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Vehicle Aggressivity: Fleet Characterization Using Traffic Collision Data

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13. ABSTRACT (Maximum 200 words)

Aggressivity of a vehicle is defined as the fatality or injury risk for occupants of other vehicles with which it collides. Because of the strong effect vehicle weight has on this risk, gross aggressivity which includes the effect of weight, and net aggressivity which excludes the effect of weight are distinguished. Data from the Fatal Analysis Reporting System (FARS) and the General Estimates System (GES) for 1991 to 1994 were used for fatalities, and for crash involvements, respectively. The relation between weight and wheelbase of cars was studied, and the concept of "overweight" introduced. For collisions between two cars, the relation of fatality risks with car weight, overweight, wheelbase and bumper height were studied. Also, adjustments were made for the higher vulnerability of older victims. Collisions between cars and light trucks – including utility vehicles, pickup trucks and vans – were studied. A limited analysis of the effect of vehicle weight was performed. The driver fatality risks in collisions between cars and light trucks were studied by collision configuration. In all cases, the risk for car drivers was much higher than for drivers of light trucks.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (ha) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

°C=5/9(°F - 32)

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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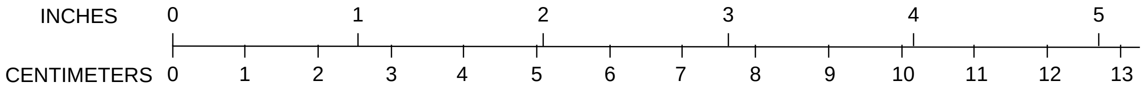
QUICK INCH-CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

Updated 8/1/96

PREFACE

This report contains the results of a study to evaluate the crashworthiness and aggressivity of cars and light trucks. Data from the Fatal Analysis Reporting System (FARS) and the General Estimates System (GES) for 1991 to 1994 were used for fatalities and for crash involvements, respectively. This work was performed by the University of Michigan Transportation Research Institute under contract to the Volpe National Transportation Systems Center in support of the National Highway Traffic Safety Administration's program on Vehicle Aggressivity and Fleet Compatibility.

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ABBREVIATIONS

AOPVIN	A computer program which determines the type of occupant restraint system by decoding the VIN, and other vehicle information.
FARS	Fatal Analysis Reporting System (formerly the Fatal Accident Reporting System)
NASS GES	National Analysis Sampling System General Estimates System (formerly the National Accident Sampling System)
HLDI	Highway Loss Data Institute
NCAP	New Car Assessment Program
NHTSA	National Highway Traffic Safety Administration
VIN	Vehicle Identification Number
VINA	A computer program developed by R.L.Polk & Co., which determines make, series and subseries, and certain characteristics from a vehicle’s VIN.
VINDICATOR	A computer program developed by the Highway Loss Data Institute (HLDI) which determines make, series and subseries and certain characteristics of a vehicle from its VIN.

EXECUTIVE SUMMARY

The objective of this study was to determine the crashworthiness and aggressivity of passenger cars, light trucks and vans (LTVs) in traffic collisions. Crashworthiness is the capability of a vehicle to protect its occupants in a collision. The aggressivity of a vehicle, on the other hand, is described in terms of the casualties to occupants of the other vehicle involved in the collision. Both crashworthiness and aggressivity had to be considered because it is not easy to separate these effects in data from traffic collisions.

The data for the analysis was taken from the NHTSA Fatal Analysis Reporting System (FARS) and the General Estimates System (GES) data for calendar years 1991 through 1994. Vehicles with airbags were excluded from the study to avoid the biases inherent in comparing airbag equipped vehicles with non-airbag equipped vehicles. For this study, the crashworthiness of a vehicle was defined to be the fatality risk to occupants of that vehicle. The aggressivity of a vehicle was defined to be the fatality risk to occupants of the other vehicle involved in the collision.

Driver age has a strong effect on the evaluation of crashworthiness and aggressivity. Younger drivers are more injury tolerant and, therefore, less likely to die from their injuries. In contrast, older drivers are less injury tolerant, and are more likely to die from their injuries. Unlike other studies of crashworthiness and aggressivity, driver fatality risks in this study were adjusted for the higher vulnerability of older victims. Note that because of the smaller sample size available for the analysis of LTV-car collisions, the fatality ratios presented below were not adjusted for age effects, and, instead, cases were limited to drivers of age 26-55 to minimize this effect.

The major findings of the study are summarized below:

- In front-to-front collisions between LTVs and cars, car drivers are much more likely to be fatally injured than are LTV drivers. For these crashes, the ratio of car driver fatalities to LTV driver fatalities are:
  - **5 fatalities in the car for each fatality in the sport utility vehicle**
  - **5 fatalities in the car for each fatality in the van**
  - **3 fatalities in the car for each fatality in the pickup truck**
- In left side impacts of LTVs striking cars, the car driver is substantially more likely to be fatally injured than in left side impacts of cars striking cars. For these crashes, the ratio of car driver fatalities to LTV driver fatalities are:
  - **30 fatalities in the side impacted car for each fatality in the striking sport utility vehicle**
  - **25 fatalities in the side impacted car for each fatality in the striking pickup trucks**

  - **13 fatalities in the side impacted car for each fatality in the striking van**
  - **6 fatalities in the side impacted car for each fatality in the striking car**
- Vehicle size, as measured by wheelbase or weight, has a critical effect upon both crashworthiness and aggressivity. In particular, the aggressivity of a vehicle, increases with vehicle weight. In vehicle-to-vehicle collisions, the greater the weight difference between the two vehicles, the greater the risk to the occupants of the lighter vehicle and the lower the risk to the heavier vehicle. However, the reduction in the fatality risk for the driver of the heavier car is less than the increase of the fatality risk for the driver of the lighter vehicle. The result is a net increase in fatalities.
- In general, the risk to car occupants in single vehicle collisions and rollover declines with vehicle size. However, the analysis showed that significant overweight in excess of the average weight offered no advantages in single vehicle collisions.
- Cars which were heavier than the average weight for their wheelbase, or "overweight", were found to be more aggressive in general, than cars of the same wheelbase, but of average weight. However, with regards to crashworthiness, "overweight" appeared to have no beneficial effect. Any apparent effects of overweight, however, should be viewed with caution. For example, if overweight is due to more powerful, heavier engines, the incremental aggressivity may be due to the fact that more aggressive drivers are drawn to these overweight cars.
- The aggressivity and crashworthiness of passenger cars was examined by vehicle make and model. The analysis demonstrated clear differences in aggressivity between different car makes and models. To obtain larger FARS and GES case numbers for the analysis, corporate twins for a particular design were combined into single car families. Because of the strong effect of the victim's age upon fatality risk, fatality risks were standardized by the overall age distribution.

- These statistical measures of aggressivity must be related to vehicle design in order to determine the specific vehicle features and structural characteristics which lead to aggressive vehicles. Crashworthiness must also be considered. This will require detailed statistical analyses of valid data bases controlling for driver and collision factors.

1. INTRODUCTION

Improving the crashworthiness of cars and other motor vehicles is one of the main functions of the National Highway Traffic Safety Administration (NHTSA). However, when manufacturers design cars with better crashworthiness in rigid barrier crash tests, they may become more “aggressive” in collisions with other vehicles, increasing the injury and fatality risk to the occupants of the other vehicle.

The objective of this work was to determine the crashworthiness and aggressivity of cars and light trucks, by car model and truck type, and to study their relationship to vehicle characteristics. To increase case numbers and reduce random variability, car models had to be aggregated into “generic” car families.

Vehicle mass plays an important role in a collision between two vehicles. The heavier vehicle experiences a lower delta v - the change in velocity during the collision -, and the lighter vehicle a higher delta v. A higher weight reduces the injury and fatality risks for the vehicle’s occupants, but increases those for the lighter vehicle’s occupants. Thus, weight increases both the apparent crashworthiness and the aggressivity of a vehicle. Compared with the effect of weight, other vehicle characteristics are likely to have smaller effects on aggressivity. Therefore, their effects will be better recognizable if the effect of weight is removed and the remaining “net” aggressivity resulting from other vehicle characteristics is studied.

There are many vehicle characteristics that could affect aggressivity. Most are probably subtle structural aspects of a vehicle’s front end. In this study, only wheelbase and front bumper height, which are readily available were considered.

Some previous studies of crashworthiness have used fatality or injury rates per crash-involved persons, others have used rates per registered or insured vehicle year. It is believed that the latter rates can be strongly affected by differing characteristics of drivers and owners, for which no adequate control is possible. Injury rates per collision involved person can be easily studied using state collision data files. A sufficient number of fatalities can be found only in the files of the Fatal Analysis Reporting System (FARS).[1] There is, however, no matching file including all non-fatal collisions and involved persons. However, there are the files of the National Analysis Sampling System (NASS)[2] General Estimates System (GES) which contain a statistically valid sample from all traffic collisions in the United States. The expanded data from GES are a statistically valid complement to FARS. Therefore, the data from these two sources together were used. This is a novel approach, which may also be useful for other studies.

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[1] Formerly the Fatal Accident Reporting System

[2] Formerly the National Accident Sampling System

The work began with simple analyses, addressing many different questions. After a general overview was obtained, more sophisticated analyses of certain questions were performed. The report, however, presents the findings not in a historical manner, but by subject. Therefore, references to later sections sometimes appear, and more simplistic ones follow sophisticated analyses.

2. DATABASES

Two databases were used in the study: Fatal Analysis Reporting System (FARS) and General Estimates System (GES). Neither of them alone is sufficient. FARS contains only fatal collisions, overturns, and some other traffic events. Therefore, no absolute fatality risks can be determined, only relative risks for different classes of vehicles. An important consequence is that the effects of crashworthiness and of aggressivity cannot be distinguished. If occupants of vehicle class A have a higher relative fatality risk than occupants of vehicle class B, that can be due either to a better crashworthiness of B, or to a higher aggressivity of B. To separate these effects by analyses of FARS data alone, additional assumptions are necessary. Such assumptions can be avoided with the use of GES data. GES is a statistically valid sample of all police reported collisions and other traffic events in the U.S, but it does not contain enough fatal cases to allow calculating sufficiently precise fatality rates. Therefore, one can use both together to calculate fatality rates. Having fatality rates, one can separate the effects of crashworthiness and aggressivity. Though GES is statistically suitable for our analyses, it has one serious weakness: critical vehicle information is frequently missing. Whereas FARS has the Vehicle Identification Number (VIN), and make and model information for most cars, the VIN is frequently missing in GES and the model is often given as “other” or “unknown.” It is of some concern that this information may not be missing randomly. While some VINs appear to be missing randomly, there are also GES Primary Sampling Units where VINs are not available at all. Some tests were performed and tentative conclusions indicate that this should not introduce a major bias, but more work is needed to be confident about this.

FARS and GES data for the calendar years 1991 through 1994 were used. Changes in the files between 1990 and 1991 would have complicated the work if 1990 had been included, and 1994 was the latest year for which data were available when the work was done. Single vehicle collisions, and collisions between two vehicles that involved at least one passenger car or a light truck, were selected for evaluation. The light truck category includes utility vehicles, vans, and pickup trucks (FARS and GES body type code <40). Collisions where crashworthiness and/or aggressivity play no, or a different role, such as collision with pedestrians and bicyclists, and some relatively rare collision types were excluded.

Cars with an airbag were excluded, because it has a well-established effect on the fatality risk and including the relatively few airbag cars would have complicated the analysis more than could be justified. Airbag cars were identified using a computer program AOPVIN obtained from NHTSA. Seat belts also have a strong effect on the fatality risk, but information on belt use is considered unreliable, and therefore it was ignored.

Only data on drivers was used because information on other occupants cannot be considered complete in GES, if they are not injured.

Because fatalities are well defined and of greatest concern, only fatality risks were included in the study. Injury risks are also of interest but injury information suffers from two weaknesses: 1) the police injury scale used in GES is crude. Even major differences in injury severity may not be recognizable on this scale if they occur only within the class of most severe injuries (i.e., A on the police scale. 2) The operational definitions of the injury-severity levels differ among and even within states. Thus the information is subject to systematic errors.

Our analyses estimated crashworthiness and aggressivity for classes of vehicles. The grossest classification was into passenger cars, utility vehicles, vans, and pickup trucks. These body styles were available in FARS and GES for nearly all cases. Passenger cars were classified further. For the initial analyses, cars were classified according to weight and wheelbase. For the later analyses, classes consisting of "sister vehicles" (also called "corporate twins," or "corporate cousins") were formed according to make and series. This posed no problem with FARS data. Make and series are only rarely missing, as are weight and wheelbase, which NHTSA derived by decoding the VIN. For GES data, the situation was not so good. Model was frequently coded "other" or "unknown." The VIN was completely missing in certain states' data, apparently randomly missing in others. Weight and wheelbase are not given in the GES files. However, NHTSA provided special files containing weight, wheelbase, and other information obtained by decoding the available VINs. These were merged with the GES files.

The initial analyses used only the FARS and GES cases for which weight and wheelbase information was available. Therefore, relatively more GES cases than FARS cases had to be omitted, and fatality risks in the initial analyses are biased upward. There may also be other biases (e.g., if the vehicle mix in the states with no VINs should differ from that in states with available VINs). However, there is no reason to suspect a specific bias.

For the later analyses, cars were classified according to make and model. To increase the number of cases with make and model, information was used from the GES make and model codes, and from the VIN, where available. Two computer programs are available to obtain make, series, and subseries from the VIN: VINA, developed by R.L. Polk & Co., and VINDICATOR, developed by the Highway Loss Data Institute (HLDI). NHTSA's files with decoded VIN information contained the VINA codes. Its three-character code may indicate series, or subseries. It is an extremely detailed code. In our file, for example, 15 different codes appear for the Chrysler Le Baron. One of the codes covered 111 cases in our files, the remaining 62 cases were spread over the other 14 codes. Therefore, translation into the FARS/GES code is not a simple matter.

VINDICATOR gives a two-digit make, two-digit series, and two-digit subseries code. Two-door, four-door, and station wagon body styles of the same car model have different codes. This makes the translation into the FARS/GES codes cumbersome.

Figure 2-1 shows for our 1994 GES file how many cases with make/model information were, in principle, obtainable from the three sources. For 55 percent, make/model information was given, for 59 percent NHTSA had derived the VINA model code, and weight and wheelbase. For 34 percent, both sources provided the information so that for 80 percent either the GES model code, or the VINA model code was available. Decoding by VINDICATOR the cases where neither model information was given nor VINA could decode the VIN, would have added model information for only 4 percent of all cases; however, translating the model codes and obtaining weight and wheelbase would have required considerable effort. Therefore, these cases were not used. For 21 percent of the total, where make/model codes were given, weight and wheelbase information was still missing. The information was obtained from various issues of the *Automobile Red Book* (National Market Reports, Chicago), and other sources where necessary.

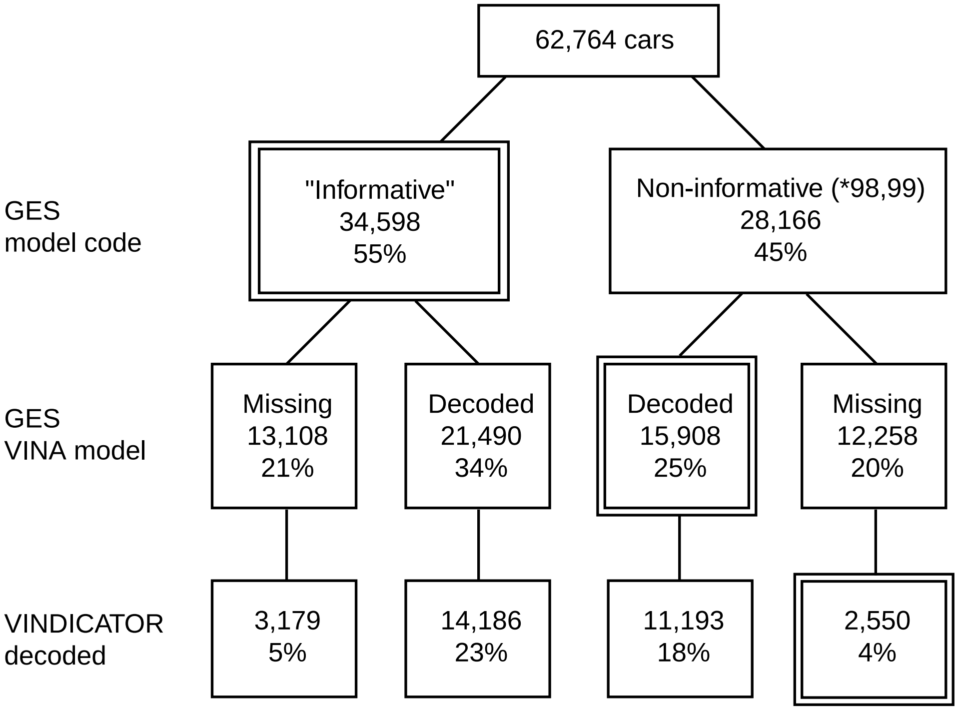

Figure 2-1. Availability of information on make/model for the 62,764 cars selected from the 1994 GES file. “Non-informative” are model codes ending with 98 or 99-other and unknown. Boxes with double frame contain the numbers of cars for which make/model information is available, and of additional cars for which it becomes available, if first decoded VINA models are added, and then decoded VINDICATOR models.

As already mentioned, the VINA model codes are much more complicated and extensive than the FARS/GES codes. Developing a codebook for translation would have required considerable work. Therefore, a simpler indirect method was used, but at the expense of losing half of the additional cases obtained from the decoded VINS. Thus, model, weight, and wheelbase information was obtained for about 67 percent of the cases in the file.

The simplified approach proceeded as follows: First, FARS data files were used to develop a conversion table from VINA model codes to FARS/GES model codes for the codes that actually appeared in the FARS files. Then, as outlined in figure 2-2, all of the GES cases were checked. If the FARS/GES code was given, no action was necessary. If the FARS/GES model code was missing (i.e., “other” or “unknown”), and the VINA code was also missing, no action was possible. If the FARS/GES code was missing, but the VINA code given, the conversion table was searched for a match. If there was no hit, no action was taken, if there was a hit, the FARS/GES code was taken and assigned to the case in the GES file.

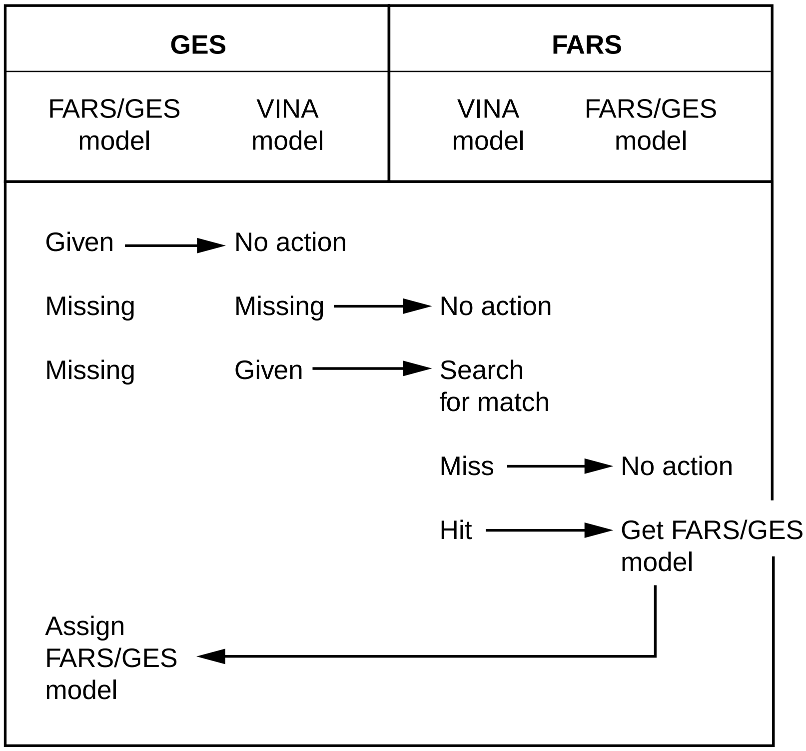

Figure 2-2. Logic of obtaining FARS/GES model codes from GES cases with VINA model code.

3. THE CONCEPT OF AGGRESSIVITY

The concept of crashworthiness is well established. It reflects the injury, or fatality risk to car occupants in specific collision situations, or over a broad range, possibly all, such situations, in comparison with other cars or with a standard car. Crashworthiness is usually defined for certain makes and models of vehicles, sometimes for certain types of vehicles.

Very specific collision situations are studied in compliance tests for motor vehicle safety standards and in the New Car Assessment Program (NCAP). Such tests, however, cannot directly measure injury or fatality risks. They can only measure indicators that are related to such risks.

To estimate crashworthiness in terms of injury or fatality risks, data from actual traffic collisions must be used. Ideally, collisions of a very specific type would be selected, in terms of configuration, speeds of the involved vehicles, and objects struck to determine in which proportion of them an occupant of a specific seating position suffered an injury of a specified severity. In mass traffic collision databases, not all needed information is given. Therefore, crashworthiness is commonly calculated for broad categories of collisions, such as frontal impacts, left-side impacts, etc., and perhaps even for “all” collisions, which depend less on precise information.

Sometimes injury risks per registered vehicle or a similar measure are used, instead of injury risks per collision involvement. The Highway Loss Data Institute, for instance, regularly publishes data on injury insurance claims per insured vehicle, implying that they reflect the crashworthiness of cars. Conceptually, rates per registered or insured vehicle are unsatisfactory for comparing vehicles. They imply that different car models get into the same number of collisions per year, and that the collision conditions are the same. This is not the case.

The concept of aggressivity is similar to that of crashworthiness, but it applies to the occupants of “the other” vehicle in a collision. Again, the ideal definition uses the fatality or injury risk to occupants of the other vehicle, given a collision with the subject vehicle. The situation is more complicated because both the crashworthiness of the other occupants’ vehicle, and the aggressivity of the other vehicle influence the injury and fatality risks. Therefore, a measure of aggressivity can be defined as either the injuries to occupants of a specific vehicle used as standard, or the average over all, or at least a representative selection, of vehicles involved in collisions.

A more subtle aspect is “compatibility.” It may happen that vehicle A poses a different injury risk to occupants of vehicle B than to occupants of vehicle C, which has the same crashworthiness. This can result from a mismatch of vehicle parts. While potentially of practical importance, it appears premature to study this question.

As in the case of crashworthiness, certain types of aggressivity can be defined. For instance, aggressivity in frontal impacts may differ from aggressivity in side impacts.

Again, as in the case of crashworthiness, aggressivity may be defined as the number of deaths or injuries in all other vehicles, resulting from collisions with the selected vehicle type, per registered vehicle of this type. This would be a valid description of the societal impact of this vehicle type, given its current users and uses. However, it would not be a valid measure of the aggressivity due to physical and engineering characteristics of the vehicle. To isolate their effects, the effect of user and use factors has to be eliminated.

The masses of the two vehicles in a collision have a very strong influence on the fatality and injury risks of the occupants of the vehicles. In a strict sense, this effect should be included in the measure of aggressivity. However, it can dwarf the effect of vehicle design features one is interested in. Therefore, it is suggested that the differences between the two types of aggressivity: "gross" aggressivity, which includes the effect of vehicle weight, and "net" aggressivity, which remains after controlling for vehicle weight, be distinguished.

Since both vehicles' weights interact in a collision, definitions cold similarly be made for "gross crashworthiness", which includes the effects of mass and engineering characteristics, and "net crashworthiness", which reflects the effects of engineering after accounting for the effect of mass. The New Car Assessment Program does this to some extent by using a barrier test, which is equivalent to a collision with a car of the same weight.

4. CONFOUNDING FACTORS

Fatality rates associated with different vehicle types, or even car models cannot be taken at face value to reflect the inherent crashworthiness or aggressivity of the vehicle, because confounding factors also influences them.

