of the weight of this car, assuming that the fatality risk is proportional to the fourth power of delta-V. The short broken line with dots shows the fatality risk for a driver in a collision with a car of 2,800 lb., as a function of the weight of his car, assuming that the fatality risk is proportional to the fourth power of delta-V.

The short broken line shows the expected total number of driver deaths in a collision between a car of 2,800 lb. and another car, versus weight of the other car, according to the model in Table C-1.

The dotted line shows the expected total number of driver deaths in collisions between a car of 2,800 lb. and another car, versus weight of the other car, assuming that the fatality risk is proportional to the fourth power of delta-V.

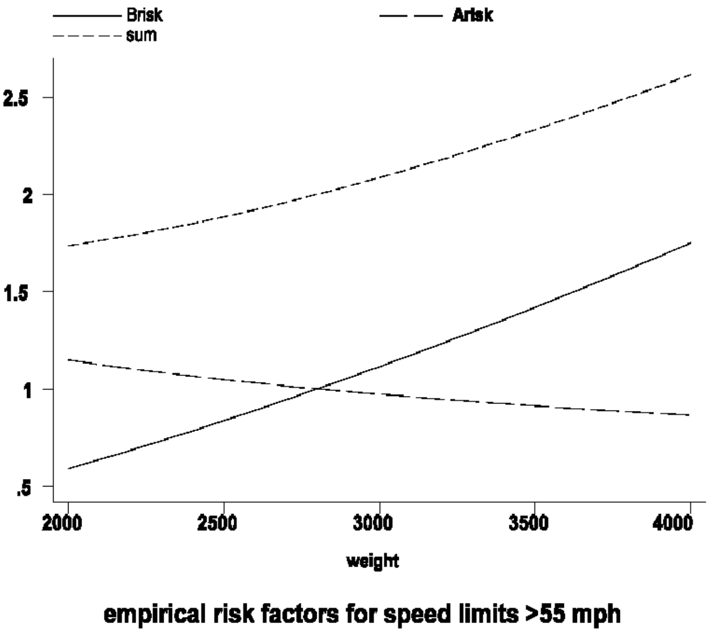


Figure C-15 Empirical and hypothetical car driver fatality risks in car-car collisions as function of car weight, normalized to one for collisions between cars of 2,800 lb. Speed limit over 55 mph.

The solid line shows the fatality risk for the driver of a 2,800 lb. car as a function of the weight of the other car, according to the model in Table C-1. The long broken line shows the fatality risk for a driver in a collision with another car of 2,800 lb., as a function of the weight of his car, also according to the model in Table C-1.

The short broken line shows the expected total number of driver deaths in a collision between a car of 2,800 lb and another car, versus weight of the other car, according to the model in Table C-1.

APPENDIX D TABLES OF AGGRESSIVITY BY VEHICLE PLATFORM

This appendix presents the aggressivity measures and the data from which they are derived, for LTVs classified by Kahane's vehicle group codes. The nine Tables show the data cross classified by

collision type:

- "all" planar collisions between car and LTVs
- collisions where the front of LTV struck the left side of the car
- front-front collisions between a car and a LTV

and vehicle type:

- pickup truck (type 1= compact, 2 = standard)
- SUV (type 3 = compact, 4 = standard)
- Van (type 5 = minivan, 6 = large van)

Each table has the following columns:

- line number
- vehicle type
- Kahane code
- average weight of vehicles used in this study
- number of actual FARS cases
- number of actual GES cases
- car driver fatality risk per 1,000 involvements
- non-standard error of car driver fatality risk
- car driver fatality risk per 1,000 involvements predicted for comparable car-car collisions
- non-standard error of predicted fatality risk
- ratio of actual risk in car-LTV collision to predicted risk for comparable car-car collisions (relative risk)
- non-standard error of the ratio

The two last columns show the aggressivity metric used in this study, and its estimated error. Vehicle groups which were represented by fewer than five FARS or GES cases were omitted.