Different vehicle types serve, to some extent, different purposes: cars, utility vehicles, vans, pickup trucks, and even sedans and station wagons. Differences in use result in differences in driving environment, which can result in different collision types, and different speeds. Also, if certain vehicle types or car models are used relatively more often in certain environments, they are more likely to collide with each other than with other vehicles.

Manufacturers aim different vehicle types, and different car models at different types of buyers and users. This has the effect that drivers are more likely to collide with similar drivers than with others - and the same holds for their preferred vehicles. Of driver characteristics, however, only age and sex information are in the collision data files. Characteristics that influence driving style is not known. (FARS contains some information on previous accidents (crashes), license suspensions, and convictions; however, it is not sufficiently complete, and cannot be reliably interpreted without matching information in GES.)

Driver age has a very strong effect. Younger and older drivers have different collision patterns. Younger drivers tend to get into more severe collisions, older drivers are more likely to die from their injuries.

Figure 4-1 shows the driver fatality risk in the selected collisions, estimated by the fatality rate per driver involved in a collision. The risk was estimated in two ways: The solid line shows the values obtained from GES estimates of driver fatalities and involved drivers. The broken line shows the values obtained using the actual FARS counts of fatalities as numerators; the GES estimates of involvement as denominators.

The overall trend of both lines is very similar. This shows that the combination of FARS and GES data gives overall the same results as the statistically valid GES sample alone. However, the line based on the combined data is much smoother. This is to be expected, because the practically complete FARS counts are precise, whereas the fatality estimates from GES are based on very small counts and therefore not very precise. There is, however, an indication of a systematic difference: if a smoother line were fitted to the GES data, the fatality risks for younger drivers (up to 40 years of age) would be lower.

The lines reflect a combination of age-related collision severity and type, and of vulnerability. Considering the line based on FARS and GES data, the fatality risk declines slightly up to 45 years, then increases slowly at first, then later the fatality risk rapidly increases.

To control for this age effect during the initial analysis, only drivers of ages 26-55 were selected; this is a large group within which the risk varies little, if only the FARS/GES data combination is considered. For the later analysis all drivers were considered, but they were standardized for differences in the age distribution among car model and vehicle type. An arbitrary decision was made to define the age groups up to 45 years, 46-70 years, and older. The overall proportion of drivers in these groups were 0.747, 0.205, and 0.048. To standardize this, age distribution risks were separately estimated for the three groups, and averaged with weights equaling the above-mentioned proportions.

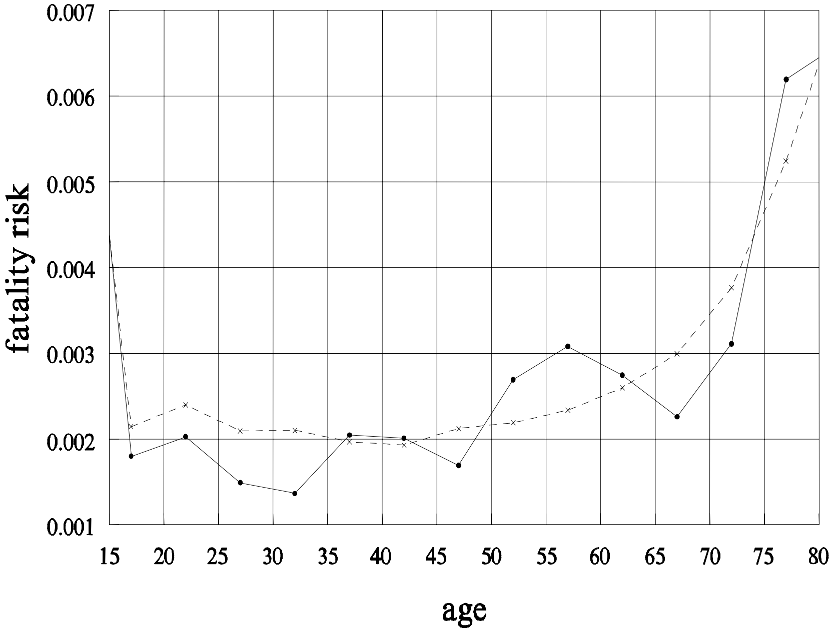

Figure 4-1. Car driver fatality risk in a collision by age. The solid line is based on GES data alone, the broken line shows rates using FARS data in the numerator, GES data in the denominator. Points for very young and very old drivers are not shown because they are based on very few drivers and are unreliable.

5. VEHICLE WEIGHT AND SIZE

5.1 THE EFFECT OF VEHICLE WEIGHT

The simplest model of a collision between two vehicles is an inelastic collision: After the collision, the two vehicles will move together at a speed determined by the conservation of momentum. (In reality, the result of a collision can be more complex; e.g., one or both vehicles may begin to spin when colliding, and move along different trajectories.)

In the simplest case when the vehicles move in the same or opposite directions, and their centers of mass are aligned with the speed vectors, they change their velocities by:

$$\Delta v_1 = \frac{m_2}{m_1 + m_2}(v_1 + v_2) \qquad (5.1-1)$$

$$\Delta v_2 = \frac{m_1}{m_1 + m_2}(v_1 + v_2), \qquad (5.1-2)$$

where m_i are their masses, and v_i their initial velocities. In angle collisions, if the centers of mass are on one of the velocity vectors, the formulas are similar, but one has separate formulas for the two components of the speed vector.

It is well known that the Δv is the best single predictor of injury and fatality risk in a crash. A rough empirical formula is.[3,4]

$$\text{fatality risk} = (\frac{\Delta v}{70})^4, \qquad (5.1-3)$$

where Δv is the velocity change in miles per hour; above 70 mph, the risk is practically one. For injuries, similar formulas hold, but the exponent is lower, of the order 2 to 3. Combining (5.1-1), (5.1-2), and (5.2-3) one obtains

$$\frac{R_1}{R_2} = (\frac{m_2}{m_1})^4, \qquad (5.1-4)$$

as long as none of the Δv exceed 70 mph.

If one uses logarithms, the formula becomes

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[3] H.C. Joksch, Velocity Change and Fatality Risk in a Collision - A Rule of Thumb. Accident Analysis and Prevention. Vol. 25, 1993, pp. 103-104.

[4] L. Evans, Driver Injury and Fatality Risk in Two-Car Collisions Versus Mass Ratio Inferred. Accident Analysis and Prevention. Vol. 26, 1994, pp. 609-16.

$$\log(\frac{R_1}{R_2}) = 4*\log(\frac{m_2}{m_1}). \qquad (5.1-5)$$

The relation is linear in a double-logarithmic graph.

Figure 5-1 shows an attempt to verify this relation. FARS data on collisions between two cars were used. To reduce the effects of confounding factors, only cars with drivers between 26 and 55 years were used, and cars with airbags were excluded. Collisions were grouped by mass ratio, and for each group the ratio of driver fatalities calculated to estimate the ratio of fatality risks.

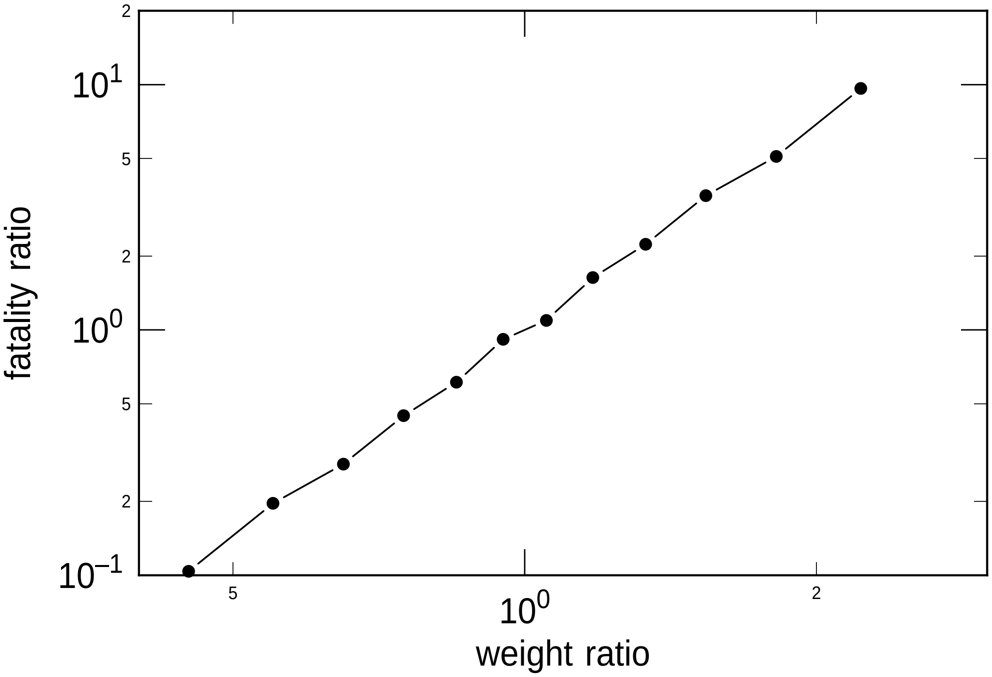


Figure 5-1. Ratio of car driver fatalities in collisions between two cars, by weight ratio of the cars. Based on FARS data, using only collisions where both drivers were 26-55 years old and no car had an airbag.

The points are practically on a straight line. However, its slope is not 4 as in equation (5.1-5), but only 3. This can be easily explained. Formulas (5.1-4) and (5.1-5) hold only as long as both Δv do not exceed 70 mph. If the closing speed exceeds 70 mph, there exists a mass ratio above which (and below its inverse) the logarithm of the risk ratio increases more slowly than proportional to the mass ratio. The higher the closing speed, the lower is this critical mass ratio. If the average of such relations are taken over a range of closing speeds $v_1 - v_2$, the result will be a less steep relation than (5.1-5).

At very high closing speeds, the situation changes. For mass ratios around one, the risk ratio is exactly one, because both drivers are killed. Only if the masses are very different will one driver have an advantage.

This hypothesis cannot be directly tested because closing speeds are unknown. However, an assumption can be made that closing speeds in a high-speed driving environment are higher than in a low-speed driving environment. Therefore, collisions were separated by speed limits, and plotted in figure 5-2 the same relation as in figure 5-1, but separate for two ranges of speed limits. Again, there are two nearly linear relations, but the one for lower speed limits is steeper, as to be expected because at low speeds the “leveling off” of the risk ratio begins only at more extreme mass ratios.

The differing slopes in figure 5-1 show that control for closing speed is desirable, especially since it may be directly, and also indirectly- via driving environment- related to driver characteristics which may be related to vehicle type and even make/model.

The databases do not allow controlling for closing speed. This could be attempted with some state databases that contain estimates of pre-collision travel speeds, or more detailed descriptions of vehicle damage Whether that would be successful is an open question.

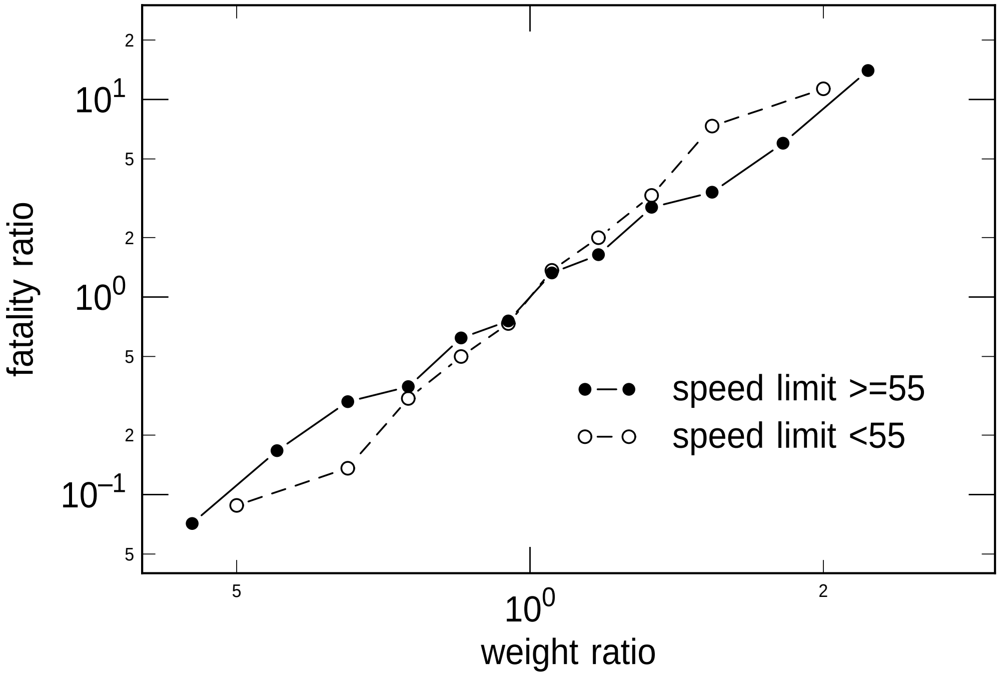


Figure 5-2. Ratio of car driver fatalities in collisions between two cars, by weight ratio of the cars and speed limit at the collision site. Based on FARS data using only collisions where both drivers were 26-55 years old, and no car had an airbag.

Finally, front-front, front-left, and front-right collision data were distinguished. The resulting relations are shown in figure 5-3. For front-front collisions the relation is, of course, again symmetric and practically linear, except at the extremes where, as expected, it levels off. Again as expected, the fatality risk for a driver is much higher if the car is impacted on the left side. However, the increase is not by a constant factor, and becomes less with more unfavorable mass ratios. The risk in right impacts is between those for frontal impacts, and for left-side impacts. What is surprising is that the patterns of the relations for left and right impacts are very similar, though they result from different sets of collisions. A hypothetical explanation is that for certain weight ratios combinations of certain car models are common, and that they have similar crashworthiness in left- and in right-side impacts.

The conclusion from these analyses is that car weight has a very strong influence on occupant fatality risk. It varies by a factor of more than 10 when mass ratios vary by a factor of 2, which is not unusual. To obtain the net crashworthiness and net aggressivity, this very large effect has to eliminated.

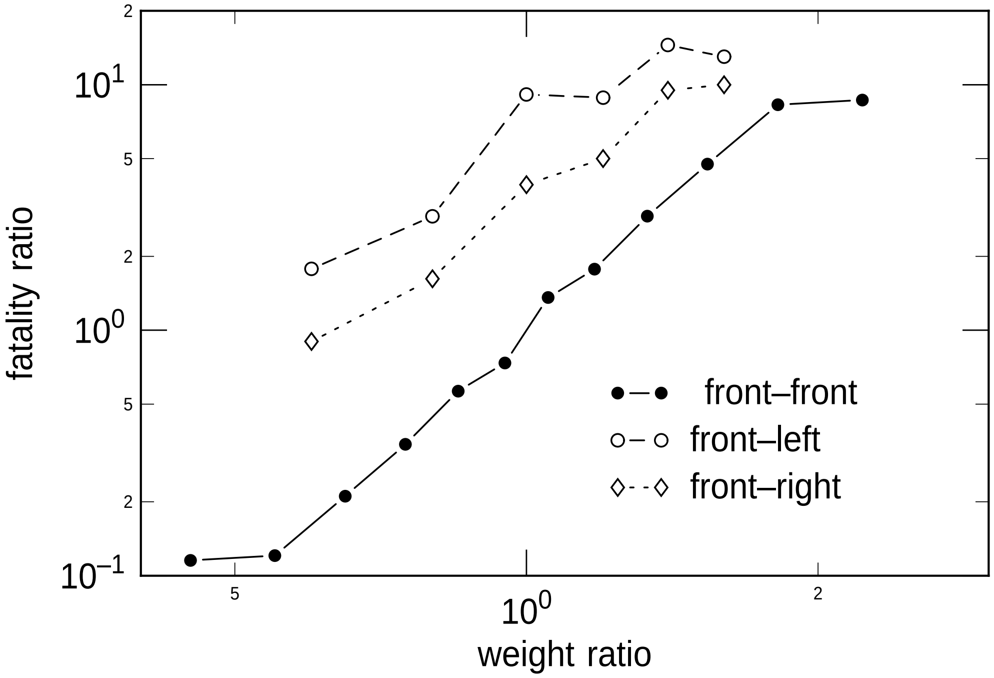


Figure 5-3. Ratio of car driver fatality risk in front-front, front-left, and front-right collisions between two cars, by weight ratio of the cars. Shown are the risks for the driver of the side-impacted vehicle in side-impact collisions. Based on FARS data, using only collisions where both drivers were 26-55 years old, and no car had an airbag.

5.2 VEHICLE SIZE

While researchers have a qualitative idea of vehicle size, there is no unique measure for it. Total volume, perhaps the volume of passenger and cargo compartment, overall length, or wheelbase are some of the obvious candidates. None of them has a direct physical relation to the injury risk or Δv. A larger vehicle can provide more crush space which can be utilized for energy management, and thus reduce the fatality risk. However, more space does not automatically provide better energy management.

Under this aspect, different dimensions could be appropriate measures of size, depending on the collision type. None of them is readily available. Only wheelbase and overall length of a vehicle are readily available. Overall width is less readily available. While the overall length may be a better indicator of potential crush space, it has some disadvantages. For instance, different body styles of the same car make/series can have different overall lengths, but be identical in configuration of the vehicle front that is involved in a high proportion of collisions.

Because wheelbase is available in the FARS file, and it is more closely related to the basic structure of the vehicle, it was used as measure of vehicle size. This choice may be criticized, but at this time no clearly preferable alternative is apparent.

5.3 THE RELATION BETWEEN CAR WEIGHT AND WHEELBASE

A larger car has a greater mass than a smaller car, if it is generally the same design; therefore, it can be expected that there is a correlation between weight and wheelbase. Although some researchers consider a distinction of weight and size unnecessary; for this study they should be distinguished. A longer wheelbase offers the opportunity to provide more crush space, and thereby to reduce effects of intrusion, and perhaps to provide better energy management. While a longer wheelbase can possibly improve crashworthiness, it is hard to imagine how by itself it could increase aggressivity. To some extent weight may be an unavoidable consequence of increasing size, but higher weight resulting from a more powerful engine, more power features, etc. does not increase crashworthiness. It is conceivable that greater weight destroys fixed objects in a collision and thereby apparently increases crashworthiness. On the other hand, as is physically well understood, a higher weight will increase the fatality risk for occupants of other vehicles in collisions. Thus, weight is related to aggressivity. Therefore, both weight and size were considered when classifying cars. For an empirical classification of the collision-involved car fleet during the study period, cases were selected from the GES file. FARS would have given higher percentages of cars with known weight and wheelbase, but because of the correlation between crashworthiness and size, the selection would have been biased toward lighter or smaller cars. Figure 5-4 shows the combination of weights and wheelbases (categorized by 250 lbs, and by 2.5 in.) in the study population. The area of each circle is proportional to the number of cars with weight-wheelbase combinations in the cell it represents. Only cells with at least 10,000 cases are shown. It is obvious that for some wheelbases the weight varies considerably - in an extreme case by a factor of about 2. Thus, though there is a correlation between weight and wheelbase, it is not close, and it may be possible to separate their effects on the fatality risk of occupants, as well as of occupants of other vehicles. To do this, the concept of overweight was introduced as a factor. Figure 5-5 shows, for each wheelbase class, the average weight of cars with that wheelbase. This is called the standard weight for the given wheelbase. The curve shown represents the relation quite well. Trial and error gave its mathematical expression.

$$\text{average weight} = -498 + 0.3078 * \text{wheelbase}^2 .$$

This curve is also shown in figure 5-4. While it appears that there are substantial numbers of cars below the average curve, this is largely due to the aggregation in wheelbase-weight classes. If one classifies by wheelbase and overweight, then most cars are within 250 lbs of the average weight, a large number is in the range 250 to 750 lbs, and some even above that, but usually very few more than 250 lbs below the average.

Any apparent effects of vehicle overweight have to be interpreted with caution. For instance, if overweight is due to more powerful and heavier engines, more aggressive drivers may drive overweight cars.

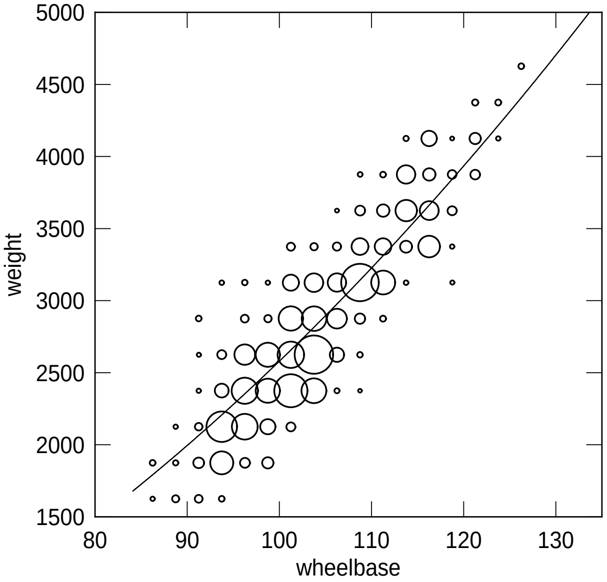


Figure 5-4. Distributions of cars involved in the studied collisions by weight (lb) and wheelbase (in.). Cars were grouped into cells of 2.5 in. x 250 lbs; the areas of the circles are proportional to the number of cars in each cell. Only circles for cells with at least 10,000 cars are shown. The curve is taken from Figure 5-5 and explained there. Based on GES cases where NHTSA was able to decode the VIN and obtain weight and wheelbase.

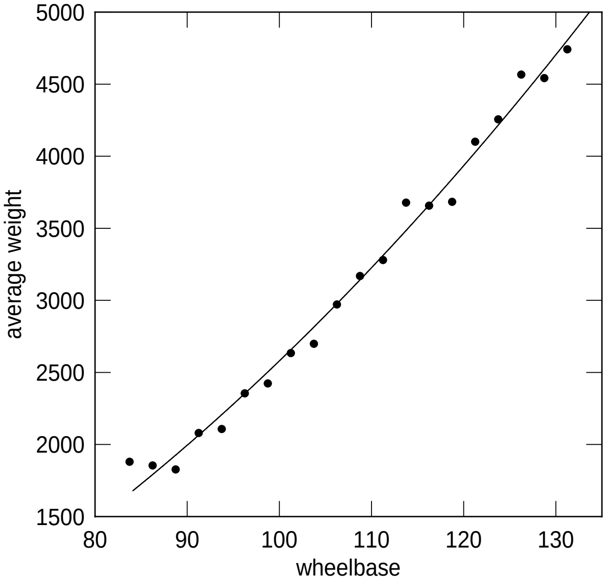


Figure 5-5. Relation between average car weight (lb) for each wheelbase class, and wheelbase (in.), for the database described in figure 5-4. The dots are the average weight of cars for wheelbase classes of 2.5 in.. The quadratic curve is empirically fitted to best represent the points, without regard to the number of cases that each point represents.

5.4 RISK TO CAR OCCUPANTS IN COLLISIONS WITH CARS

For the initial analyses, cars were first classified by wheelbase, in 5-in. ranges, then by weight relative to the average weight for the wheelbase range, the "overweight."

Figure 5-6 shows the fatality rate for the driver of the case vehicle, reflecting its crashworthiness, figure 5-7 for that of the other car, reflecting the aggressivity of the case vehicle.

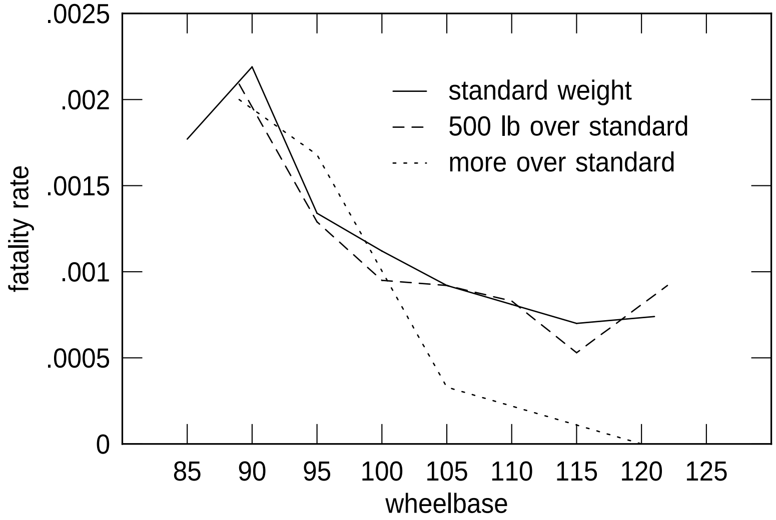


Figure 5-6. Car driver fatality rate, per involved driver, in collisions with other cars, by wheelbase (inches) of his car, for cars of "standard" weight, for cars 250 to 750 lbs over the standard weight, and for cars more than 750 lbs over the standard weight. Drivers 26-55 years old, no airbag.

Figure 5-6 shows that larger cars are more crashworthy than smaller cars, but the effect levels off beyond 110 in.. wheelbase. Overweight of 250 to 750 lbs appears to have no beneficial effect, and greater overweight only for cars over 105 in. wheelbase.

Aggressivity increases with car size (figure 5-7). The role of overweight differs from that in crashworthiness; for overweight in the range of 250 to 750 lbs, the aggressivity is nearly always greater than for standard cars. For cars with more overweight, the pattern is less clear: In the middle range it does not differ much from standard weight cars. At the extremes it differs in counterintuitive directions.

Since these figures show connected points based on grouped data, and some groups contain relatively few cases, the relations are not always smooth. Therefore, a technique was used to smooth the data; it is described in Appendix A. It gives the fatality rate (as an indicator of risk) as a smoothed function of wheelbase and overweight, on the points of a two-dimensional grid. Figures 5-8 and 5-9 show the smoothed function which correspond to figures 5-6 and 5-7; they are based on the same collision cases.

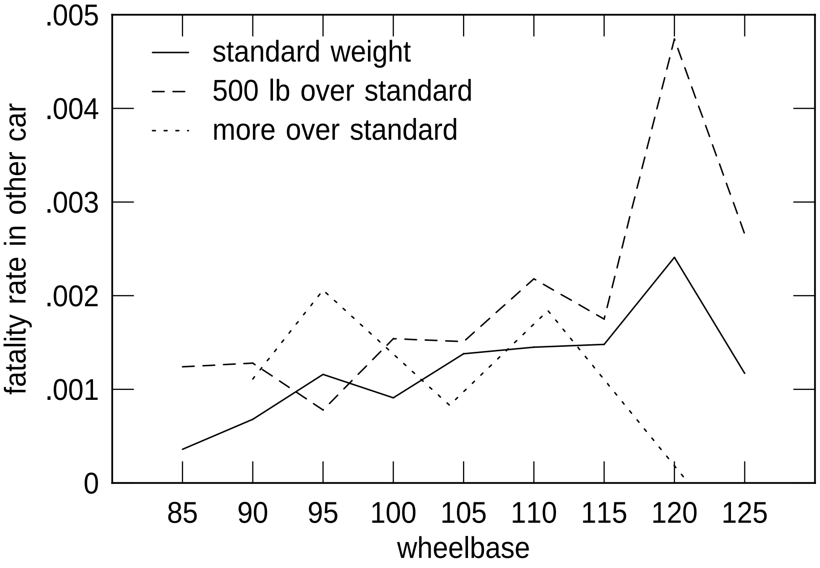


Figure 5-7. Car driver fatality rate, per involved driver, in collisions with other cars, by wheelbase (in.) of the other car, for cars of “standard” weight, for cars 250 to 750 lbs over the standard weight, and for cars more than 750 lbs over the standard weight. Drivers 26-55 years old, no airbag.

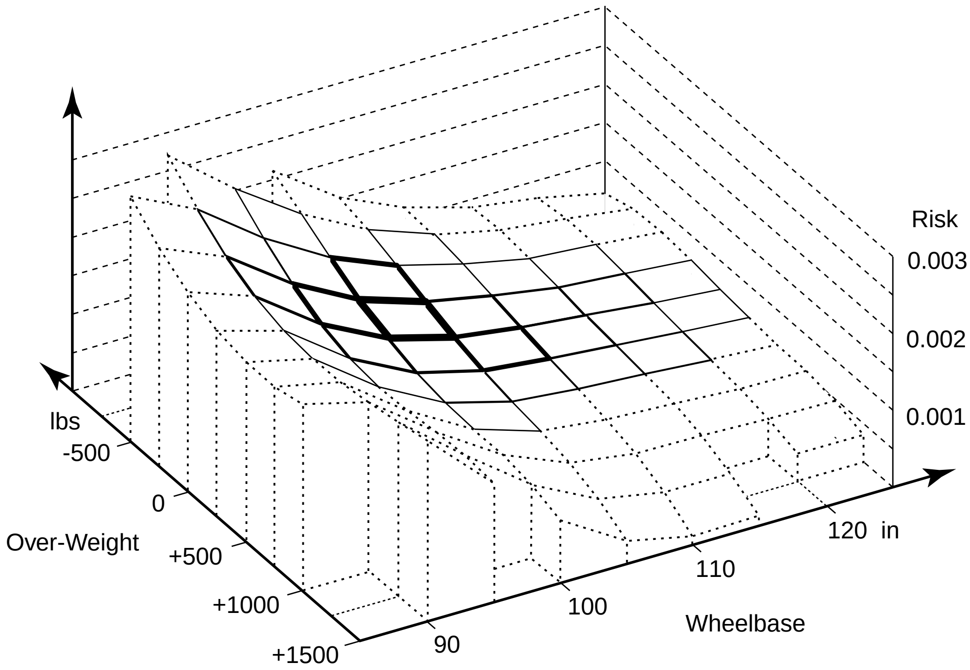


Figure 5-8. Car driver fatality rate, per involved driver, in collisions with other cars, by wheelbase and overweight of his car. Drivers 26-55 years old, no airbag. Smoothing window 7.5 in. x 750 lbs The information corresponds to that of figure 5-6.

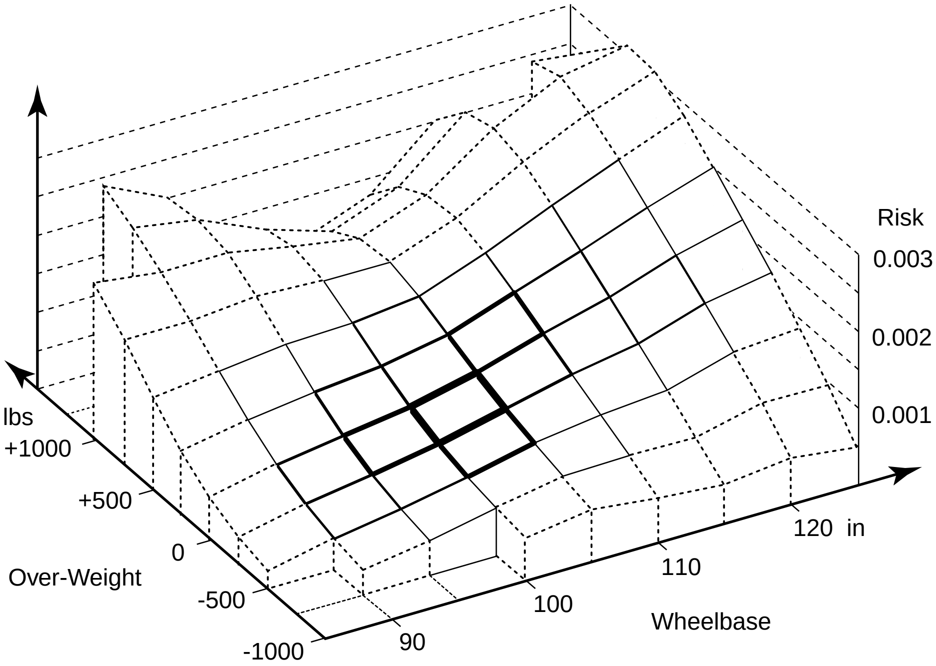


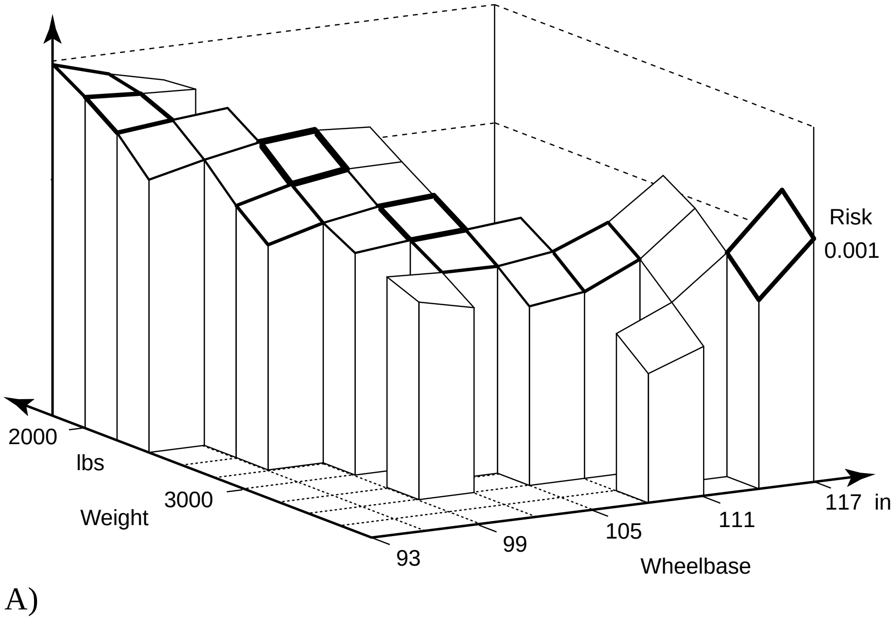
Figure 5-9. Car driver fatality rate, per involved driver, in collisions with other cars, by wheelbase and overweight of the other car. Drivers 26-55 years old, no airbag. Smoothing window 7.5 in. x 750 lbs The information corresponds to that of figure 5-7.

Figure 5-8 shows the pattern of figure 5-6 more clearly in the range of no or little overweight, the risk declines with wheelbase up to about 110 in., and remains practically constant beyond that. Overweight has relatively little effect in the middle range, but beyond 110 in. wheelbase it reduces the risk. “Underweight” has a paradoxical effect: it seems to reduce the risk for the largest cars, but to increase it for the smallest cars. No serious attempt should be made to interpret the pattern at the extremes; as indicated by the dotted grid-lines, there are relatively few collision cases, and also relatively few car models, in these areas. Random fluctuations and peculiarities of certain models that go beyond weight and wheelbase can have a strong influence.

Figure 5-9 shows a simpler pattern than figure 5-8, and a clearer pattern than figure 5-7. Aggressivity increases nearly everywhere with wheelbase, but to varying degrees. In addition, aggressivity increases nearly everywhere with overweight, and it does so much more rapidly than crashworthiness increases in Figure 5-8. The only exception to this clear pattern is the area between 95 and 115 in. wheelbase for the heaviest cars.

These analyses ignored confounding factors. One of them is driver age. Younger drivers get into more severe collisions, older drivers are more likely to die in collisions of a certain severity than younger drivers are. Furthermore, drivers of similar ages tend to collide more often than would be expected if the ages were randomly mixed. To account for these effects, three separate analyses were performed (for three age groups of drivers). These results were averaged with weights equaling the overall proportions of drivers for the three age classes. (0.747 for those under 46, 0.205 for those 46 to 70, and 0.048 for those older).

Figure 5-10A shows the fatality rate for all drivers by weight and wheelbase of the car they are in. It corresponds to figure 5-8, but uses weight instead of overweight. Figure 5-10B shows the standardized rates. There is a clear difference. The risk in large cars is much lower than apparent in the unadjusted data. This is due to the higher proportion of older drivers in larger cars, which makes them appear less crashworthy than they are. On the other hand, the effect of weight, for a given wheelbase, appears to be less. There is no obvious explanation for this.



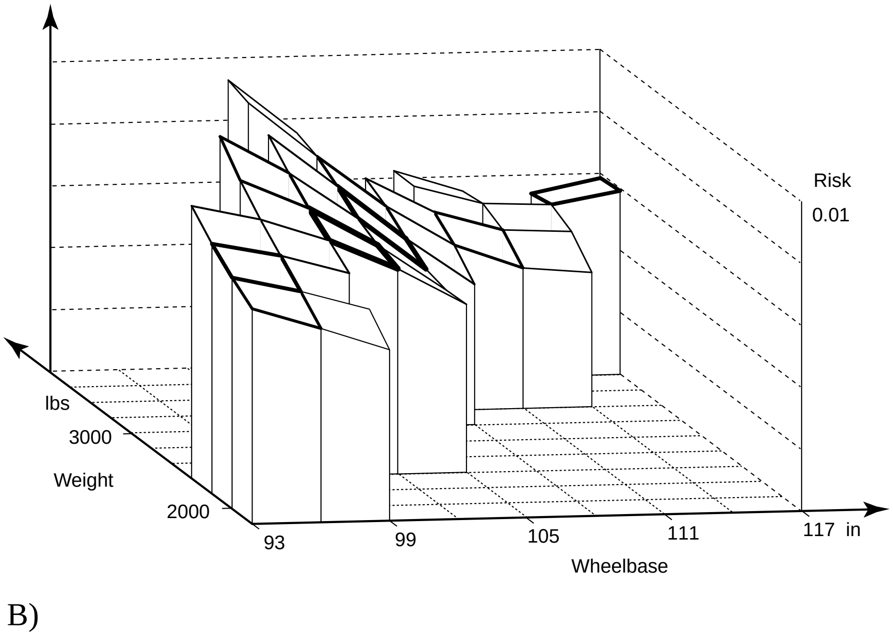
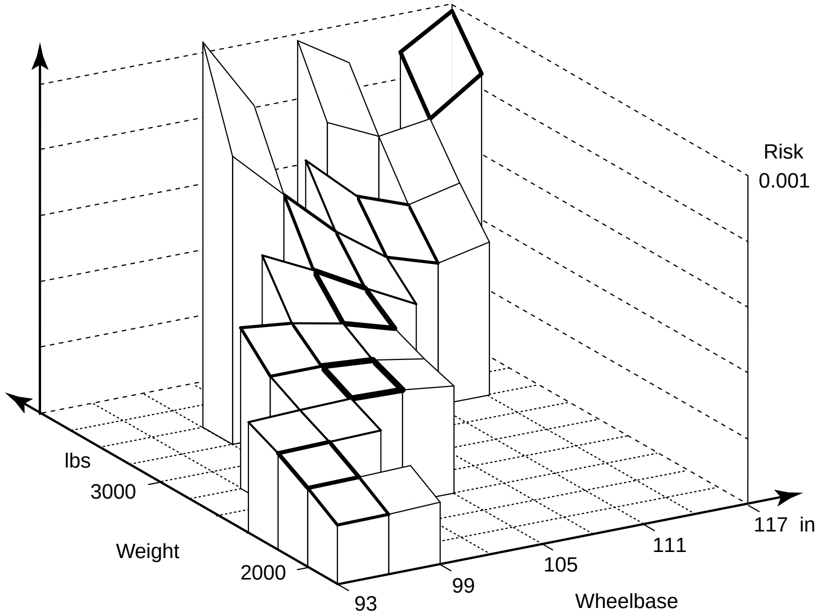
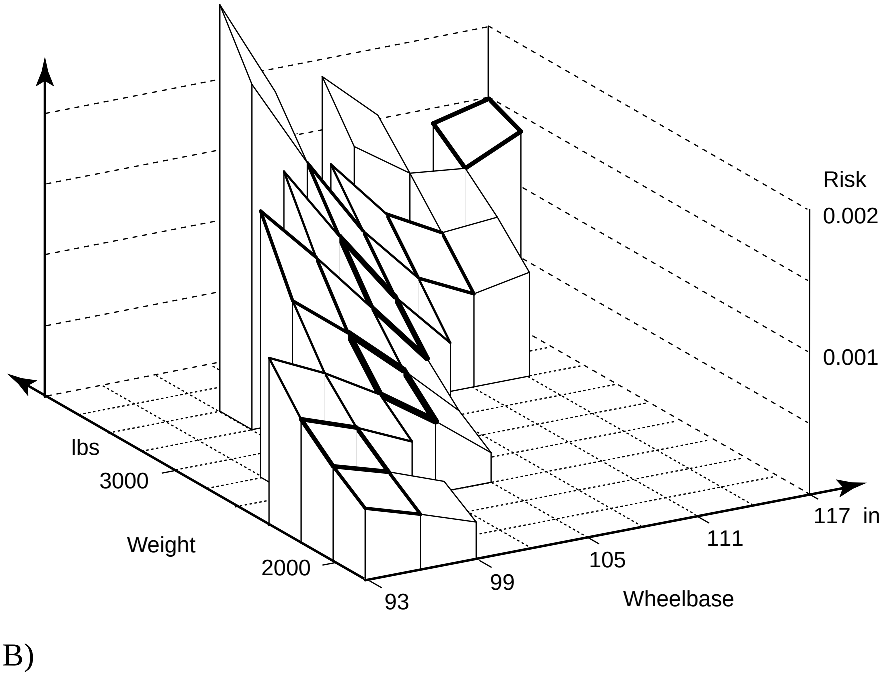


Figure 5-10. Car driver fatality rate, per involved driver, in collisions with other cars, by wheelbase (in.) and weight (lb) of the car. All drivers, no airbag. A) actual rates, B) rates standardized to a common driver age distribution. Note that the weight axis in part B is reversed to give a better view of the surface.

Figure 5-11 shows the fatality rate for all drivers, by weight and wheelbase of the other car. This figure corresponds to figure 5-9, but uses weight instead of overweight. This figure shows mostly no relation , or no consistent relation between risk and wheelbase for a given weight. The adjusted data show a very different pattern: The risk declines generally with the wheelbase of the other car, but increases with its weight. The latter is to be expected, but there is no obvious explanation for the first.



A)



B)

Figure 5-11. Car driver fatality rate, per involved driver, in collisions with other cars, by wheelbase and weight of the other car. All drivers, no airbag. A) actual rates, B) rates standardized to a common driver age distribution.

From these analyses, some tentative conclusions were drawn:

- Crashworthiness in car-to-car collisions increases with wheelbase, however, only up to about 110 in.. Beyond that it varies only little. Overweight contributes relatively little or nothing to crashworthiness.
- Aggressivity increases nearly everywhere with wheelbase, over its entire range. It also increases nearly everywhere strongly with overweight.
- Standardizing fatality rates for the victims' ages has a strong quantitative, but no qualitative, effect on risk patterns.

5.5 RISK TO CAR OCCUPANTS IN SINGLE-CAR COLLISIONS AND ROLLOVER

Single-car collisions or rollover do not directly tell us anything about vehicle compatibility or aggressivity. However, they provide information on crashworthiness that can help to separate the effects of crashworthiness and aggressivity in collisions. The following analyses are similar to those in section 5.4.

Figure 5-12 shows the driver fatality risk by wheelbase, separately for cars of "standard" weight, cars with 250 to 750 lbs overweight, and heavier cars. For cars of standard weight, the fatality risk clearly decreases with vehicle size, roughly by one half from short wheelbases to the long wheelbases.

For cars with an average of 500 lbs overweight, the same overall trend holds. However, there is a surprise. The risk in overweight cars is not lower than in standard cars of the same wheelbase. To the contrary, it appears higher for cars of shorter wheelbases. While it cannot be concluded that overweight is harmful for the driver of the car, the data also does not suggest that weight per se has a protective effect. However, it is conceivable that more aggressive drivers drive overweight cars, and that this may overcompensate for any greater crashworthiness they might possibly have.

For cars with even more overweight, the situation is less clear, for long and for some short wheelbase, the driver fatality risk is much higher than for lighter cars. For midsize cars, the reverse holds. It may well be that this is not a vehicle effect, but a driver or environment effect related to certain make/models. It needs to be studied further, going down to the make/model level.

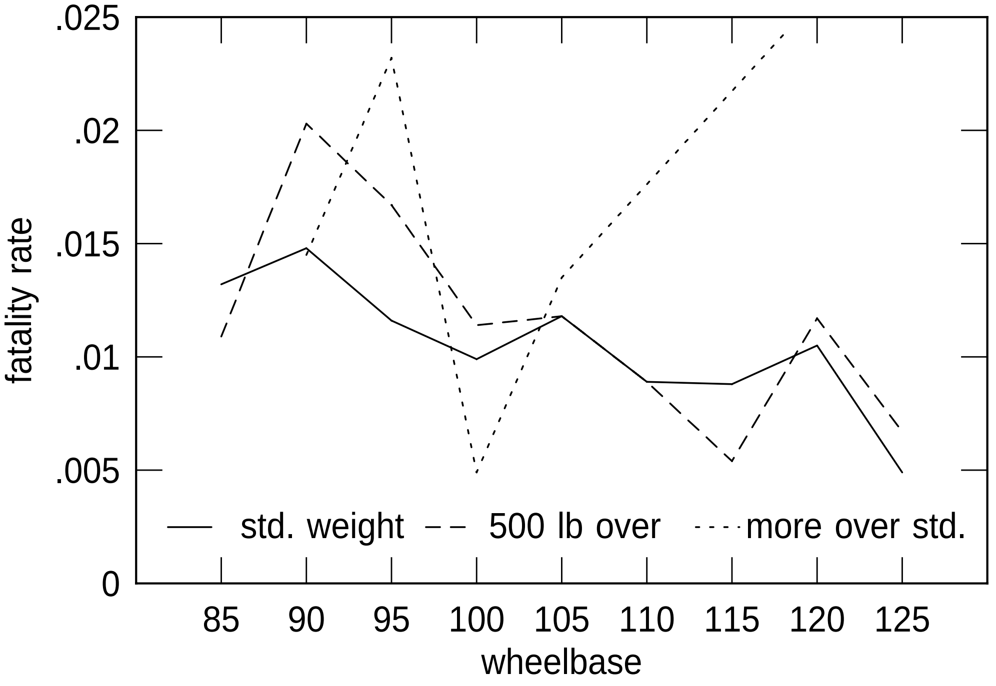
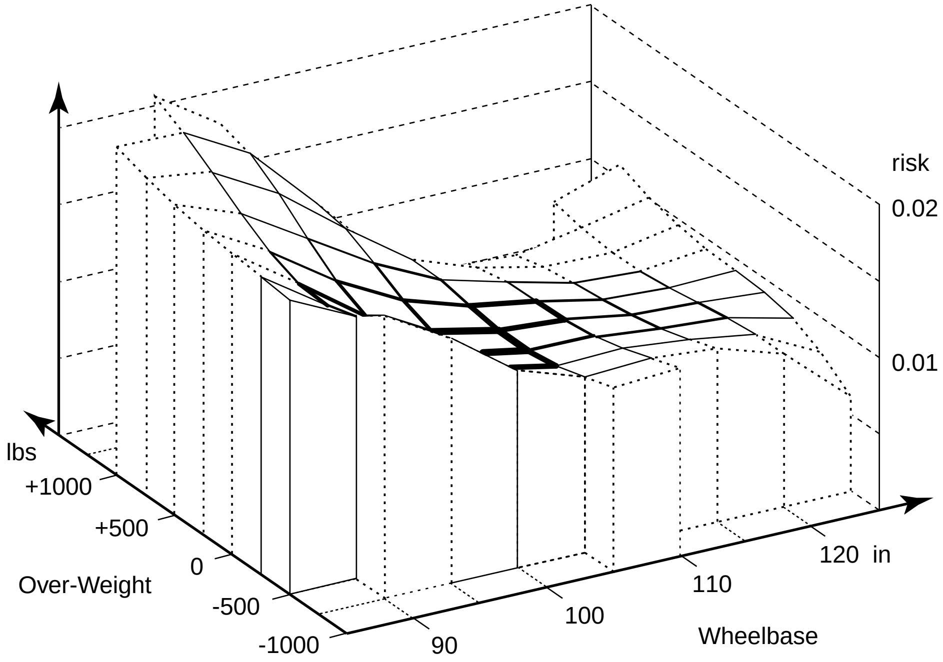


Figure 5-12. Car driver fatality rate, per involved driver, in single car collisions, by wheelbase (in.), for cars of “standard” weight for cars 250 to 750 lbs over the standard weight, and for cars more than 750 lbs over the standard weight. Drivers 26-55 years old, no airbag.