Table D-1 Absolute and relative risk for car drivers in all collisions between a car and a pickup truck

	type	cgb	avwt	nf	ng	z	e(z)	pz	e(pz)	z/pz	e(z/pz)
1.	1	7008	2997	18	18	4.997	1.775	2.130	1.004	2.345	1.537
2.	1	7009	2987	18	23	4.335	1.730	1.956	0.725	2.216	1.053
3.	1	7011	3020	16	18	6.044	1.925	2.055	0.891	2.940	1.411
4.	1	7108	3108	184	293	3.529	0.473	1.927	0.235	1.831	0.352
5.	1	7111	3565	123	163	4.213	0.658	1.658	0.242	2.539	0.612
6.	1	7401	2782	275	582	2.645	0.369	1.453	0.172	1.820	0.310
7.	1	7410	3115	95	187	2.497	0.351	1.709	0.179	1.461	0.219
8.	1	7416	3025	186	424	2.450	0.456	1.346	0.123	1.819	0.336
9.	1	7417	3366	78	178	2.720	0.583	1.656	0.220	1.642	0.464
10.	1	7601	2549	151	316	2.690	0.420	1.268	0.150	2.122	0.360
11.	1	7613	2872	388	878	2.471	0.342	1.542	0.103	1.601	0.257
12.	1	7614	3123	130	325	2.247	0.291	1.742	0.215	1.289	0.226
13.	1	8101	2735	19	50	2.292	0.765	1.359	0.382	1.686	0.732
14.	1	8102	2936	18	42	2.803	0.840	1.520	0.408	1.844	0.707
15.	1	8103	2932	203	356	3.797	0.584	1.660	0.270	2.287	0.421
16.	1	8104	3257	103	201	3.297	0.590	1.541	0.214	2.138	0.342
17.	1	8198	3637	6	24	1.667	0.746	1.784	0.753	0.934	0.597
18.	1	8201	2490	11	29	2.039	0.848	1.608	0.440	1.268	0.613
19.	1	8202	2682	5	13	3.430	1.653	1.362	0.440	2.517	1.427
20.	1	8204	2799	25	53	3.053	1.000	1.892	0.540	1.613	0.839
21.	1	8301	2709	50	117	2.706	0.519	1.306	0.198	2.071	0.521
22.	1	8302	2829	28	59	2.709	0.782	1.260	0.419	2.149	0.956
23.	1	8501	2988	136	347	2.672	0.511	1.788	0.278	1.493	0.347
24.	1	8502	2949	70	132	3.358	0.623	1.634	0.188	2.054	0.417
25.	1	8506	3206	37	95	2.392	0.666	2.049	0.422	1.167	0.390
26.	1	8513	2903	17	48	2.207	0.572	1.362	0.270	1.619	0.496
27.	1	8514	3248	23	85	1.657	0.567	1.391	0.222	1.191	0.464
28.	1	8601	2596	14	48	1.656	0.577	0.957	0.221	1.729	0.687
29.	1	8603	2681	34	83	2.794	0.740	1.247	0.158	2.240	0.598
30.	1	8604	2895	9	24	2.173	1.044	1.642	0.352	1.323	0.666
31.	2	7102	3637	100	173	3.334	0.486	2.099	0.244	1.587	0.345
32.	2	7103	4046	59	72	4.284	0.718	2.935	0.590	1.459	0.378
33.	2	7110	4493	13	35	2.317	0.944	2.457	0.528	0.943	0.431
34.	2	7115	4151	94	154	3.165	0.455	2.699	0.394	1.172	0.235
35.	2	7116	4644	51	43	6.812	1.335	4.142	1.071	1.644	0.527
36.	2	7117	4766	122	150	4.659	0.762	3.245	0.483	1.435	0.348
37.	2	7402	3743	457	706	3.626	0.404	2.435	0.286	1.488	0.215
38.	2	7403	4265	217	245	5.062	0.705	3.169	0.486	1.597	0.338
39.	2	7404	4070	168	286	3.411	0.790	2.553	0.359	1.336	0.319
40.	2	7405	4804	127	127	5.963	1.010	3.613	0.611	1.650	0.382
41.	2	7412	5109	62	75	5.333	1.329	4.008	0.441	1.330	0.356
42.	2	7424	4054	28	60	2.855	0.712	2.423	0.467	1.178	0.356
43.	2	7425	4313	69	101	4.003	0.854	2.005	0.326	1.996	0.535
44.	2	7602	3511	221	344	3.537	0.599	2.194	0.209	1.611	0.328
45.	2	7603	3872	112	104	7.404	1.137	3.102	0.423	2.386	0.542
46.	2	7612	4451	33	33	6.263	1.764	3.258	0.956	1.922	0.646
47.	2	7615	4007	630	1054	3.525	0.492	2.751	0.203	1.281	0.188
48.	2	7616	4427	191	204	5.126	0.673	3.276	0.297	1.564	0.247
49.	2	7617	4543	128	203	3.535	0.905	3.409	0.340	1.037	0.277
50.	2	7620	4392	258	540	2.889	0.613	2.249	0.168	1.284	0.283
51.	2	7622	5434	17	20	4.710	2.072	5.874	0.594	0.801	0.352
52.	2	8509	3627	19	37	3.400	0.883	2.235	0.513	1.520	0.584

Table D-2 Absolute and relative risk for car drivers in all collisions between a car and a SUV

	type	cgb	avwt	nf	ng	z	e(z)	pz	e(pz)	z/pz	e(z/pz)
1.	3	7004	2651	7	17	2.511	1.273	0.470	0.077	5.343	2.787
2.	3	7005	3020	160	442	2.043	0.304	1.318	0.172	1.549	0.263
3.	3	7006	3175	13	25	3.374	1.730	0.880	0.210	3.835	2.104
4.	3	7010	3054	59	181	2.054	0.484	1.352	0.148	1.519	0.418
5.	3	7114	3681	137	296	2.708	0.522	1.462	0.173	1.851	0.404
6.	3	7406	3180	104	183	2.948	0.442	1.474	0.208	1.999	0.393
7.	3	7413	3871	43	79	2.984	0.997	1.457	0.177	2.047	0.775
8.	3	7414	4012	209	318	4.064	0.602	1.551	0.122	2.619	0.394
9.	3	7420	4188	59	128	2.886	0.664	2.256	0.309	1.279	0.346
10.	3	7421	3922	9	34	1.618	0.622	2.083	0.380	0.777	0.344
11.	3	7604	3224	305	737	2.319	0.351	1.495	0.206	1.550	0.294
12.	3	7621	3891	220	495	2.490	0.290	2.003	0.199	1.243	0.161
13.	3	8105	3854	50	162	2.100	0.517	1.678	0.311	1.250	0.368
14.	3	8107	4082	10	43	1.260	0.575	1.540	0.292	0.818	0.379
15.	3	8203	3443	15	38	2.171	0.879	1.778	0.408	1.221	0.526
16.	3	8206	3174	10	11	4.662	2.306	1.188	0.373	3.923	2.121
17.	3	8208	3805	44	65	3.937	0.955	1.947	0.542	2.021	0.729
18.	3	8211	3871	14	35	2.431	1.139	2.778	0.653	0.875	0.435
19.	3	8503	3932	54	107	3.120	0.674	2.272	0.504	1.372	0.476
20.	3	8510	3813	19	62	2.131	0.901	1.718	0.527	1.240	0.718
21.	3	8512	2737	5	26	1.436	0.759	0.999	0.349	1.437	0.832
22.	3	8602	3207	9	18	2.558	1.304	1.098	0.352	2.329	1.265
23.	3	8607	4037	5	30	0.814	0.475	1.832	0.488	0.444	0.280
24.	3	8702	2364	29	150	1.119	0.240	0.875	0.199	1.278	0.379
25.	3	8703	2893	8	26	1.980	0.868	0.915	0.336	2.161	1.204
26.	3	8901	3205	5	23	1.807	1.110	1.075	0.379	1.680	1.097
27.	4	7007	4411	13	37	2.039	0.815	1.695	0.428	1.203	0.523
28.	4	7105	4159	25	46	2.971	0.878	2.350	0.767	1.264	0.479
29.	4	7407	4496	89	138	4.001	0.727	2.972	0.272	1.346	0.278
30.	4	7423	4943	15	53	1.655	0.605	2.644	0.463	0.626	0.273
31.	4	7605	4536	66	86	4.477	0.986	2.563	0.355	1.746	0.411
32.	4	7606	4652	99	212	2.856	1.073	3.420	0.556	0.835	0.263
33.	4	7607	5053	24	28	6.187	2.541	2.657	0.526	2.328	0.933
34.	4	7623	4825	30	53	3.606	1.171	2.761	0.492	1.306	0.464
35.	4	7624	4903	54	149	2.242	0.841	1.930	0.393	1.161	0.374
36.	4	7625	5361	8	13	3.561	1.889	4.785	1.927	0.744	0.545
37.	4	7628	5211	34	74	2.821	0.647	2.809	0.544	1.004	0.317
38.	4	8507	4850	12	21	4.167	2.202	1.508	0.467	2.761	1.480