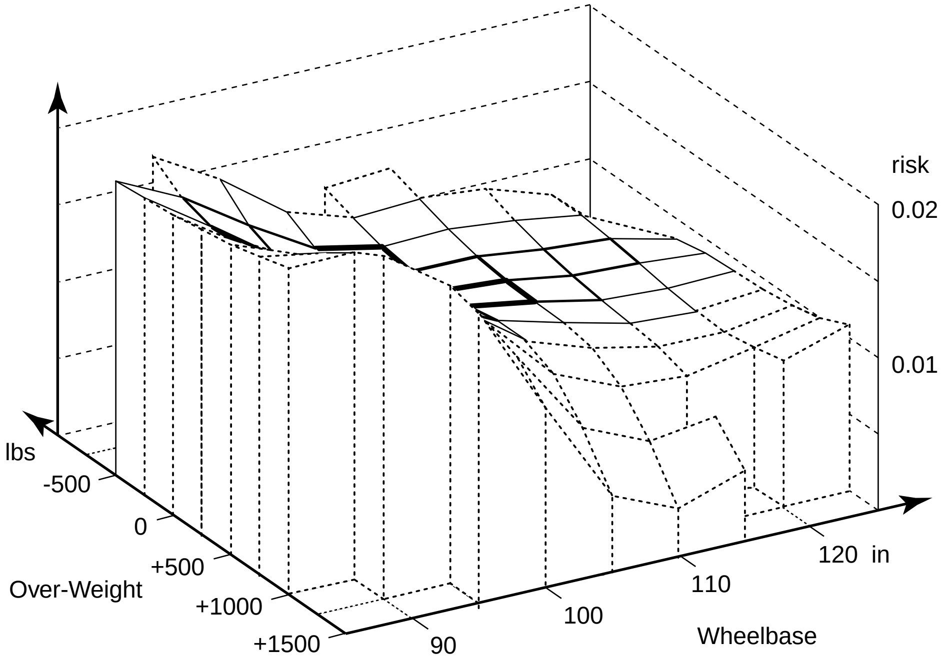
Figure 5-13 shows, similar to figure 5-8 values smoothed over wheelbase and overweight, rather than connecting of points representing cells. Parts A and B of the figure show the same surface, but with different directions of the overweight scale. This allows a clear view of the parts of the surface that are hidden on one of the figures. The pattern is similar, though somewhat clearer, than in figure 5-12. In the part of the grid heavily covered with cases, the risk declines with wheelbase, up to 105 in. and 110 in.. Beyond that it remains constant. In general, the risk changes little, or increases, with increasing overweight. It is difficult to imagine a direct physical reason for this. However, there could be indirect reasons. The overweight could be due to larger and heavier engines that attract more aggressive drivers. Only in the range between 100 in. and 115 in. does the risk decline with very high overweights. There is no obvious physical reason for this; it could be due to a few make/models that have better crashworthiness, or attract drivers taking fewer risks.

In these figures, some control for driver age differences was exercised by selecting cases with drivers 26 to 55 years old. Figure 5-14 uses all drivers, and controls for driver age by standardizing to a common driver age distribution. Part A) shows the risk by weight and wheelbase, for all drivers combined. Part B) shows the standardized risk. One obvious difference is that the surface in part B) is smoother than in part A). Also, the pattern appears clearer; the risk declines with wheelbase up to 111 in., and it increases with weight everywhere.

The conclusions of this analysis are that overweight offers no advantage in single car collisions. To the contrary, overweight may be related to characteristics that increase the fatality risk. As in the case of car-to-car collisions, standardization for age differences result in clearer patterns.

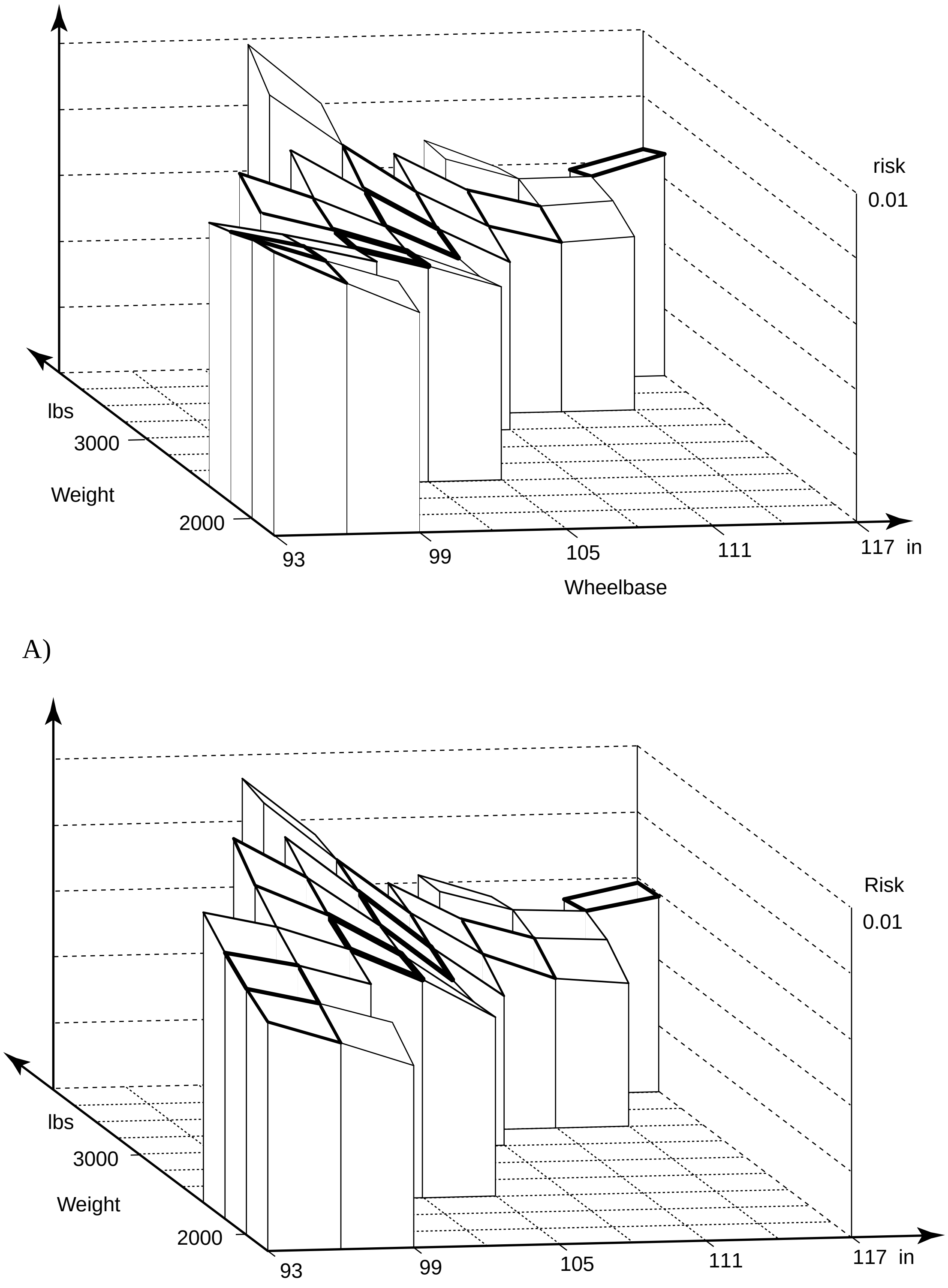


A)



B)

Figure 5-13. Car driver fatality rate, per involved driver, in single car collisions, by wheelbase and overweight of the car. Drivers 26 to 55 years old, no airbag. Smoothing window 7.5 in. x 750 lbs A) and B) show the same data, but with opposite overweight scales.



A)

B)

Figure 5-14. Car driver fatality rate, per involved driver, in single car collisions, by wheelbase and weight of the car. All drivers, no airbag. A) shows actual rates, B) rates standardized to a common driver age distribution.

6. CLASSIFYING CARS

6.1 PURPOSE OF CLASSIFYING CARS

Some information on aggressive physical characteristics of cars may be obtainable by clinically investigating individual collisions. While this might reveal that certain features could have effects on the occurrence and severity of occupant injuries, they cannot provide quantitative information on the magnitude of such effects. Neither can they reveal effects that are small or whose magnitude depends on other factors. To make quantitative estimates of the effects of vehicle characteristics on injury risk and severity in “the other” vehicle in collisions, a large numbers of cases must be analyzed. To obtain large numbers, vehicles must be aggregated.

For gross analyses, broad classes of vehicles, such as cars, utility vehicles, vans, and pickup trucks can be aggregated. Such broad classes differ in many characteristics; if differences in their aggressivity are found, another type of analysis is needed to determine how the various characteristics contribute to the differences in aggressivity.

For more specific analyses classes of practically identical, or at least very similar, vehicles may need to be studied. “Identical” and “similar” are the critical terms. Cars are offered in many makes, series, subseries and body styles, and often differ in optional features as well. If classes of truly identical or nearly so vehicles are formed, the result is a very large number of classes, each of which contains only a small number of vehicles. As a practical matter, vehicles with gross similarities may be grouped. Some options, such as an automatic transmission are unlikely to have a directly “aggressive” effect; any effect is likely due to the additional weight, and can be accounted for when accounting for vehicle weight. Engine options pose a more difficult problem. Different engines configurations (at least front engines when compared to rear engines) could have different aggressive effects, but the main effect is probably that larger and more powerful engines attract more aggressive drivers, which would result in apparently greater aggressivity.

Since aggressivity is mainly apparent in the vehicle striking with the front end (though a vehicle with a very stiff side could also be considered aggressive), different body styles of the same car model will probably have the same aggressivity, because the front configurations are similar if not identical. However, station wagons and convertibles tend to be heavier than sedans, and therefore more aggressive.

For a first study of the problem, differences in options and body styles may be ignored. The first practical level of disaggregation is by make/series/subseries, over the model years when the basic design of a model did not change, though the sheet metal and some features may have changed. In most cases, differences between subseries can also be ignored. Still, at this level case, numbers for many car models are too small for a meaningful analysis.

“Corporate twins” (also called “corporate cousins” or “sister vehicles”) offer an opportunity to obtain larger case numbers. They are physically very similar, often practically identical, but they may differ in trim and luxury options, price, and target groups of drivers. Still, if classification of the physical aggressivity of vehicles is desired, it appears justified to aggregate these vehicles into “families.” Doing this, however, would eliminate the opportunity to look at differences between twins in relation to their driver population. This would, in principle, allow for the separation of the effects of vehicle characteristics and some driver characteristics on the apparent aggressivity. However, since only the grossest driver characteristics, age and sex, are given in the data files, this does not seem to be a great loss.

A similar situation exists if a vehicle is made by a foreign manufacturer, sold under the manufacturer’s own make, but also sold by a domestic manufacturer under his make.

For many make/models case numbers remain small, even if the vehicles are aggregated across model years, and over models that show clear dissimilarities. In order not to lose the information from these cases, further aggregation may be needed. Weight and wheelbase dimensions may be used for classification. However, since both are continuous variables, it is not possible to simply aggregate small classes of similar vehicles stepwise, but instead arbitrary cuts must be made to define classes.

6.2 ATTEMPTS AT STATISTICAL CLASSIFICATIONS

For a first, simple classification of cars only the two most obvious and readily available characteristics were considered: weight and wheelbase. Weight and wheelbase are continuous variables, they do not provide a “natural” classification. However, cars may fall into natural classes if they cluster around relatively few combinations of weight and wheelbase. There are statistical techniques that can identify such clusters. In some situations, where clear clusters of cars with similar weight and wheelbases exist, these techniques can identify them. In others, where there are no clearly separate clusters, these techniques will develop a sequence of clustering patterns, beginning with a trivial set where every point is a cluster by itself, and ending with a trivial set where all cars form one single cluster. Between these extremes, the techniques proceed stepwise: They check “distances” between clusters which have so far been formed, and combine the closest clusters into larger clusters.

There are several techniques available, and with each technique there are certain options. An important one is the choice of a measure of distance. Because the techniques use different approaches, and the options also influence the outcome, different sequences of cluster patterns will be obtained, except in situations where the clusters are clear and well separated.

Experimenting with techniques and options showed that no nontrivial cluster patterns could be obtained. A closer examination showed the reasons: In the weight-wheelbase plane, the points representing cars lie on straight lines, corresponding to certain specific wheelbases; on the lines, the points are usually widely scattered. In such a situation, clustering techniques do not work well, because the tests they use implicitly assume that the points form “clouds.” Therefore, this approach was abandoned.

6.3 DEVELOPING CAR FAMILIES

The approach finally used started with make and model, as defined by the FARS and GES codes. In most cases, these codes define, over certain ranges of model years, physically very similar, sometimes practically identical vehicles. In some cases, there were differences between subseries, or between body styles. There are also differences, especially in weight, related to options. Typically, wheelbase for a model is constant over several model years; the weight can vary by up to 500 lbs.

The “big three” U.S. manufacturers have several makes. In many cases, the “same” vehicle is available under several makes, and different model years. Actually, there may be differences in trim and/or equipment, resulting in weight differences. There are also cases where essentially the same vehicle is made by a foreign manufacturer, sold under its make, and also sold by an American manufacturer.

Foreign manufacturers do not have corporate twins. However, some offer different models that are fairly similar. In those cases, the models were combined, though they are less similar than the typical American corporate twins are.

To obtain larger case numbers for vehicle classes, corporate twins were combined into one family. Sometimes foreign cars were combined that are fairly similar in to one family.

The information for doing this came from several sources: the *Automobile Red Book* published by National Market Reports, *Year/Model Interchange List*, prepared by Scalia Safety Engineering, Madison, Wisconsin, and a list provided by the Volpe National Transportation Systems Center. Occasionally, other sources were also used.

Table 6-1 illustrates some of the complications arising. Cars with the make/model code 18002 differ, depending whether they are station wagons or not, in weight, wheelbase, and body structure. The same holds for code 21002. For code 22002 the situation is more complex. Through model year 1986, all body styles fall into the same family. From 1987 on, the station wagon continued with the same wheelbase, weight and body structure, and remained in the same family, while the other body styles had a shorter wheelbase, lower weight, and different body structure.

The table shows only rounded weights. Actually, weights sometimes vary considerably over model years. Sometimes an arbitrary decision was made when forming a new family. An illustration is the Chevy Caprice, code 20002. It was included in the family 120.002.05 because of general similarity, despite the Caprice’s weight being much lower than that of other family members. For the initial study of the problem it is important to have families with many members. More refined future studies should be able to handle smaller, more homogeneous families.

Table B-1 in Appendix B lists member of the families finally used, ordered by family. Models not listed were treated as one-member families.

Table 6-1. Illustration of the Formation of Car Families. Style “6” means that only station wagons are included, “-6” that station wagons are excluded.

Make Code	Model Code	Make Name	Model Name	Model Year	Body Style	Weight
Family 120.002.05 wheelbase 115.9 in., body structure: frame						
18	002	Buick	Estate Wagon	86-90	6	4100
	004	Buick	Roadmaster	91-96		4100
20	002	Chevy	Caprice	91-96		3400
21	002	Olds	Custom Cruiser	81-92	6	4100
22	002	Pontiac	Parisienne	83-86	6	4000
	002	Pontiac	Safari SW	87-89	6	4000
Family 118.002.05 wheelbase 110.8 in., body structure: unibody						
18	002	Buick	LeSabre	86-96	-6	3400
21	002	Olds	Delta 88	86-96	-6	3400
22	002	Pontiac	Bonneville	87-96	-6	3600

7. COMPARING FAMILIES OF CARS

Fatality risks for the car families described in the previous section were calculated and compared. In addition to the risks to others ("*riskby*")in collisions with cars of each family, the risks for occupants of cars of each family, in single car collisions ("*risk1*") and in collisions with other cars ("*riskin*"), were calculated in order to check the consistency of the findings.

Because of the strong effect the victim's age has on the fatality risk, fatality risks standardized to the overall age distribution were also calculated. In the case of *risk1* and *riskin*, this was the age of the driver of the case vehicle, in the case of *riskby* the age of the driver of the other vehicle.

Other factors may also influence collision type and severity to a non-negligible degree. In addition, the risks are affected by sampling errors, estimates of which are beyond the scope of the present work. Therefore, the risks should be interpreted with caution and not taken at face value.

The relations of the risks to the average weight of the cars in each family were studied to determine to what extent weight differences might explain differences in risk. Beyond that a single vehicle characteristic, bumper height was studied, because incompatibility of bumper height is suspected to be a factor in aggressivity.

7.1 RISKS BY FAMILY

Three groups of car families were considered: those with less than 250 actual (not expanded national total) GES collision involvements, those with between 150 and 1000 such cases, and those with more cases. Risks calculated for the first group were very uncertain because of the small collision numbers and even smaller fatality numbers. Therefore, they were not studied any further. For the other two groups, the results are presented separately because trends may be more apparent in the group with the largest case numbers and greatest statistical precision of the estimates.

Figures 7-1 to 7-3 show the fatality risks for drivers of cars of the largest car families, "raw" (table a) and adjusted for the age of the victim (table b).

Figures 7-4 to 7-6 show the same information for the medium size car families.

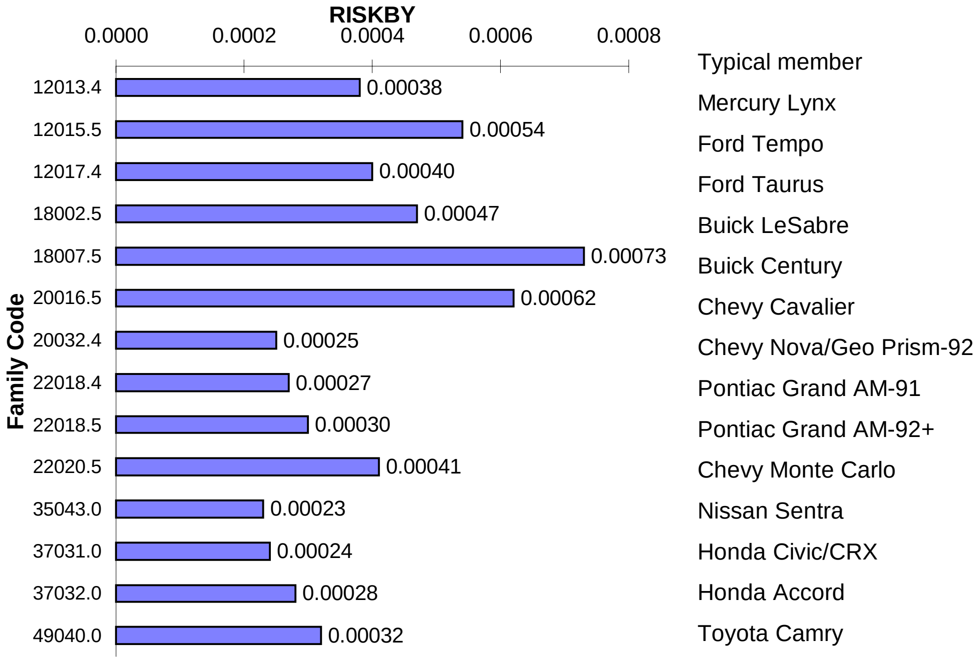


Figure 7-1a. Fatality Risk to Other Car Drivers ("*riskby*") in Collisions with Cars Families having the Largest Sample Sizes

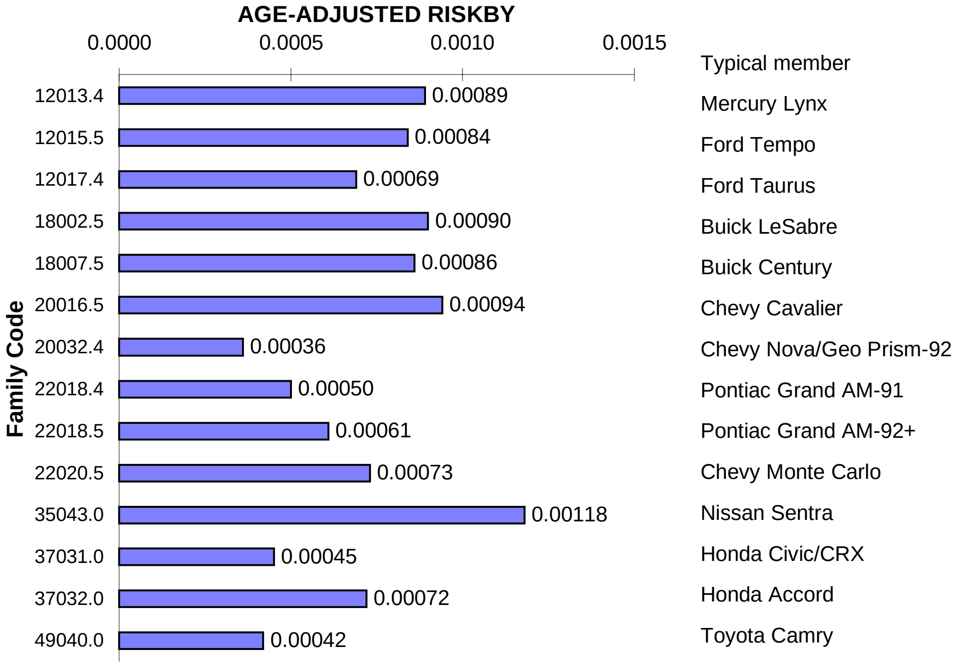


Figure 7-1b. Fatality Risk to Other Car Drivers ("*riskby*") in Collisions with Large Sample Car Families, Adjusted for the Victim's Age.

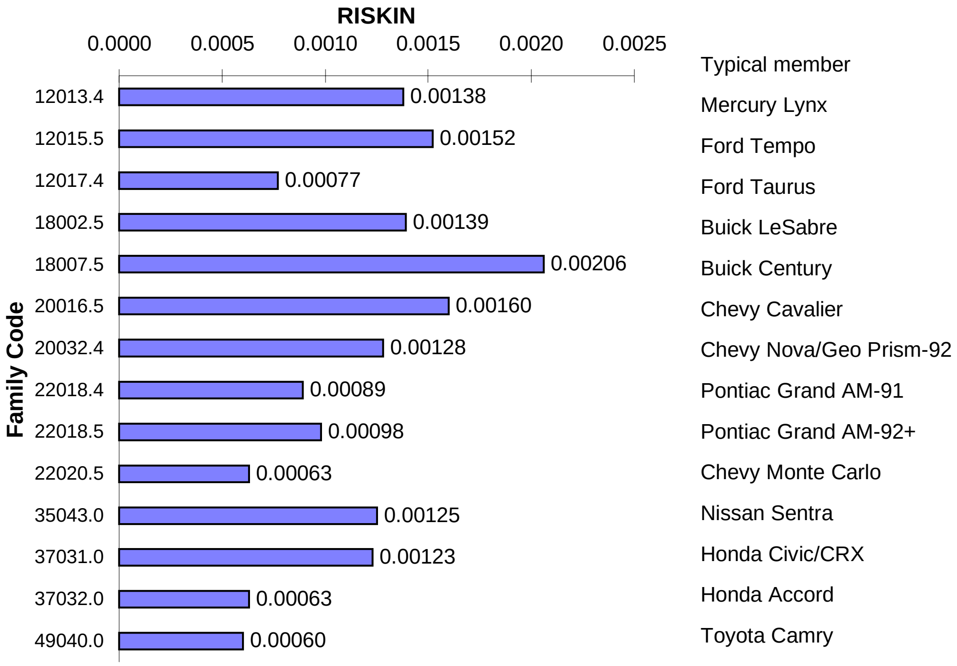


Figure 7-2a. Fatality Risk to Drivers of Cars of the Largest Car Families ("*riskin*") in Collisions with Other Cars.