Table D-3 Absolute and relative risk for car drivers in all collisions between a car and a van

	type	cgb	avwt	nf	ng	z	e(z)	pz	e(pz)	z/pz	e(z/pz)
1.	5	7101	3133	211	491	2.405	0.314	1.268	0.136	1.896	0.290
2.	5	7109	3386	90	249	2.129	0.321	1.172	0.136	1.816	0.344
3.	5	7112	3332	119	380	1.919	0.297	1.163	0.111	1.650	0.305
4.	5	7113	3703	106	364	1.700	0.213	1.636	0.196	1.039	0.176
5.	5	7118	3590	30	92	1.732	0.448	1.493	0.329	1.160	0.424
6.	5	7119	3913	50	223	1.330	0.266	1.666	0.239	0.798	0.168
7.	5	7411	3443	182	611	1.779	0.263	1.531	0.123	1.161	0.187
8.	5	7418	3963	35	128	1.703	0.396	1.547	0.292	1.101	0.313
9.	5	7419	3817	41	169	1.421	0.344	1.438	0.172	0.988	0.256
10.	5	7608	3501	285	673	2.281	0.288	1.638	0.118	1.391	0.211
11.	5	7619	3580	69	223	1.667	0.397	1.582	0.146	1.053	0.263
12.	5	7630	3845	12	44	1.387	0.633	1.933	0.521	0.717	0.384
13.	5	8303	3647	38	85	2.700	0.717	1.342	0.253	2.011	0.619
14.	5	8504	2910	18	65	1.625	0.414	0.951	0.189	1.709	0.515
15.	5	8508	3747	18	43	2.854	0.985	1.378	0.255	2.071	0.885
16.	6	7106	3705	100	226	2.262	0.420	1.491	0.143	1.516	0.300
17.	6	7107	4304	57	114	3.064	0.660	2.469	0.395	1.240	0.368
18.	6	7408	3805	84	150	3.577	0.549	1.787	0.260	2.001	0.350
19.	6	7409	4470	127	192	3.525	0.596	3.125	0.482	1.128	0.217
20.	6	7415	4988	152	283	2.779	0.414	2.478	0.225	1.121	0.164
21.	6	7609	3887	216	315	3.674	0.480	1.998	0.282	1.838	0.313
22.	6	7610	4438	78	77	6.145	1.062	2.896	0.611	2.121	0.547
23.	6	7618	5372	8	25	1.751	0.661	3.584	1.128	0.488	0.230

Table D-4 Absolute and relative risk for car drivers in all collisions where the front of a pickup truck struck the left side of a car

	type	cgb	avwt	nf	ng	z	e(z)	pz	e(pz)	z/pz	e(z/pz)
1.	1	7108	3001	66	27	16.341	4.077	3.554	0.976	4.596	1.416
2.	1	7111	3540	32	20	10.528	3.063	2.748	0.723	3.831	1.348
3.	1	7401	2731	82	56	10.688	2.610	3.213	0.897	3.325	1.369
4.	1	7410	3087	27	11	17.817	7.419	2.142	0.691	8.315	3.999
5.	1	7416	3021	67	32	12.653	3.670	3.163	0.925	4.000	1.528
6.	1	7417	3327	27	26	7.140	2.140	2.415	0.685	2.956	1.185
7.	1	7601	2551	30	38	5.372	1.170	4.116	0.992	1.304	0.373
8.	1	7613	2899	111	98	7.783	1.782	3.104	0.344	2.507	0.587
9.	1	7614	3128	38	31	9.492	2.565	2.965	0.665	3.201	1.099
10.	1	8101	2815	10	6	28.754	18.183	3.823	0.939	7.520	4.887
11.	1	8103	2897	47	54	7.631	1.924	3.436	1.040	2.220	0.808
12.	1	8104	3188	25	24	9.307	3.673	2.382	0.842	3.906	1.520
13.	1	8204	2711	6	5	5.677	4.454	9.164	1.916	0.619	0.524
14.	1	8301	2719	15	18	8.850	3.236	1.657	0.265	5.338	2.083
15.	1	8501	2894	33	35	8.007	2.396	4.132	0.785	1.937	0.529
16.	1	8502	3032	13	13	6.492	2.339	3.776	1.652	1.719	1.050
17.	1	8506	3352	15	9	20.434	8.638	11.707	5.367	1.745	0.996
18.	1	8514	3054	8	7	6.629	3.274	2.936	1.014	2.257	1.285
19.	1	8603	2610	7	10	4.362	2.640	3.048	1.092	1.431	0.952
20.	2	7102	3556	9	17	3.756	1.941	2.823	0.765	1.330	0.760
21.	2	7103	4072	10	6	10.814	7.089	4.915	2.771	2.200	1.856
22.	2	7115	3996	26	22	7.260	2.319	6.381	2.259	1.137	0.467
23.	2	7116	4416	14	6	16.321	8.059	3.659	0.897	4.459	1.920
24.	2	7117	4751	39	11	19.229	6.922	7.723	4.581	2.489	1.553
25.	2	7402	3733	121	69	12.342	2.134	5.869	1.179	2.102	0.495
26.	2	7403	4297	61	20	20.719	7.891	6.299	2.092	3.289	1.315
27.	2	7404	4042	53	40	10.624	3.761	4.715	1.246	2.253	0.833
28.	2	7405	4799	30	15	21.163	6.886	17.068	5.027	1.239	0.547
29.	2	7412	5146	17	9	13.784	8.568	3.937	0.511	3.500	1.970
30.	2	7425	4223	17	11	11.581	5.815	15.583	6.530	0.743	0.427
31.	2	7602	3459	48	35	10.327	2.700	2.078	0.374	4.969	1.529
32.	2	7603	3833	32	11	27.681	10.068	7.773	2.925	3.560	1.544
33.	2	7612	4616	10	6	10.706	6.548	11.106	4.791	0.964	0.689
34.	2	7615	3961	142	120	8.440	1.709	5.404	0.981	1.561	0.383
35.	2	7616	4405	40	21	11.250	2.905	5.162	1.018	2.179	0.734
36.	2	7617	4427	18	24	4.410	1.944	12.871	4.750	0.342	0.244
37.	2	7620	4510	51	63	6.086	1.957	6.836	1.478	0.890	0.353
38.	2	8509	3524	8	5	11.648	7.343	6.691	3.396	1.740	1.228

Table D-5 Absolute and relative risk for car drivers in all collisions where the front of a SUV struck the left side of a car

	type	cgb	avwt	nf	ng	z	e(z)	pz	e(pz)	z/pz	e(z/pz)
1.	3	7005	3001	58	33	10.932	2.316	4.196	1.721	2.605	1.235
2.	3	7010	3074	16	18	6.456	2.337	2.713	0.929	2.379	0.917
3.	3	7114	3738	46	26	14.612	3.997	7.997	4.631	1.827	1.287
4.	3	7406	3182	34	21	10.745	3.014	3.496	1.005	3.072	0.947
5.	3	7414	4036	56	43	7.691	1.728	3.537	0.821	2.174	0.572
6.	3	7420	4172	19	13	12.318	4.362	3.672	1.412	3.354	1.387
7.	3	7604	3266	84	79	7.157	1.325	2.746	0.649	2.606	0.796
8.	3	7621	3911	63	56	9.117	1.513	5.153	0.928	1.769	0.437
9.	3	8105	3830	10	18	4.569	1.499	2.027	0.395	2.253	0.871
10.	3	8503	4119	24	9	24.423	12.199	3.258	0.488	7.495	3.585
11.	3	8510	3708	7	8	9.176	4.954	1.986	0.312	4.620	2.364
12.	3	8702	2372	15	13	6.112	2.815	2.119	1.232	2.884	2.032
13.	4	7105	4209	6	5	5.088	3.952	4.124	2.000	1.233	0.892
14.	4	7407	4527	14	17	5.136	1.654	8.398	2.984	0.611	0.293
15.	4	7605	4533	23	12	12.051	3.930	2.490	0.558	4.838	1.536
16.	4	7606	4603	32	20	12.337	4.259	7.819	2.567	1.577	0.807
17.	4	7624	4948	13	13	7.405	4.583	6.770	4.184	1.093	0.780
18.	4	7628	5140	8	7	8.551	5.612	16.815	9.298	0.508	0.469