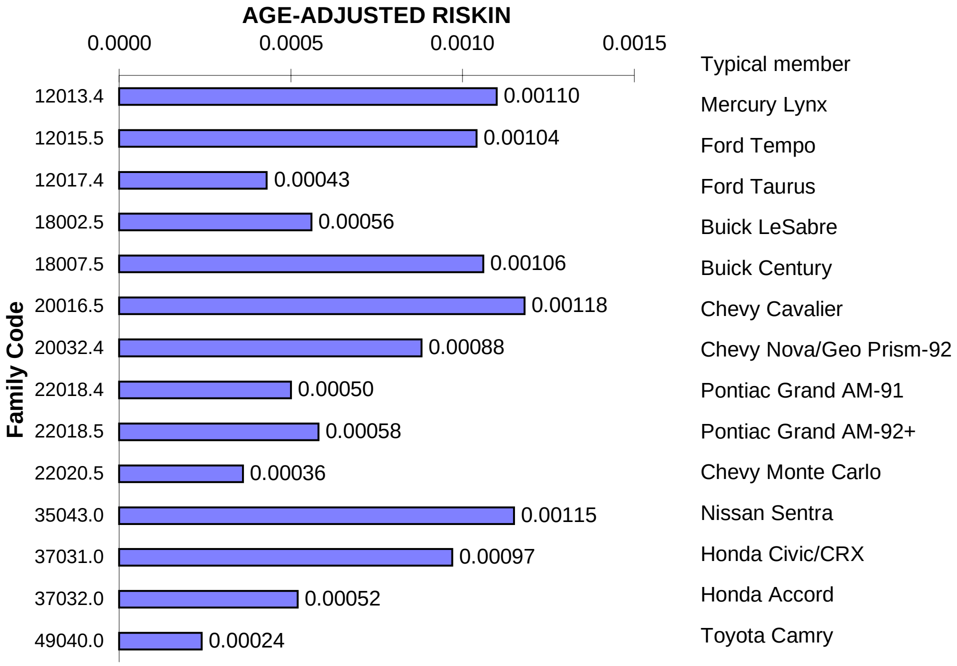


Figure 7.-2b. Fatality Risk to Drivers of Cars of the Largest Car Families ("*riskin*") in Collisions with Other Cars, Adjusted for the Victim's Ages.

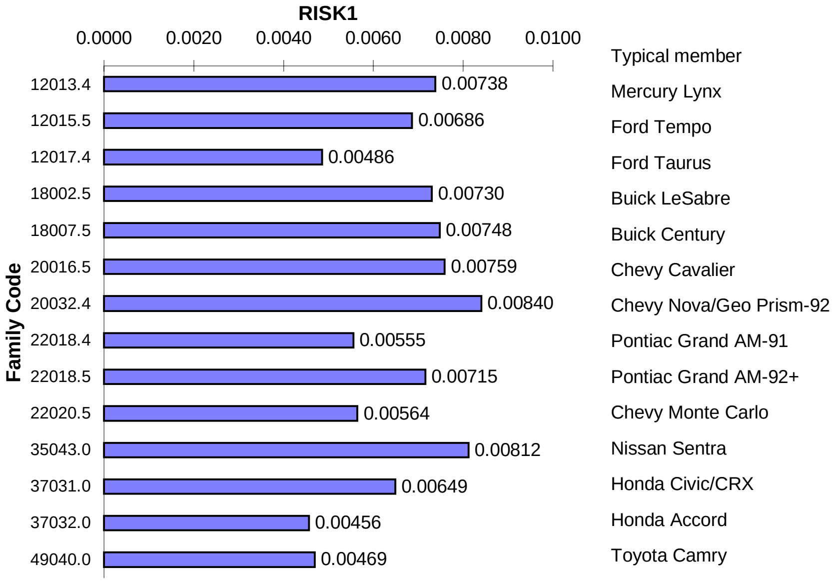


Figure 7-3a. Fatality risk for Drivers of Cars of the Largest Car Families in Single Car Collisions (“*risk1*”).

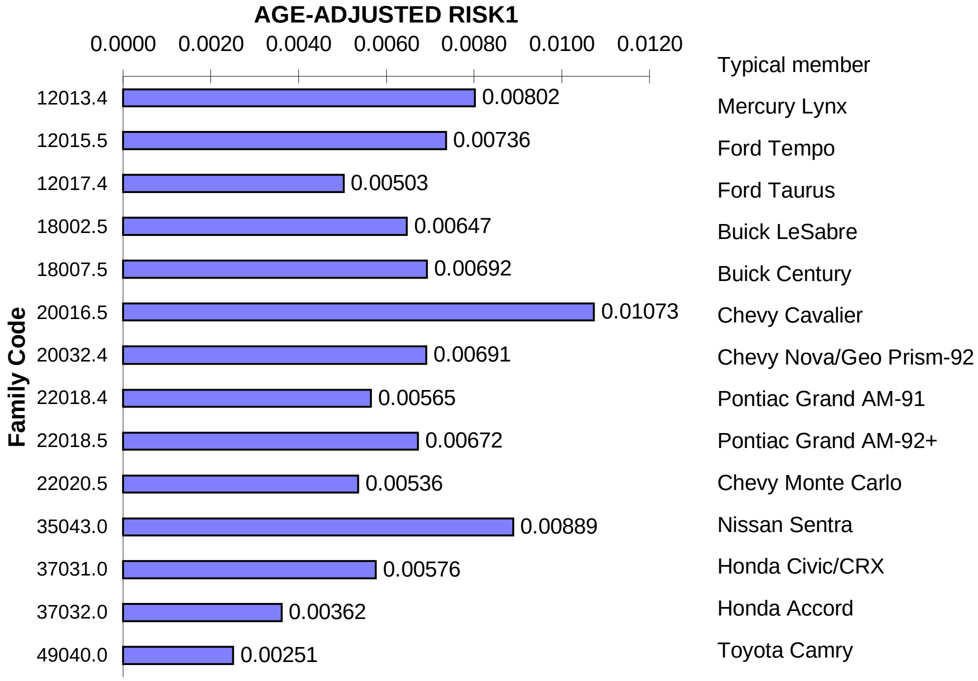


Figure 7-3b. Fatality risk for Drivers of Cars of the Largest Car Families in Single Car Collisions (“*risk1*”), Adjusted for the Victim’s ages.

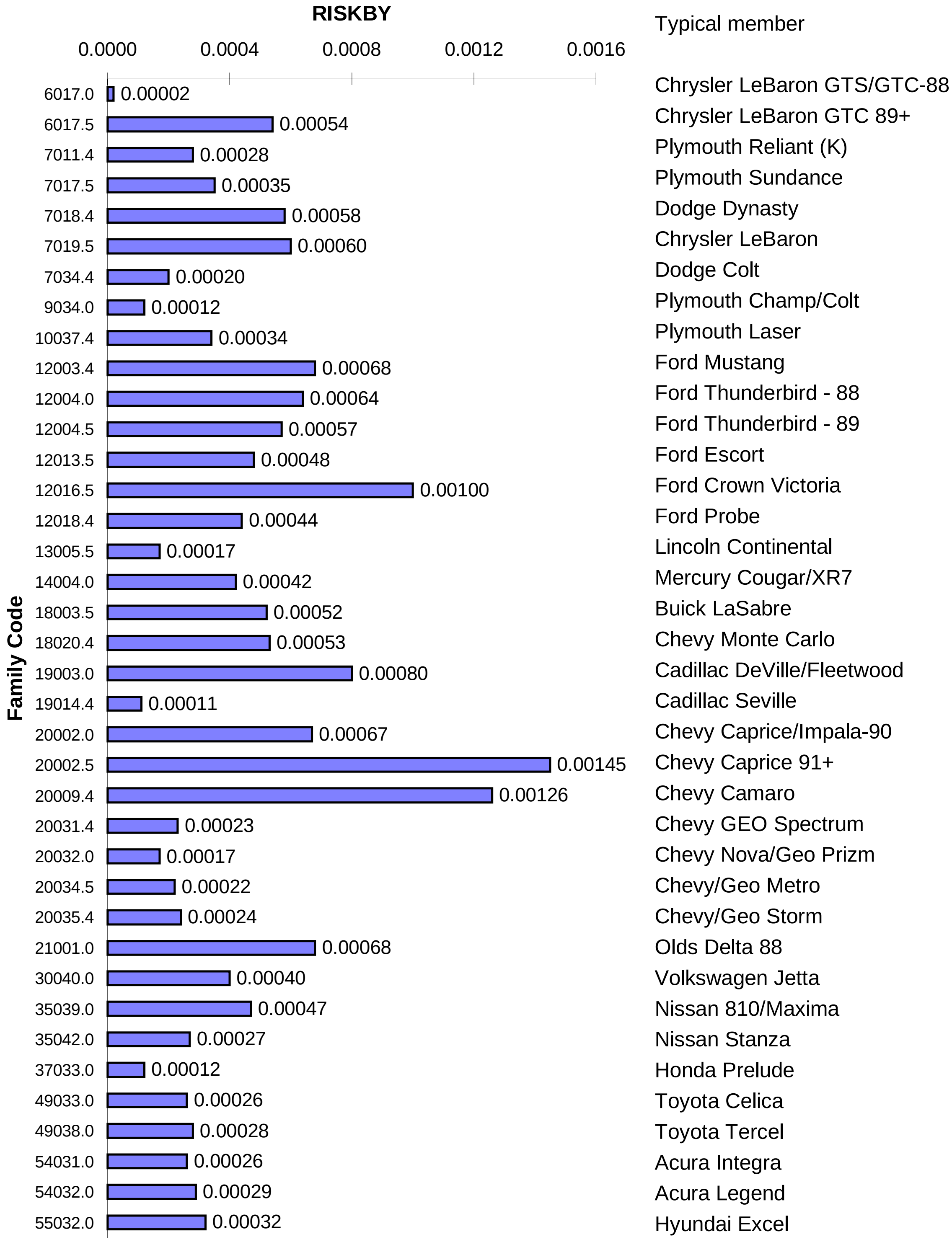


Figure 7-4a. Fatality Risk to Other Car Drivers ("*riskby*") in Collisions with Cars having Medium Sample Sizes.

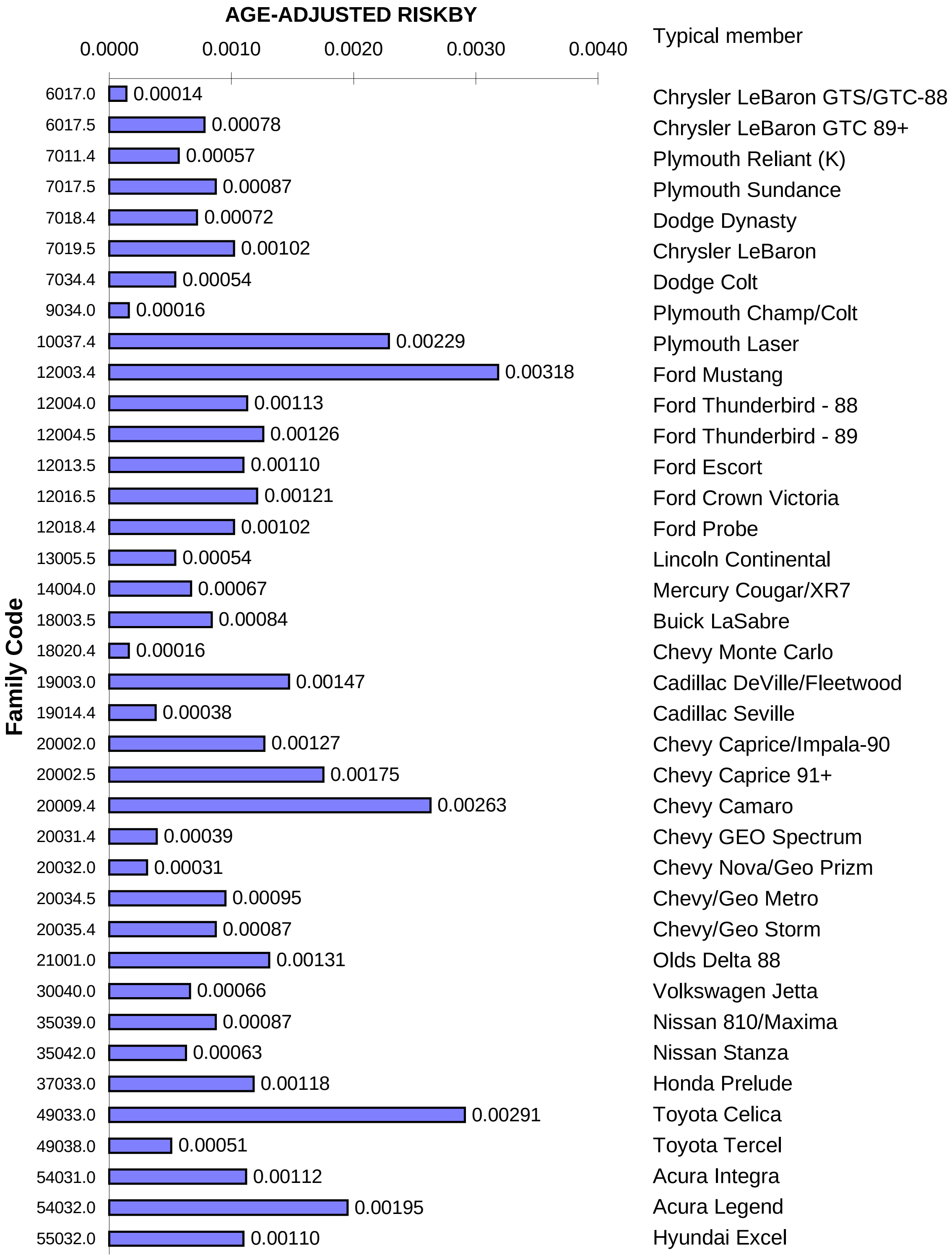


Figure 7-4b. Fatality Risk to Other Car Drivers ("*riskby*") in Collisions with Medium Sample Size Car Families, Adjusted for the Victim's Ages.

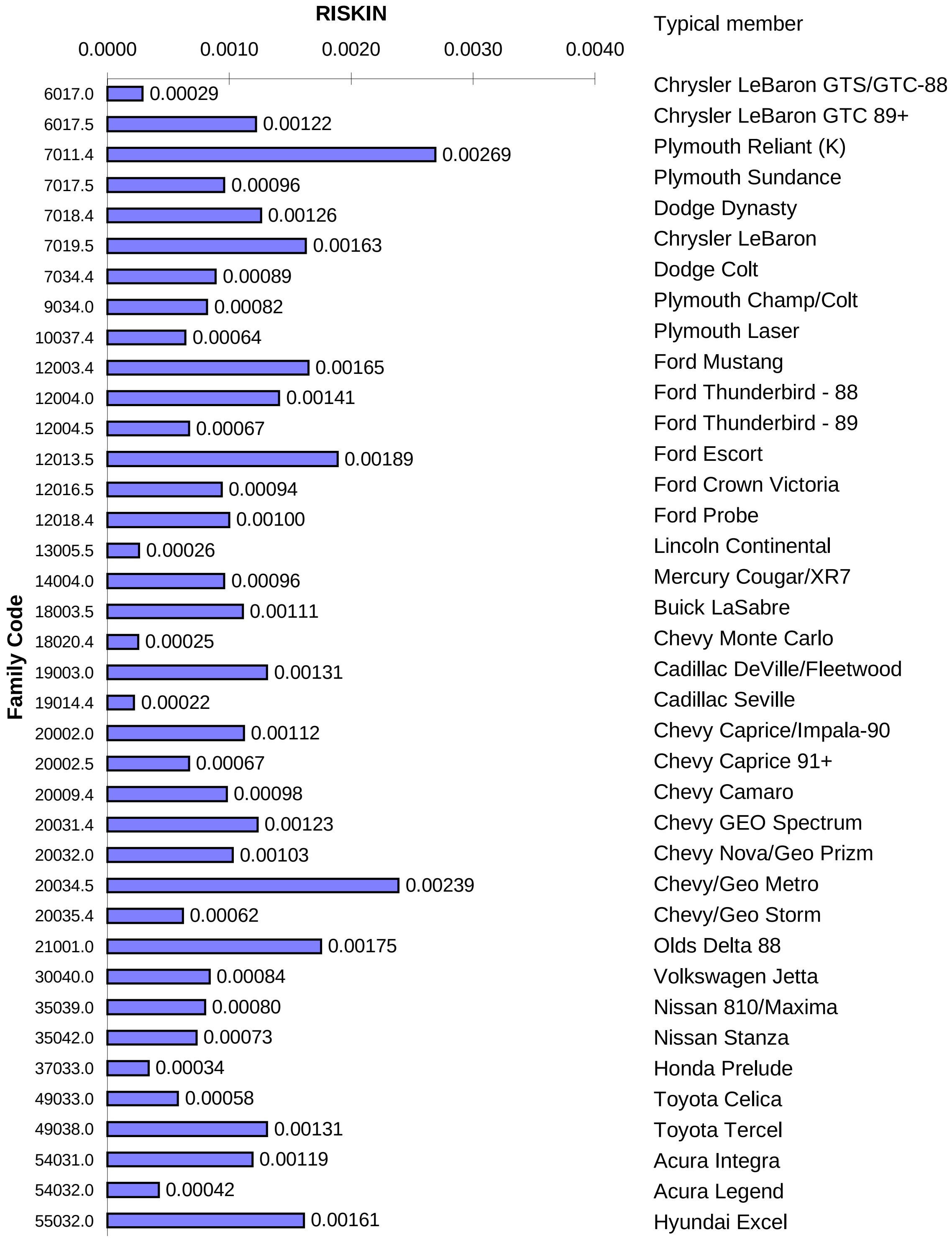


Figure 7-5a. Fatality Risk to Drivers of Medium Sample Size Car Families (“*riskin*”) in Collisions with Other Cars.

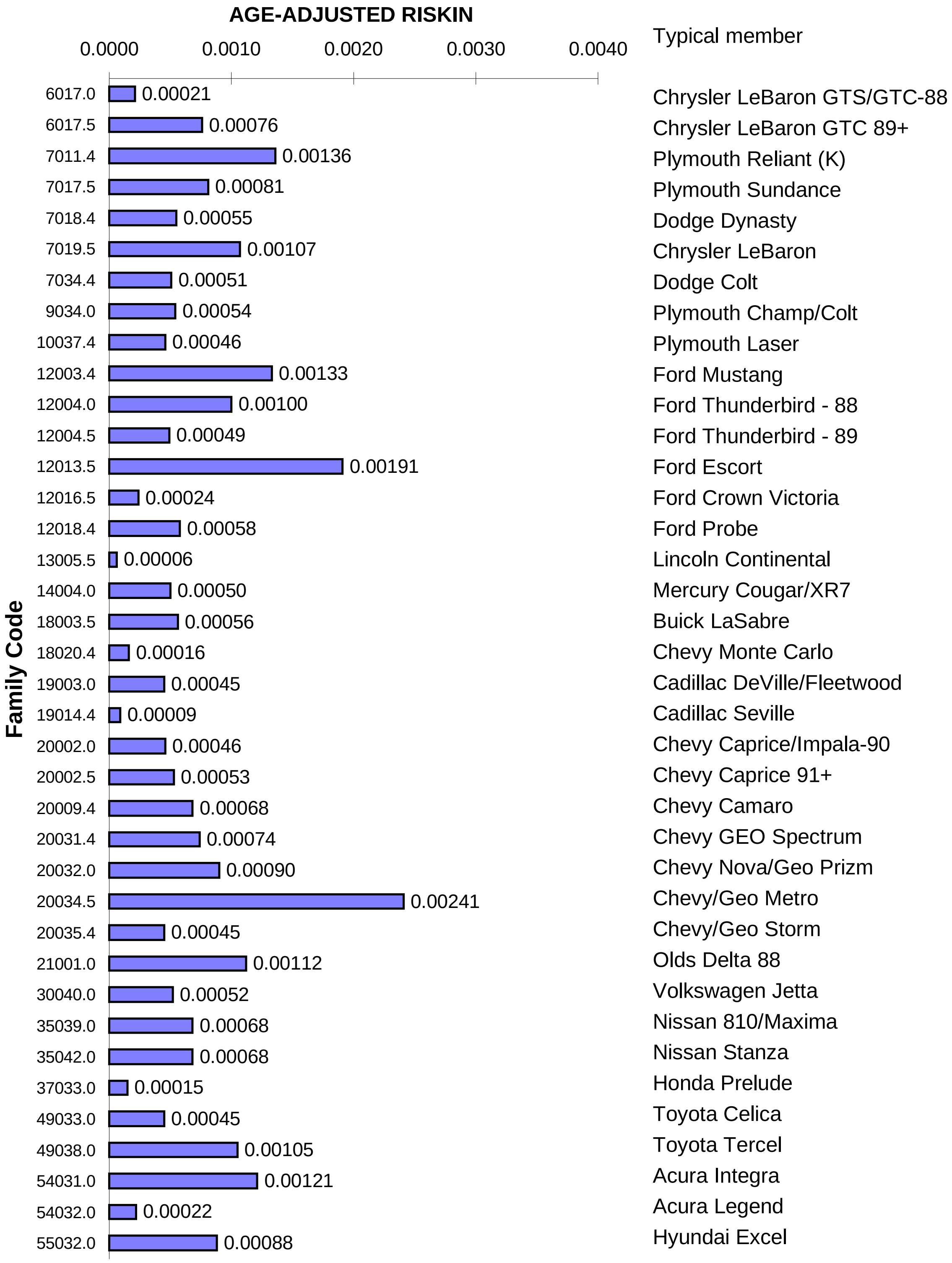


Figure 7-5b. Fatality Risk to Drivers of Medium Sample Size Car Families (“*riskin*”) in Collisions with Other Cars, Adjusted for the Victim’s Ages.

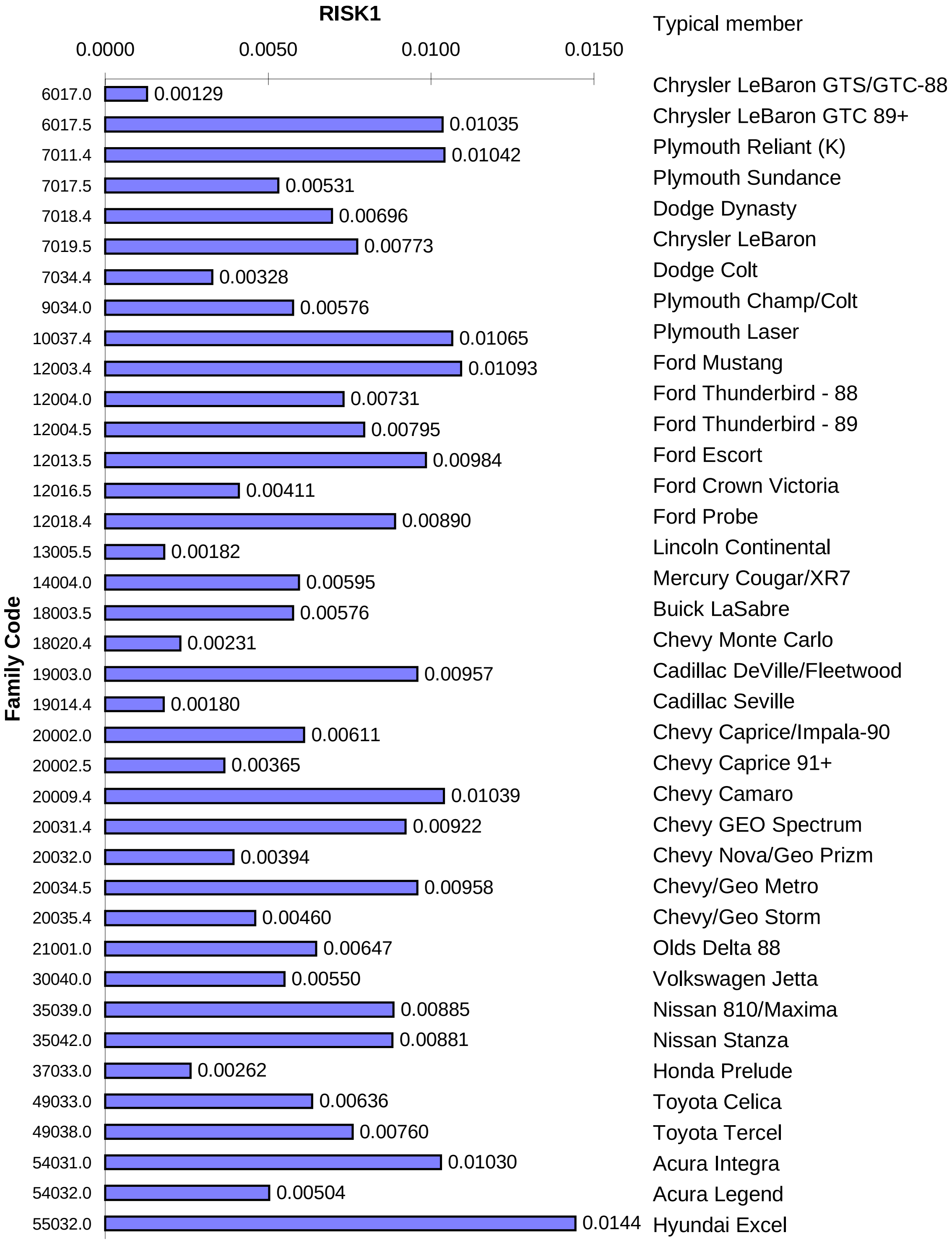


Figure 7-6a. Fatality risk for Drivers of Medium Sample Size Car Families in Single Car Collisions ("*risk1*").

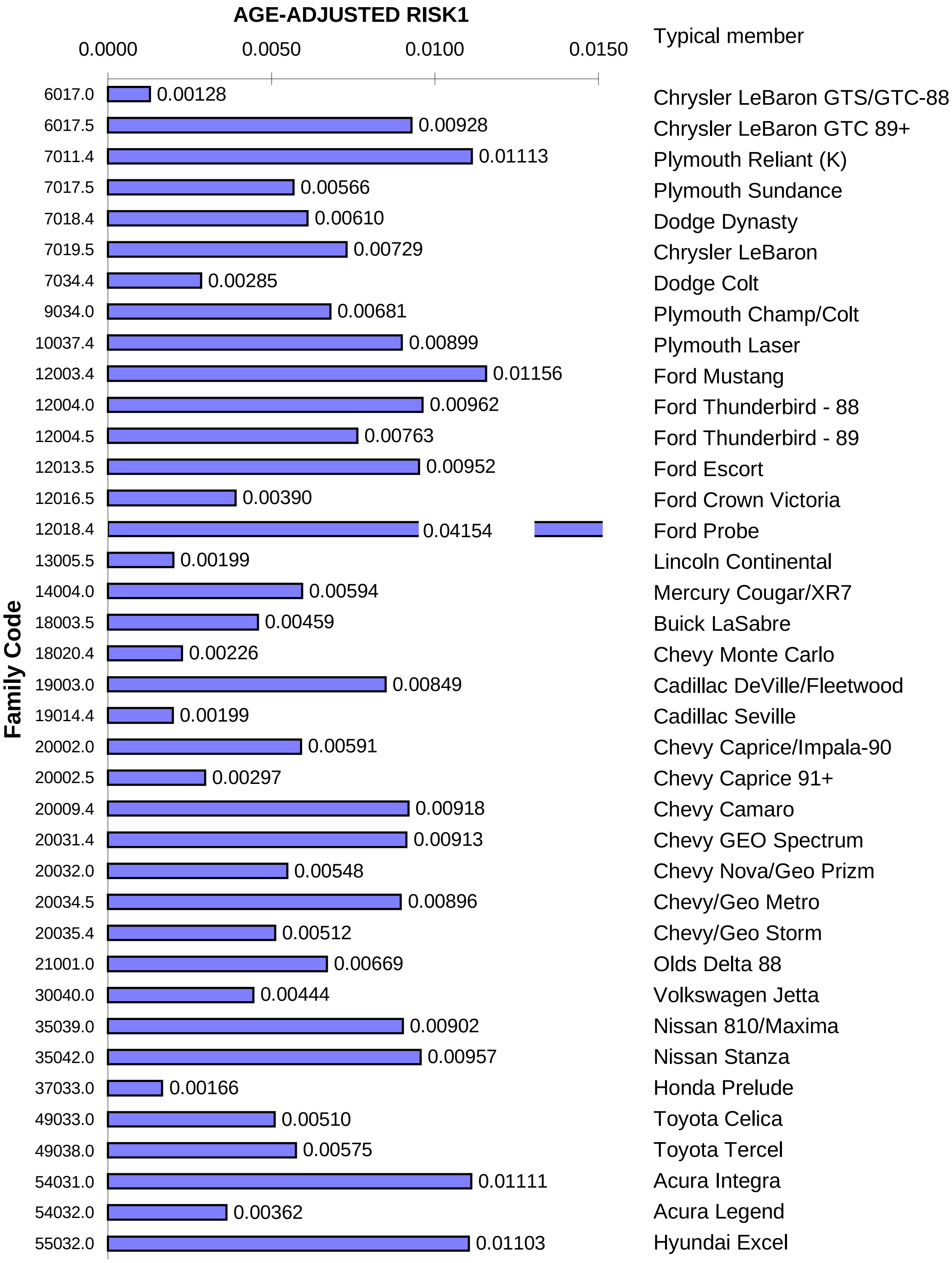


Figure 7-6b. Fatality risk for Drivers of Medium Sample Size Car Families in Single Car Collisions ("*risk1*"), Adjusted for the Victim's ages.

7.2 RELATIONS BETWEEN DIFFERENT TYPES OF RISKS

The lack of error estimates makes the risk estimates in section 7.1 difficult to assess. However, to some extent their consistency can be assessed, and patterns recognized, if the driver fatality risk in single vehicle collisions ("*risk1*"), the fatality risk in collisions with other cars ("*riskin*"), and the fatality risk for drivers of other cars in collisions ("*riskby*") are related.

Figure 7-7 shows a plot of *risk1* versus *riskin*. One extreme outliner (Ford Probe, with a very high *risk1* and a moderate *riskin*) is not shown. All values are standardized for the victims' ages. Figure 7-7a shows values for the large and for the medium size car families. Figure 7-7b shows values only for the large ones. It is somewhat comforting to notice that in a rough approximation *risk1* and *riskin* cluster around a line representing proportionality (ratio R = 10), and that most are within the range R = 5 and R = 20: the risks in single vehicle collisions, and in collisions follow a similar overall pattern.

A closer look at figure 7-7b, however, shows for the large car families (for which the points scatter less) some deviation from the general pattern. There is one cluster where the risks are low, and the risk in single-car collisions tends to be relatively higher than that in collisions; and another cluster where the risk in collisions is much higher, but that in single-car collisions is not much higher than in the first cluster. The ratios, R, are all lower than 10, centered around R = 7.5. Cars in the families in the first group tend to be heavier than those cars in the second group. This pattern is in agreement with the findings of sections 5.4 and 5.5, a higher weight offers an advantage in collisions with other cars, but, beyond a certain value, no advantage in single-car collisions.

A closer inspection of the graphs shows the following:

- Adjustment for the victims' ages changes some risks considerably, and
- The ranges of variation of the risks are much larger among the medium size families than among the largest families.

There are two potential explanations for the latter observation. One is that the risks calculated from the smaller case numbers of the middle size car families show a greater random fluctuation. The other explanation is that the mid-size car families cover a wider range of design characteristics and, as a consequence, have a wider range of risks.

The first explanation could have been explored by calculating the standard errors of the risks. However, because of the complex sampling scheme used in GES, this would have been a very complicated task and beyond the scope of this work.

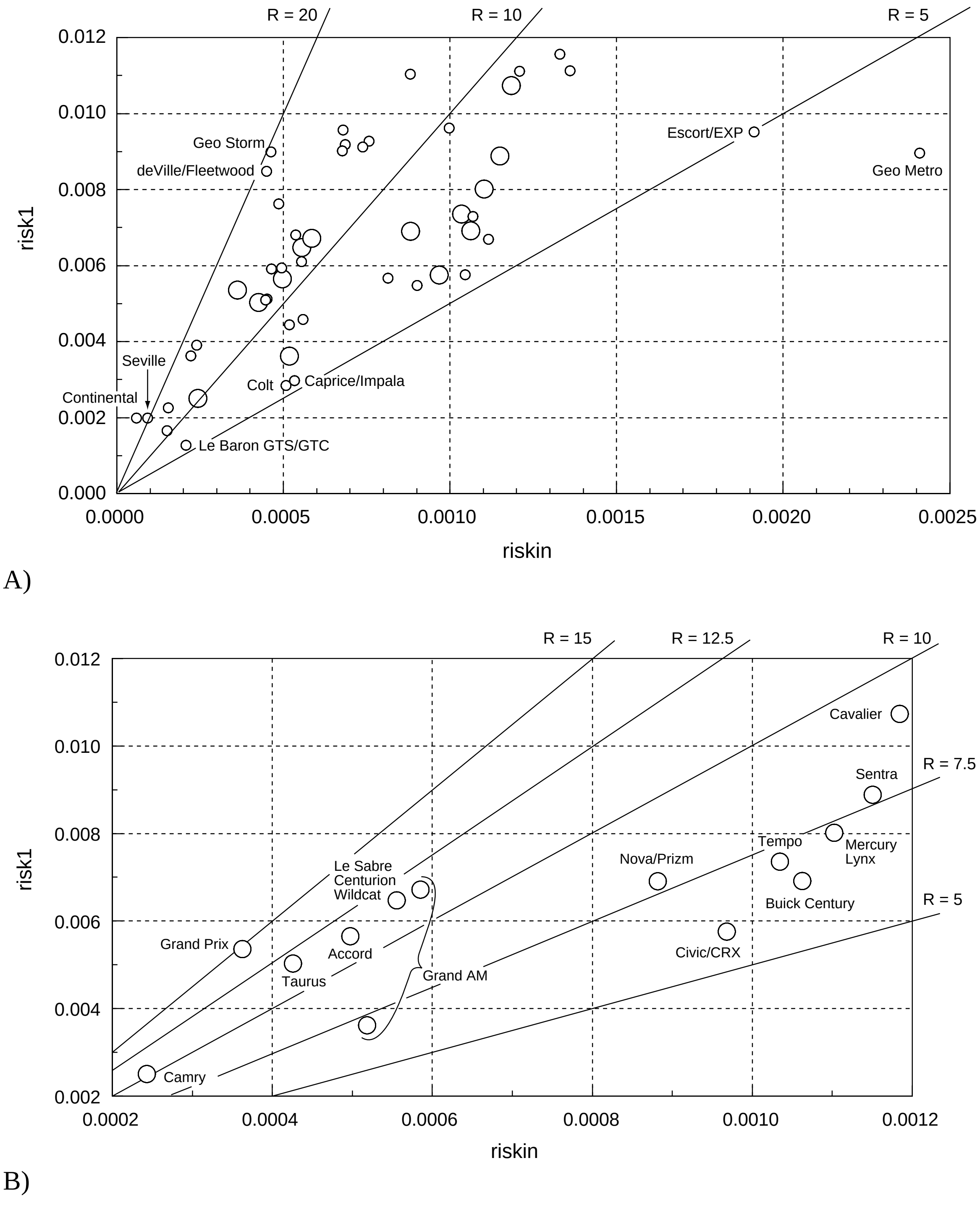
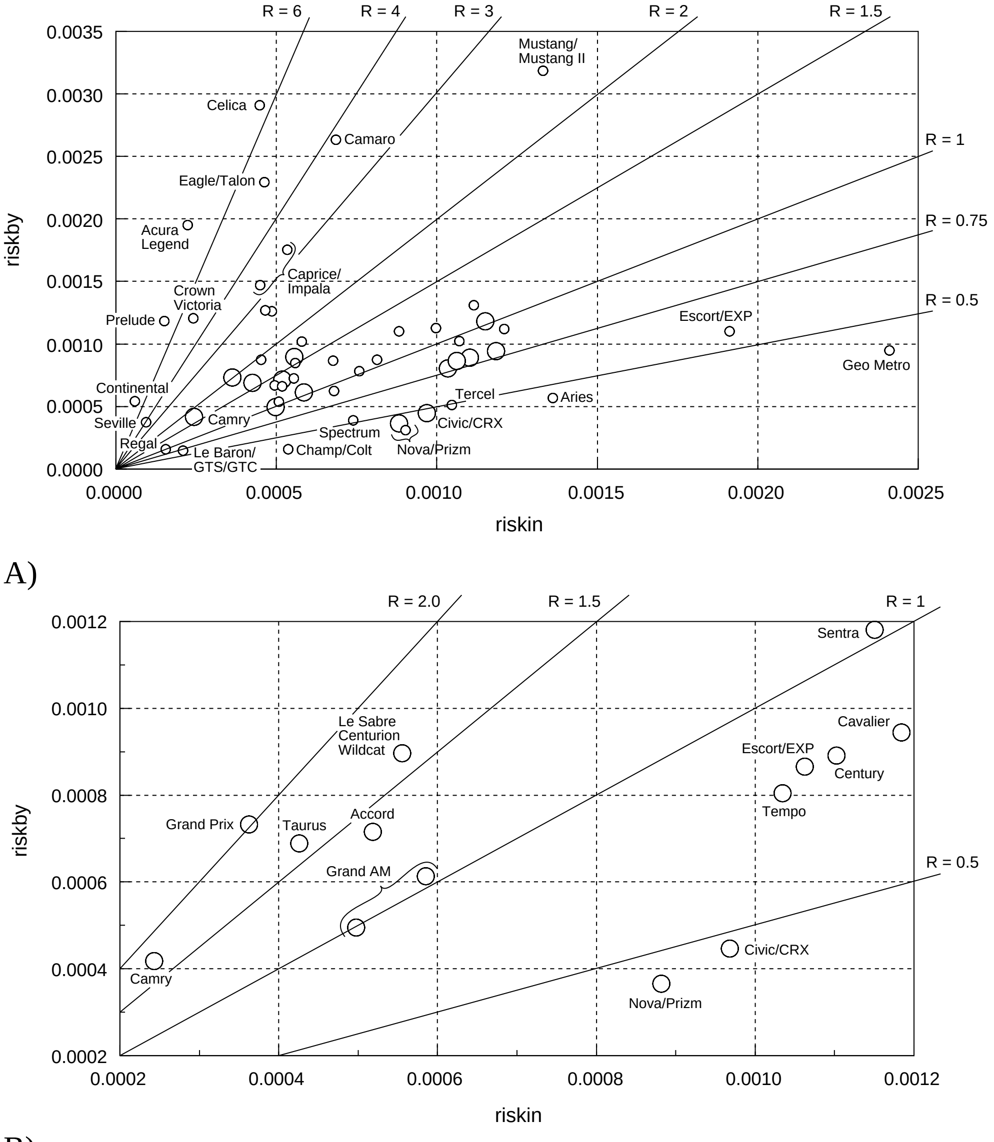


Figure 7-7. Fatality risk of a car driver being killed in a single car collision ("*risk1*"), versus the risk of being killed in a collision with another car ("*riskin*") by car family.

Both values are standardized for the victims' ages. Part A) shows the values for large car families (large circles) and medium car families (small circles). Part B) shows only the values for large car families. The line shows constant values for the ratio R of the two risks.

Figure 7-8 shows the fatality risk for car drivers when colliding with cars of certain families ("*riskby*") versus the fatality risk for drivers of cars of these families ("*riskin*"), both risks adjusted for the victims' ages. Because of the strong effect of car weight on these risks, one would expect a relation where low *riskin* corresponds to high *riskby*, and vice versa. The points should cluster around a curve from the upper left to the lower right. However, there is no indication of that in figure 7-8a, which shows the large and mid-size families. In figure 7-8b, which shows only the large families, there is even an indication of the opposite trend: *Riskby* tends to increase with *riskin*.



A)

B)

Figure 7-8. Fatality risk of a car driver in collisions with cars of certain families ("*riskby*") versus the fatality risk of drivers of cars of these families in collisions with cars ("*riskin*"). Both values are standardized for the victims' ages. Part A) shows the values for large car families (large circles) and medium car families (small circles), Part B) only those for large car families.

There are two obvious potential explanations for this. One is that drivers of certain car families may drive more aggressively. This would have the effect that both the *riskin* and the *riskby* could be higher. The risks for the victims' ages were adjusted, but not for drivers' ages. The two are the same for *riskin*, but may differ in *riskby*. In addition, driver age is only a very crude indicator of aggressive driving. It is likely to be influenced by more subtle personal characteristics on which there is no information available. The only possibility to account for such an effect seems to be a more detailed consideration of collision configuration, and whatever information on vehicle damage and collision speed is available.

The second potential explanation is that in the GES certain vehicle models may be "lost" more often than others may because model information is not given, or the VIN is not given or cannot be decoded. In such a situation, the point would be "moved" along a straight line through the origin; the more lost, the more to the upper right.

If increasing collision severity would influence *riskin* and *riskby* proportionally, the same would happen if collision severity increased, the points would "move" on a straight line through the origin to the upper right.

Therefore, figure 7-8 also shows straight lines with constant ratios between *riskby* and *riskin*. While there is less confidence about the position of the points relative to the coordinate axes, there is more confidence about their relation relative to these lines - and not very confident about their position along each line. Under this aspect, the pattern appearing in Figure 7-8a appears plausible. Near the line representing the high ratio R = 6 between *riskby* and *riskin*, cars tend to be heavy, near the line representing the low ration R = 0.5, cars tend to be light.

The conclusion that can be drawn from inspecting Figures 7-7 and 7-8 is that the risks for car families derived in section 7.1 reflect at best gross aggressivity, including the effect of weight. It appears that there is also another factor active: obvious candidates are more aggressive drivers in certain car families, and, less likely, less complete identification of certain car models in the GES files.

7.3 RELATING RISKS TO WEIGHT AND WHEELBASE

The findings of the preceding section suggest again that vehicle weights play a major role in apparent crashworthiness and aggressiveness. Therefore, how the effect of weight might be controlled was explored, so that the net aggressivity of vehicle characteristics could be separated.

Figure 7-9 shows the driver fatality risk in asingle-car collision by average weight of the cars in the car's family. Part (A) shows one extreme "outlier", the point for the class including the Chrysler New Yorker/E class. For such a car, the high risk in a single car collision is extremely unlikely. Otherwise, the data points show no pattern. To recognize the pattern, the median of the points in each 500-lbs interval is shown by a horizontal line. The median was selected because it is less sensitive against outliers, and questions on the proper weighting of families with differing case numbers are avoided.

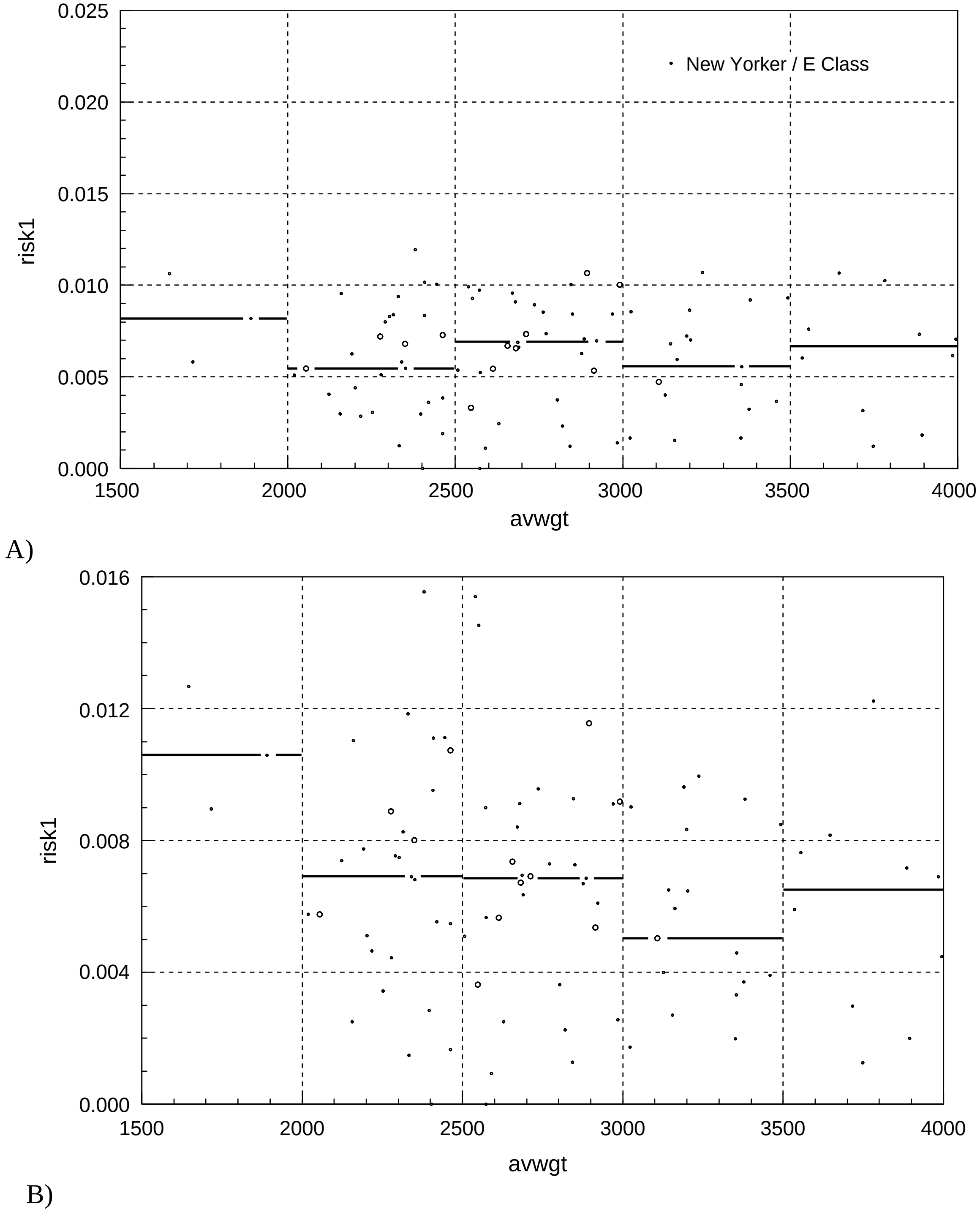


Figure 7-9. Fatality risk for drivers of cars of certain families, in single vehicle collisions, versus average weight (lb) of cars in the family.