Table D-6 Absolute and relative risk for car drivers in all collisions where the front of a van struck the left side of a car

	type	cgb	avwt	nf	ng	z	e(z)	pz	e(pz)	z/pz	e(z/pz)
1.	5	7101	3123	53	60	6.100	1.406	2.072	0.386	2.942	0.867
2.	5	7109	3433	23	28	4.726	1.248	2.324	0.439	2.033	0.670
3.	5	7112	3313	21	50	3.278	0.803	3.489	1.074	0.939	0.397
4.	5	7113	3715	21	27	5.689	1.803	2.306	0.817	2.467	1.001
5.	5	7118	3549	13	8	2.979	2.298	4.543	0.831	0.655	0.600
6.	5	7119	3942	12	18	4.115	1.925	1.950	0.391	2.110	1.186
7.	5	7411	3448	47	81	3.961	0.878	2.847	0.704	1.391	0.527
8.	5	7418	3930	5	13	4.637	2.867	2.155	0.483	2.151	1.379
9.	5	7419	3819	14	11	11.547	4.435	3.738	1.567	3.089	1.582
10.	5	7608	3459	73	78	6.437	1.103	3.927	0.936	1.639	0.554
11.	5	7619	3601	9	20	3.094	1.796	3.389	1.441	0.913	0.634
12.	5	8303	3692	11	12	9.541	3.606	1.938	0.369	4.921	1.881
13.	6	7106	3697	21	19	5.808	1.625	3.091	0.773	1.878	0.684
14.	6	7107	4251	15	10	14.109	5.855	3.293	1.255	4.283	2.032
15.	6	7408	3803	30	23	11.520	3.546	3.711	0.935	3.104	1.105
16.	6	7409	4626	32	20	12.513	4.432	5.714	1.602	2.189	0.876
17.	6	7415	5144	46	21	13.079	4.519	11.696	4.763	1.118	0.588
18.	6	7609	3781	57	36	10.283	2.378	3.400	0.968	3.024	0.968
19.	6	7610	4574	13	10	9.238	4.325	9.036	3.906	1.022	0.667

Table D-7 Absolute and relative risk for car drivers in all frontal collisions between a pickup truck and a car

	type	cgb	avwt	nf	ng	z	e(z)	pz	e(pz)	z/pz	e(z/pz)
1.	1	7108	3023	55	9	36.365	21.084	29.076	10.389	1.250	1.077
2.	1	7111	3441	41	10	31.359	10.243	21.715	13.065	1.444	0.831
3.	1	7401	2742	92	21	30.494	8.690	18.796	6.295	1.622	0.787
4.	1	7416	3028	45	16	20.281	5.975	11.783	3.926	1.721	0.817
5.	1	7417	3377	20	8	23.995	10.707	5.056	0.729	4.745	1.967
6.	1	7601	2541	63	19	20.632	7.412	14.818	4.454	1.392	0.575
7.	1	7613	2968	128	51	17.257	4.065	25.280	6.092	0.682	0.260
8.	1	7614	3126	26	12	25.600	9.530	21.289	8.180	1.202	0.588
9.	1	8103	3034	82	20	34.011	8.613	23.394	10.752	1.453	0.826
10.	1	8104	3444	37	11	23.077	8.914	5.607	1.118	4.115	1.270
11.	1	8301	2711	17	5	28.837	14.767	11.333	8.311	2.544	2.035
12.	1	8501	3056	51	21	21.796	8.423	24.102	6.359	0.904	0.465
13.	1	8506	2872	6	6	11.095	6.557	2.908	0.648	3.815	2.012
14.	1	8601	2474	5	6	4.864	2.800	9.053	6.236	0.537	0.393
15.	1	8603	2723	12	5	19.664	9.149	7.171	3.711	2.741	1.842
16.	2	7102	3603	46	13	22.620	7.769	23.531	4.399	0.961	0.395
17.	2	7115	4090	30	6	26.069	12.649	15.479	10.043	1.684	1.177
18.	2	7402	3774	121	45	20.520	4.759	20.913	4.083	0.981	0.243
19.	2	7403	4293	57	13	27.471	8.912	17.647	8.096	1.556	0.675
20.	2	7404	4074	40	10	26.036	9.820	13.815	6.752	1.884	0.898
21.	2	7405	5058	28	5	35.756	19.545	26.254	16.402	1.361	0.900
22.	2	7425	4246	19	6	24.095	11.163	14.429	6.279	1.669	0.887
23.	2	7602	3501	63	23	23.859	9.788	17.419	3.353	1.369	0.662
24.	2	7615	4035	205	56	29.301	6.483	22.755	3.943	1.287	0.390
25.	2	7616	4747	44	6	44.199	20.756	12.007	1.453	3.680	0.396
26.	2	7620	4289	64	18	34.303	9.770	26.053	9.989	1.316	0.582