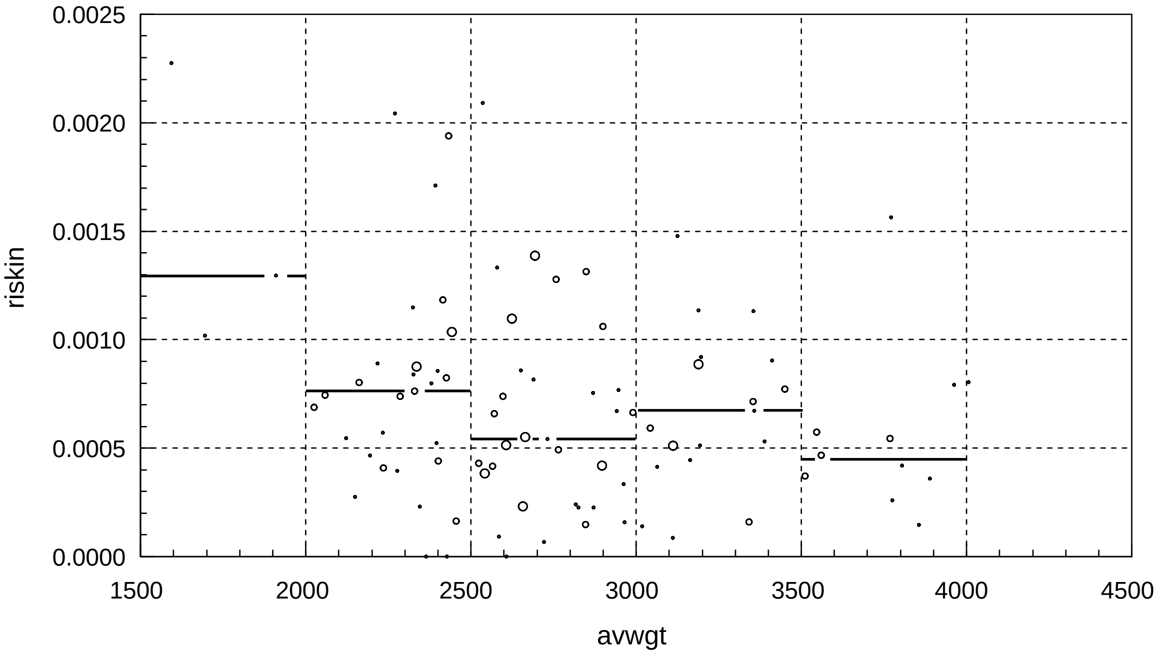
The medians show no pattern relative to the average weights. Part (B) shows risks adjusted for the victim's age. Here a pattern appears: the points show a tendency to slightly lower values for higher weights. The medians support this to some extent. Risk 1 for the lowest weights is much higher than for all the higher weights. Whether the values for the higher weight reflect a constant value, or whether together with the value for the highest group they reflect a somewhat declining trend would require a more thorough analysis.

Figure 7-10 shows the driver fatality risk in collisions with other cars, by average weight of his car's family. Again, the points scatter widely, but show a clear trend of declining risks with increasing weights. This trend becomes clearer and consistent if the risks are adjusted for the victims' ages (part B).

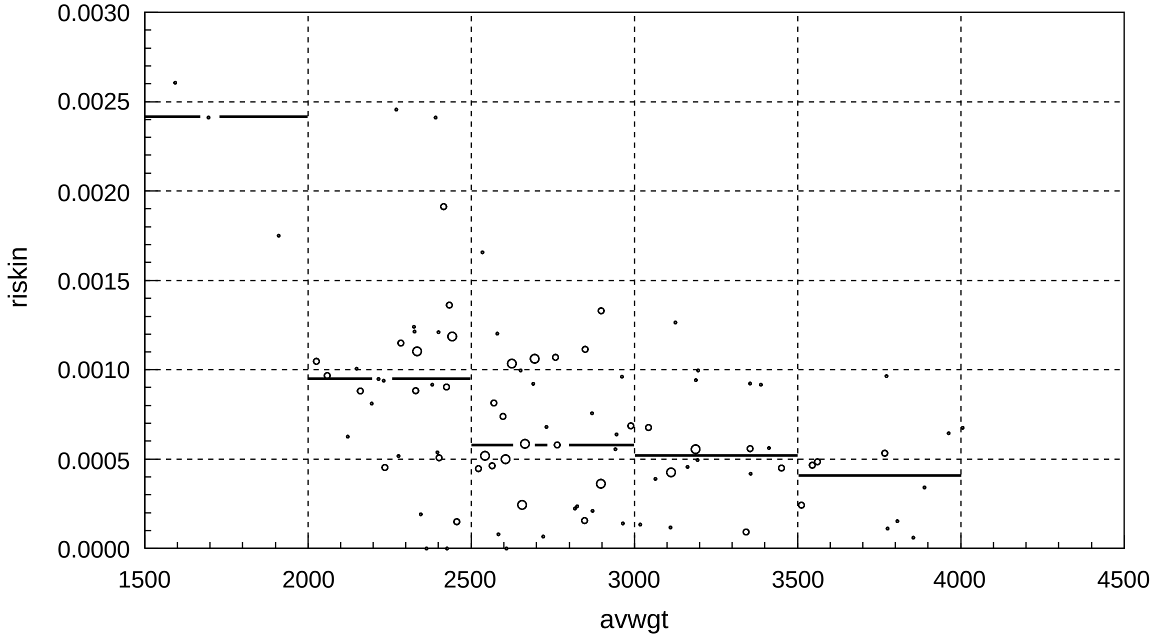
Figure 7-11 shows the driver fatality risk in a collision versus the average weight of the other car's family. Here, for both the raw (part A) and the standardized (part (B)) risks, the trend of increasing risks with weight is clear. It is noteworthy that the standardization for the victim's age increases the scatter of the points considerably (note the different vertical scales of part (A) and (B); this is not surprising: reducing a bias often increases the variance.

In these analyses only the weight of one car in a collision was considered. If case numbers are large, the assumption can be made as a first approximation that the average weight of the other cars that the cars of the study family collide with is the average of all cars on the road. If case numbers are small, the expected value is still the average weight, but the variance can be large. In a second approximation, the possibility that similar cars are more likely to collide with each other must be considered, and that therefore the "other" cars are no longer a random sample from the entire car population. Finally, the ratio of the weights is an important factor that must be considered, and that the average of a ratio is not the ratio of the average of the numerator and denominator.

Circles represent families with median case numbers, dots those with low case numbers. The horizontal line shows the median *risk1* for each 500-lb range. Part (A) shows "raw" risks, (B) those adjusted for the victim's age.

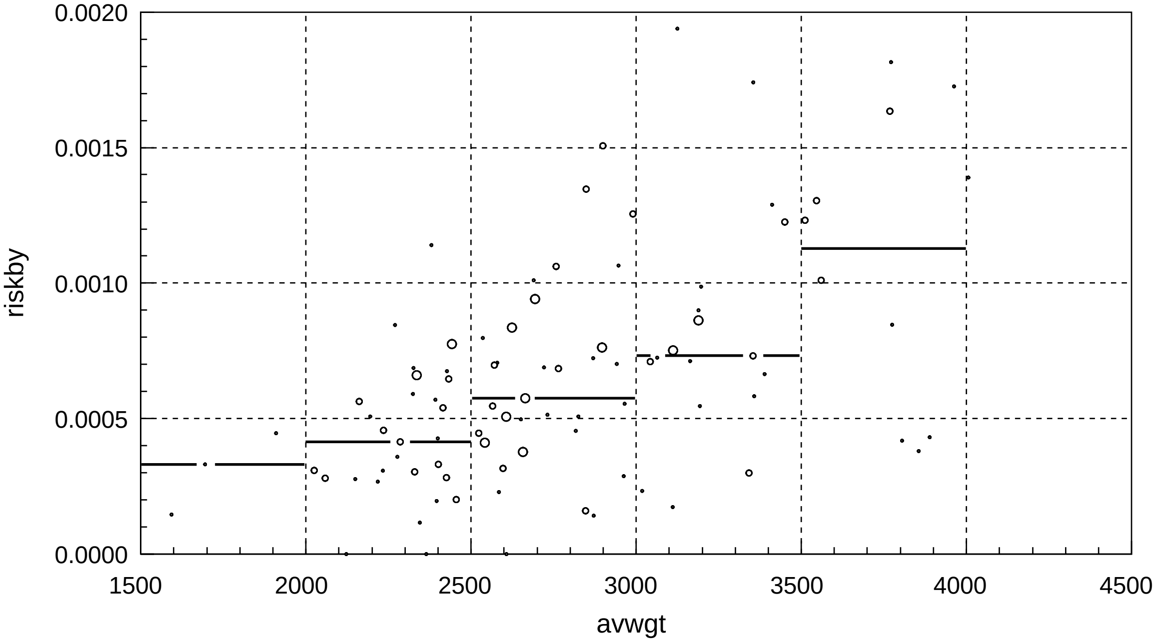


A)

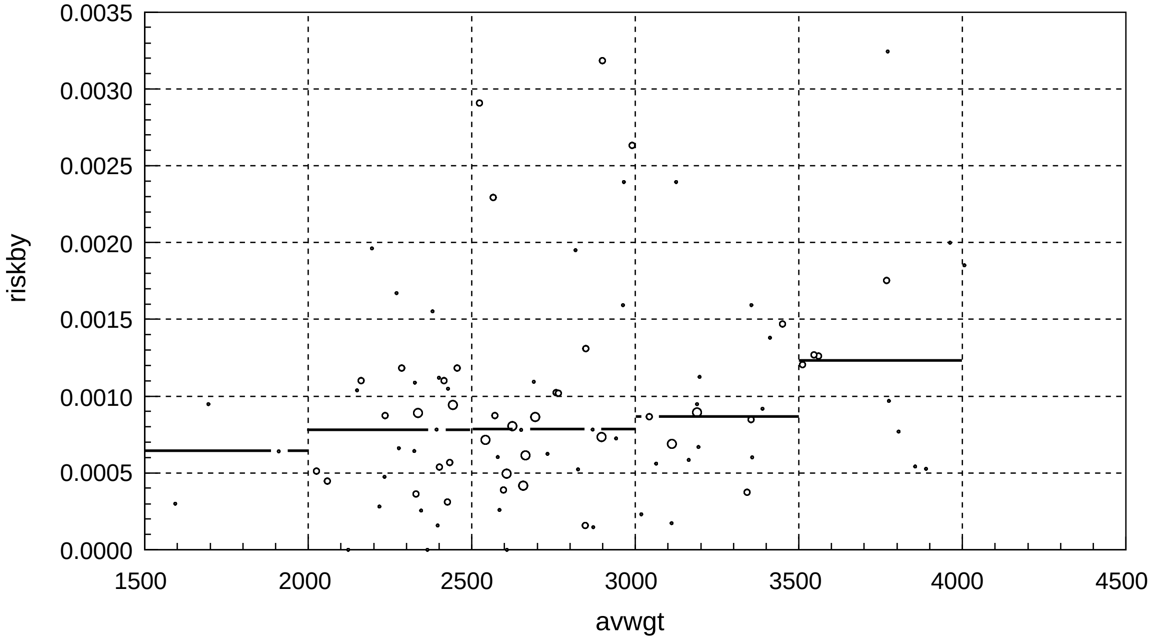


B)

Figure 7-10. Fatality risk for drivers of cars of certain families in collisions with other cars, versus average weight (lb) of cars in the family. Large circles represent families with large case numbers, small circles those with medium case numbers, and dots those with low case numbers. The horizontal lines show the median of the *riskin* in each 500-lbs interval. Part (A) shows “raw” risks, (B) those adjusted for the victim’s age.



A)



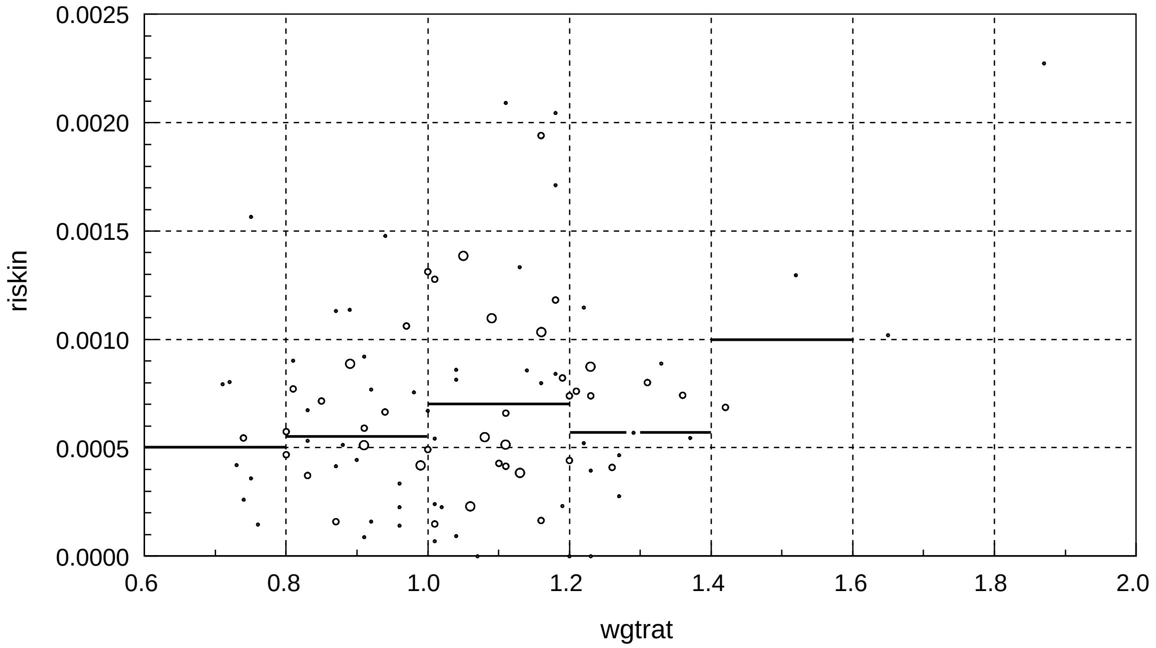
B)

Figure 7-11. Fatality risk of car driver in collisions with other cars, by average weight (lb) of cars in the other car's family. Large circles represent families with large case numbers, small circles those with medium case numbers, and dots those with low case numbers. The horizontal lines show the median of the risks in each 500-lb interval. Part (A) shows the "raw" risks, (B) those adjusted for the victim's age.

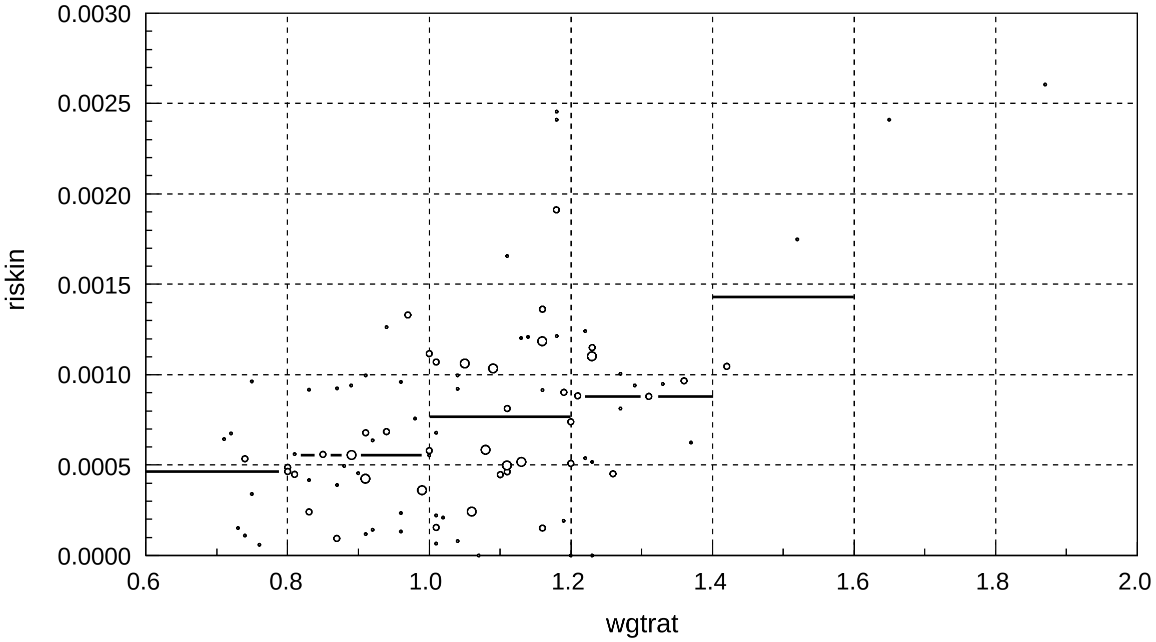
Therefore, an analysis was performed considering, for each collision, the ratio of the weights of the two cars involved. Figure 7-12 shows the driver fatality risk by car family, versus the average weight ratio (weight of the other car divided by the weight of the studied driver's car) in the collisions involving the cars of this family. The raw risks (part (A)) show the expected trend of increasing risk with increasing weight ratio; the age-adjusted risks (part (B)) show the trend more consistently and clearly. Figure 7-13 shows in a similar manner the risk for car drivers in collisions by family of the other car and the average ratio of the weights of the two cars. The numerator is the weight of the other car the case driver is in. The denominator is the weight of the other car which belongs to the family represented by the point. Even in the raw data the trend is nearly consistent and in the expected direction. In the victims' age-adjusted data, the trend is consistent.

In section 5.1, the relation of the fatality risk with the fourth power of Δv and the consequent relations of the ratio of the fatality risks with the fourth, or a similar, power of the mass ratio was mentioned. Therefore, the relations between *riskin* and the average fourth power of the weight ratio and between *riskby* and the average of the fourth power of the weight ratio were explored. The resulting data points show more scatter than those in figures 7-12 and 7-13, and a less clear trend. This is probably due to the fact that the ratio of two fourth powers increases the effect of errors of the weights greatly.

The conclusion from these analyses is that standardization for the victims' ages "smoothes" the apparent relation considerably, though it may increase the scatter of the individual data points. This, in addition to the well-known relation between age and vulnerability is a strong argument for adjusting the data for the victims' ages. Also, the relations between the risks and vehicle weight, or weight ratio, are as expected. Though these relations are strong, the variation among car families appears large, sometimes larger than the total variation due to weight differences. However, to determine whether the remaining "net" variation is due to vehicle-related factors (physical characteristics, or driver selection), or to random fluctuations, one would need to perform an error analysis that would incorporate the complex sampling scheme of GES. This is a major undertaking.

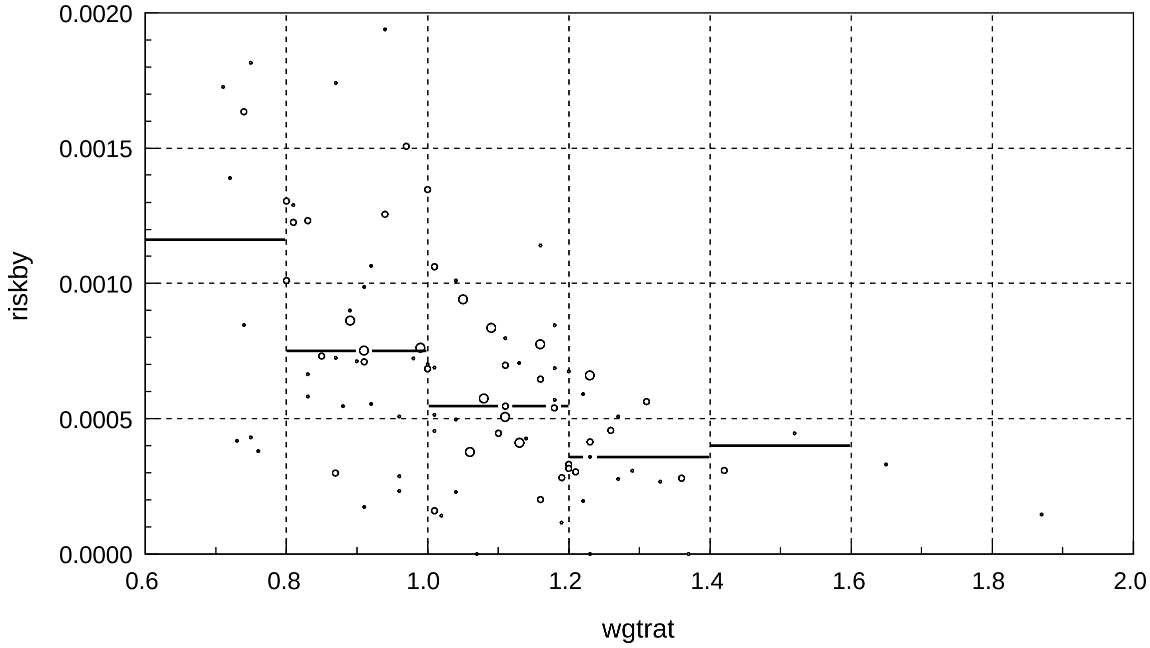


A)

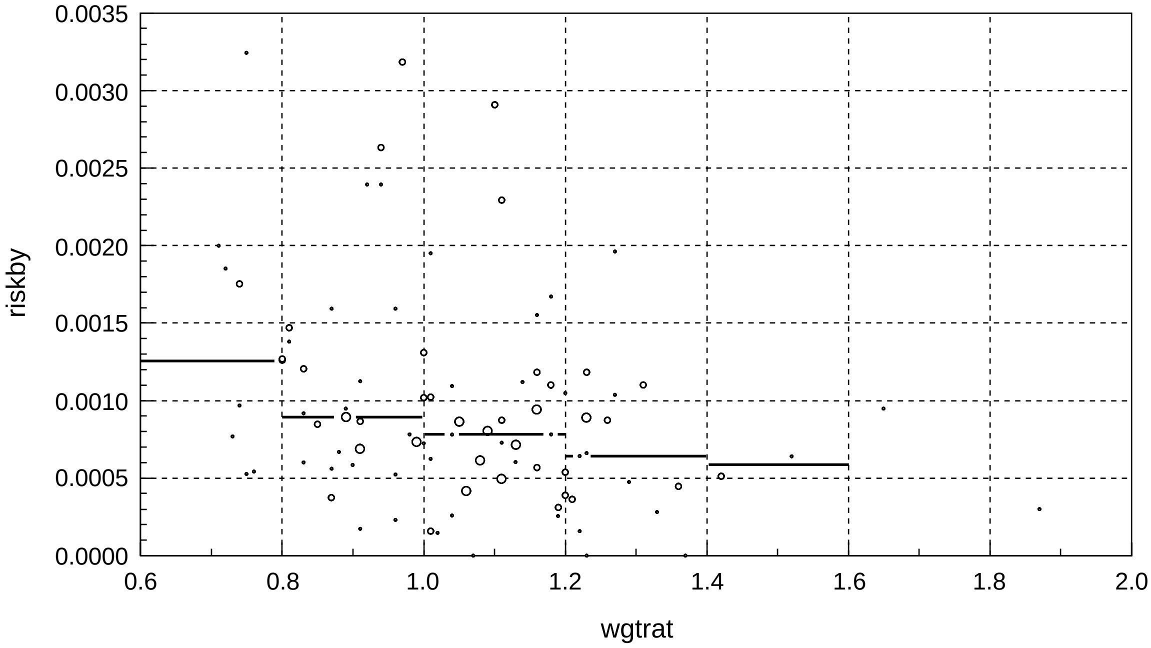


B)

Figure 7-12. Fatality risk for drivers of cars of certain families, in collisions with other cars, versus average of the ratios of the weights of the two cars (weight of the other car divided by weight of his car). Large circles represent families with large case numbers, small circle families with medium case numbers, and dots families with low case numbers. The horizontal line show the median of the risks in each 0.2 interval of the ratio. Part (A) shows the “raw” risks, (B) those adjusted for the victim’s age.



A)



B)

Figure 7-13. Fatality risks for car drivers in collisions with cars of certain families, versus the average of the ratios of the weights of the two cars (weight of the victim's car divided by the weight of the other car). Large circles represent families with large case numbers, small circle families with medium case numbers, and dots those with low case numbers. The horizontal line show the median of the risks in each 0.2 interval of the ratio. Part (A) shows the "raw" risks, (B) those adjusted for the victim's age.

7.4 AGGRESSIVITY AND BUMPER HEIGHT

Bumper height is an obvious vehicle characteristic. It appears likely that the differences in bumper height between cars and light trucks (including pickup trucks, utility vehicles, and vans) contributes to the apparent aggressivity of light trucks in collisions with cars (see section 8). Bumper heights also differ among passenger cars, so there might be similar effects, but to a lesser degree. A list of bumper heights for passenger cars by make, model, and model year was obtained from NHTSA.