Table D-8 Absolute and relative risk for car drivers in all frontal collisions between a SUV and a car

	type	cgb	avwt	nf	ng	z	e(z)	pz	e(pz)	z/pz	e(z/pz)
1.	3	7005	3075	39	17	16.248	6.786	7.638	4.426	2.127	1.072
2.	3	7010	3020	19	13	10.063	3.772	17.928	9.594	0.561	0.317
3.	3	7114	3654	35	19	10.675	3.828	11.645	5.529	0.916	0.573
4.	3	7406	3170	37	6	62.168	27.613	21.731	13.207	2.860	2.165
5.	3	7414	4017	54	14	36.851	9.861	11.635	6.121	3.167	1.818
6.	3	7604	3236	96	44	16.237	3.818	12.123	4.373	1.339	0.596
7.	3	7621	3844	59	18	20.548	7.136	15.475	6.750	1.327	0.822
8.	3	8503	3833	10	6	19.905	12.660	4.957	0.823	4.015	1.935
9.	4	7407	4446	33	6	41.185	26.622	20.664	8.135	1.993	1.209
10.	4	7606	4626	16	11	9.398	3.696	29.424	16.901	0.319	0.198
11.	4	7624	4942	13	8	19.639	8.922	5.697	1.150	3.446	1.412

Table D-9 Absolute and relative risk for car drivers in all frontal collisions between a van and a car

	type	cgb	avwt	nf	ng	z	e(z)	pz	e(pz)	z/pz	e(z/pz)
1.	5	7101	3147	69	19	30.506	9.321	21.853	9.992	1.395	0.820
2.	5	7109	3304	35	15	17.077	5.837	3.693	0.992	4.623	1.333
3.	5	7112	3321	41	13	29.933	9.930	4.595	0.658	6.514	1.616
4.	5	7113	3732	37	13	19.045	6.418	9.279	3.281	2.052	0.839
5.	5	7119	3878	15	10	9.785	4.086	19.966	7.843	0.490	0.320
6.	5	7411	3466	57	29	14.518	3.940	20.954	4.234	0.692	0.229
7.	5	7418	4035	16	5	29.285	13.738	18.693	12.628	1.566	1.303
8.	5	7419	3818	16	10	13.543	6.369	10.804	4.924	1.253	0.717
9.	5	7608	3625	84	31	18.519	5.199	15.763	3.282	1.174	0.378
10.	5	7619	3493	20	9	21.848	10.376	11.206	6.061	1.949	1.131
11.	5	8303	3697	11	5	19.229	10.371	6.002	1.916	3.203	1.581
12.	6	7106	3646	32	13	15.178	5.504	4.507	0.634	3.367	0.963
13.	6	7107	4311	19	5	45.094	22.067	6.011	1.892	7.501	1.845
14.	6	7408	3800	15	6	23.825	14.696	19.013	15.062	1.253	0.862
15.	6	7409	4911	34	7	31.700	15.762	13.213	7.652	2.399	1.385
16.	6	7415	5060	39	15	18.574	6.655	10.086	3.855	1.841	0.748
17.	6	7609	3846	60	14	32.433	10.750	5.664	0.895	5.720	1.306