Within the car families defined in section 6, bumper heights can vary considerably (e.g., between 30 and 45 cm in one extreme case; bumper heights were given in cm.) In most families, however, the differences are much smaller. Calculating a true average for each family would have required a great effort; therefore, the mean of the greatest and smallest value on bumper height for a family was used. A more thorough calculation would also not have been justified. The bumper heights available were apparently measured at the foremost part of the bumper. In many cases, this is a plastic or weak metal part, and with some big bumpers the rigid structure of the bumper behind it, which can inflict damage, can have a very different height.

To study the potential aggressivity of bumper height for each car involved in a collision, the bumper height (for the car family, not the individual make-model-year combination) and the weight of the other car was obtained, and then related them to the driver fatality risk in the first car.

Figure 7-14a shows the result. There is the expected increase in risk with weight of the other car. For lower weights, the risk appears to increase slightly with bumper height. For the heavier cars, the risk is lowest for bumper heights of 32 cm, greater for higher and lower bumpers.

If adjustments are made for the victim’s age, the picture changes somewhat (figure 7-14b). For light cars, there is no apparent relation between risk and bumper height. For heavier cars, the overall pattern remains unchanged, but there is a quantitative shift. The risks for low bumper heights are much higher and those for greater bumper heights much smaller. There is a striking increase in risks for some mid-weight families, with great bumper heights (they include the Mustang, and the Mercury Capri). This, together with the fact that sports cars, e.g., Camaros, tend to have low bumpers, suggests that the pattern that appears in the figure does reflect not only any effects of bumper height, but also effects of driver factors which are indirectly related to bumper height. To separate such effects would require a much deeper analysis. For instance, it might be necessary to stratify cars according to how sporty their image is, or by an objective measure, such as horsepower-to-weight ratio.

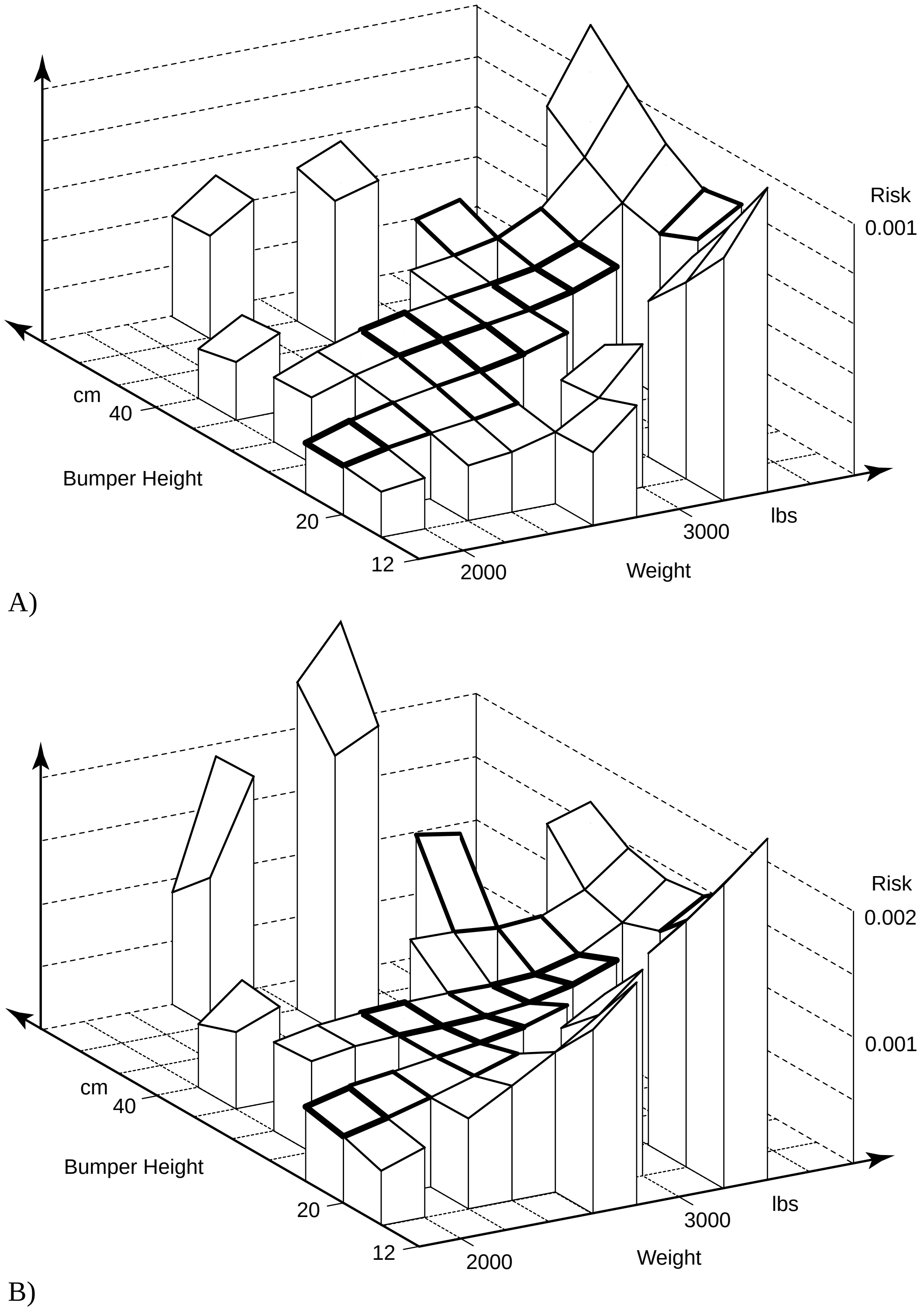


Figure 7-14. Car driver fatality risk in collisions with another car, by the other car's bumper height and weight, smoothed. Part (A) shows all data combined, part (B) adjusted for the victim's age.

8. COLLISIONS BETWEEN CARS AND LIGHT TRUCKS

8.1 SOME PRACTICAL DIFFICULTIES WITH LIGHT TRUCKS

Light trucks comprise pickup trucks, vans, and utility vehicles - a very heterogeneous group in terms of physical characteristics and use. They account for a high proportion of new vehicle sales. In our database they are about a quarter of the collision involved vehicles. This limits the available case numbers.

The situation is relatively simple for vans and utility vehicles. Make and model describe most of them adequately, even the difference between a cargo version, and a passenger version of the same van is not that great, and FARS and GES (to some extent) provide weight and wheelbase. The situation for utility vehicles is similar.

Many pickup trucks, however, are offered in several versions, which can differ in wheelbase and body style, including type of cab. These cannot be distinguished by the codes provided in FARS and GES. Wheelbase is generally available, however, not the specific wheelbase of the case vehicle, but the range of wheelbases for the make/model. In most cases the actual weight is not available. Instead the gross vehicle weight rating (GVWR) is shown, which is very different.

Pickup trucks and utility vehicles are sometimes modified. They may have winches on the front bumper, or a snowplow during the winter (and the frame for mounting it during the other seasons). Some are modified by lifting the body. Such features are likely to increase the aggressivity of the vehicle, especially in a side impact to a car, but their presence is not shown in mass collision data files. Thus, pickup trucks and utility vehicles, as they leave the factory, may be less aggressive than apparent from the collision data.

Because of these problems, these three vehicle types were not disaggregated further, but treated each as one vehicle type.

8.2 AGGRESSIVITY OF LIGHT TRUCKS IN RELATION TO WEIGHT

Figure 5-3 compared the fatality risks of cars in front-front, front-left, and front-right collisions, controlling for the mass ratio of the cars by showing the risks as functions of the mass ratio. A similar comparison can be made for the risks of collisions between cars, and between cars and the three types of light trucks. Control for mass ratio is important, because light trucks tend to be somewhat heavier than cars, though not as much as might be expected.

In practice, plotting graphs with grouped data is difficult because of the small number of pickup trucks with known weights (e.g., only nine fatal collisions between cars and pickup trucks of known weight). Points scatter widely and no pattern appears.

The alternative of modeling relations such as shown in figures 5-1 to 5-3 using individual cases is not practical, because for most collisions, where only one driver is killed, the logarithm of the risk ratio is $-\infty$ or $+\infty$. Only in the relatively few cases where both drivers are killed is it finite, namely zero. One frequently used approach avoiding this difficulty is logistic regression, with a dependent variable 0 if the driver of one vehicle is not killed and 1 if he is killed. Though in the first case, the driver of the other vehicle must have been killed if selected for the collision evaluation; in the second case he may or may not have been killed. Relations between this observed variable and the risks of being killed are complex.

If the analysis is restricted to cases where exactly one driver is killed, ignoring those where both are killed, the situation becomes a little simpler. It can be shown that the conditional probability π_1 that driver 1 is killed, given that exactly one driver is killed, is

$$\pi_1 = \frac{p_1/(1-p_1)}{p_1/(1-p_1)+p_2/(1-p_2)} \qquad (8.2\text{-}1)$$

If the absolute values of the unconditional probability p_1 and p_2 are small, then

$$\pi_1 \approx \frac{p_1}{p_1+p_2} \qquad (8.2\text{-}2)$$

and the outcome of a collision is then a binomial variable z = 0 or 1 with $\pi_1 = 1$ for z = 1.

The appearance of the fraction $p_1/(1-p_1)$ and $p_2/(1-p_2)$, and of the dichotomous variable z suggests fitting a logistic regression to the individual data points. This is simple, and frequently done. However, a logistic regression imposes a certain functional relation, which may be very different from the true physical relation. Validation (or refutation) of a specific functional form requires many more cases than available.

Therefore, a simpler approach was used, isotonic regression. Isotonic regression obtains a best fit to the data points in a least-squares sense, subject to the conditions that the fitted values form a nondecreasing (or nonincreasing) sequence. The same technique provides a maximum likelihood fit to a sequence of binomial variables, subject to the condition of isotony.[5]

This was done for collisions between passenger cars and light trucks (all types combined) as well as utility vehicles, vans, and pickup trucks separately. Car-to-car collisions were also modeled, to provide a basis for comparison. To control for confounding effects of the victims' ages, only drivers of age 26 to 55 were used for the analysis. Also, cars with airbags were excluded to eliminate distortions that would result if the younger cars with airbags would have different collision frequencies with light trucks than older cars. Figure 8-1 shows the results.

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[5] R.E. Barlow, D.J. Bartholomew, J.M. Brenner, H.D. Brunk, Statistical Inference Under Order Restrictions, Wiley, 1972

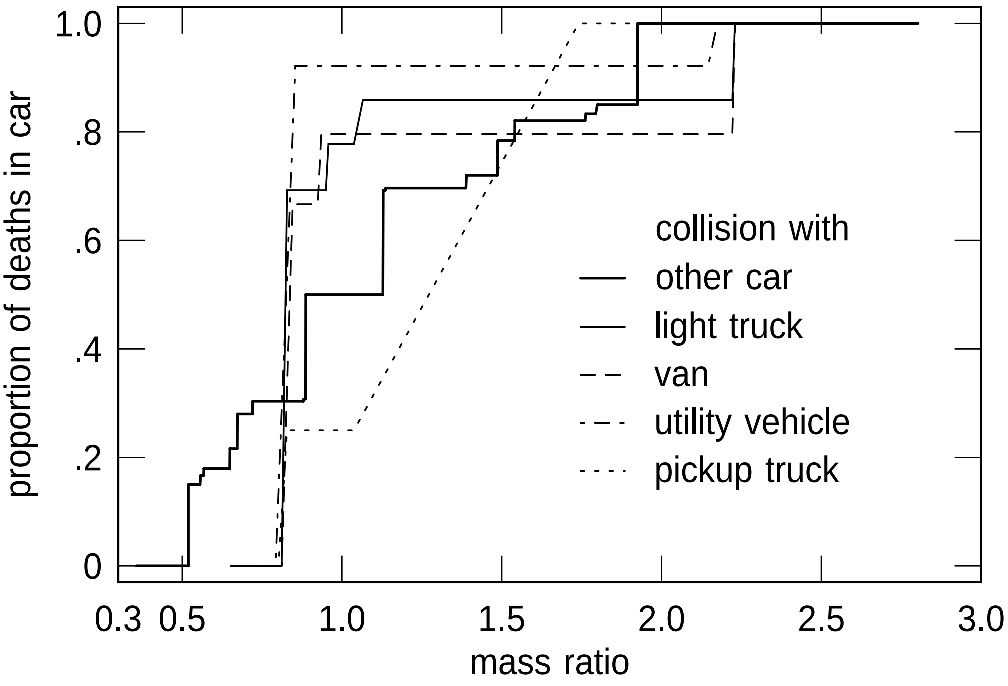

Figure 8-1. Collisions between two cars, and between a car and a light truck. Light trucks combine vans, utility vehicles, and pickup trucks. The step functions are fitted by isotonic regression to the data.

The step-function for cars obtained by isotonic regression corresponds to the broken line in Figure 5-4. With the exception of pickup trucks (for which there are only nine cases, making the results very uncertain) over the middle part of the relation the functions for car-to-light truck collisions are far above that for car-to-car collisions. That means that a car driver is much more likely to be killed when colliding with a light truck than when colliding with another car of the same weight as the truck, in the range of weight ratios between about 0.8 to 1.5. Above that, the risks are about equal; below that, the risk appears to be lower than in collisions with cars. However, the latter may be deceptive. There are no collisions between cars and trucks with a weight ratio below 0.65, and only 9 in the range between 0.65 and 0.83, in some of which there was a fatality in the car.

This figure should be interpreted with caution because some case numbers are small. Error estimates are extremely complex because of the discontinuous nature of isotonic regression and complex dependencies among the estimates.

At face value, these data show that either light trucks are more crashworthy than cars, or more aggressive. The data shown in Tables 8-1 and 8-2 suggest that light trucks are not more crashworthy than passenger cars; therefore it is more likely that they are not compatible with cars in collisions, and thereby aggressive.

Table 8-1. Driver Fatality Risk in Single Vehicle Collisions by Vehicle Class. Drivers 26-55 years old, no airbag.

	Vehicle Class			
	Car	Utility Vehicle	Van	Pickup Truck
Killed drivers	10233	1427	753	5324
Involved drivers	1,759,876	134,719	205,124	503,507
Fatality rate,	0.0058	0.0106	0.0037	0.0106
relative to car	1	1.8	0.6	1.8

Table 8-2. Driver Fatality Risk in Collisions between Two Vehicles of the Same Class. Drivers 26-55 years old, no airbag.

	Vehicle Class			
	Car	Utility Vehicle	Van	Pickup Truck
Killed drivers	1901	23	45	397
Involved drivers	1,745,419	9368	30,522	105,952
Fatality rate,	0.00054	0.00123	0.00074	0.00187
relative to car	1	2.3	1.4	3.4

8.3 AGGRESSIVITY AND CRASHWORTHINESS OF LIGHT TRUCKS IN RELATION TO CAR SIZE

For a meaningful analysis of weight effects in collisions, the weight of both vehicles is necessary, because much of the effect depends on the mass ratio. With regard to size however, one vehicle's dimensions are sufficient, though it would be preferable to also have both vehicles' weights. Without them, only gross aggressivity can be studied.

Figure 8-2 shows the fatality rates in cars by their wheelbase, in collisions with the three classes of light trucks, and also in collisions with another car as a basis for comparison. Over practically the entire range of weights, the risk of being killed in a collision with a light truck is substantially higher than in a collision with another car. The relations for pickup trucks and utility vehicles are practically the same; the risk is roughly double of that in collisions with another car. In collisions with a van, the risk is not as high as in collisions with other light trucks; for wheelbases of 110 in. and more, there may be no difference.

Figure 8-3 shows the fatality risk in light trucks, in collisions with cars of the indicated wheelbase, and with other cars as a basis for comparison. Over the entire range of wheelbases, drivers of light trucks have lower fatality risks than car drivers when colliding with a car. The risk for drivers of pickups is highest or nearly so, for drivers of vans it tends to be the lowest or nearly so. Because weight had to be ignored, rates reflect gross aggressivity.

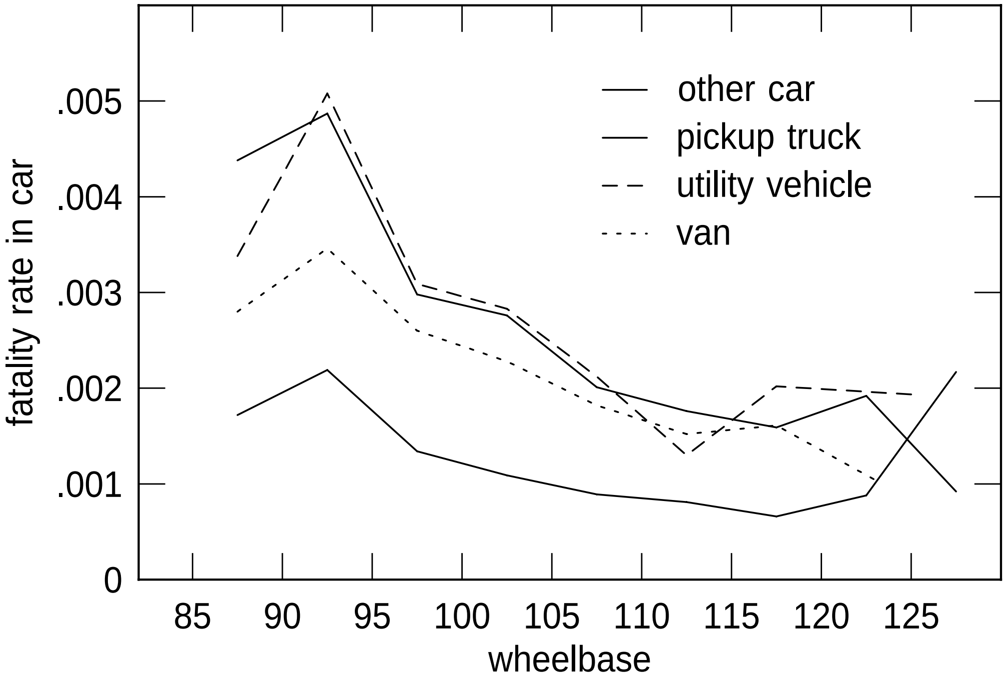

Figure 8-2. Driver fatality rate in a car, colliding with a car or light truck, by wheelbase (in.) of car. Based on FARS and GES data, using only cases where both drivers were 26 to 55 years old, and no vehicle had an airbag.

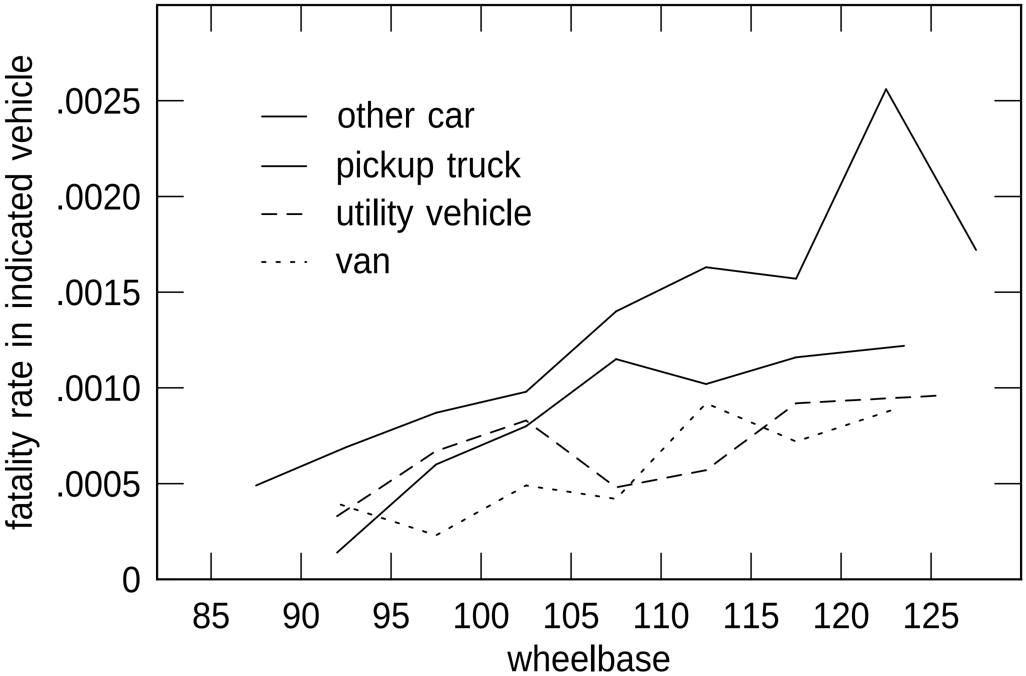

Figure 8-3. Driver fatality rate in cars or light trucks, colliding with a car, by wheelbase (in.) of car. Based on FARS and GES data, using only cases where both drivers were 26 to 55 years old, and no vehicle had an airbag.

8.4 AGGRESSIVITY OF LIGHT TRUCKS BY COLLISION CONFIGURATION

Again, to reduce the effect of confounding factors, for this analysis only collisions where both drivers were 26 to 55 years old were used, and no vehicle had an airbag. Because weights had to be ignored, rates reflect gross aggressivity.

Figure 8-4 compares fatalities in front-front collisions. For instance, in car-to utility collisions, 35 utility vehicle drivers were killed, compared with 195 car drivers. The number of car drivers killed is much larger than that of light truck drivers. It is surprising that the ratio for pickup trucks is only about half as high as for vans and utility vehicles.

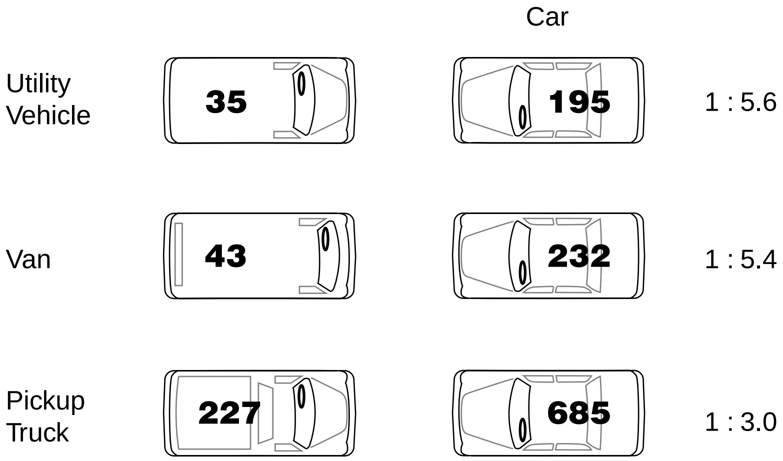

Figure 8-4. Fatalities in front-front collisions between cars and light trucks. Based on FARS data, using only collisions where both drivers were 26 to 55 years old, and no vehicle had an airbag.

Figure 8-5 shows front-left side collisions. Because of the asymmetry, car-car collisions are also shown as baseline. A car driver whose vehicle is struck on the left side is 6.6 times as likely to be killed as the driver of the striking car. If the struck vehicle is a light truck, this ratio is reduced to one-sixth! On the other hand, if the striking vehicle is a light truck, the risk for the driver of the struck car is increased between twofold and nearly fivefold.

Figure 8-6 shows front-right side collisions. Though the impact is not as close to the driver as in left-side impacts, the risk for the struck car’s driver is still more than three times as high as for that of the striking car. If the struck vehicle is a light truck, the relative risk is reduced by a factor of 5 to 9. If the light truck is the striking vehicle, then the relative risk for the car driver is increased by a factor of 2 to 6.

These comparisons are of relative risks, because only FARS data were used. Absolute risks, which are relative to collision involvement, may compare differently.

8.5 AGE ADJUSTED COMPARISONS

The previous analyses of collisions with light trucks were done for drivers in a limited age range, to reduce effects of driver vulnerability. In this analysis, all collisions, independent of driver age were used and adjusted to the common distribution of driver ages as described in section 4.

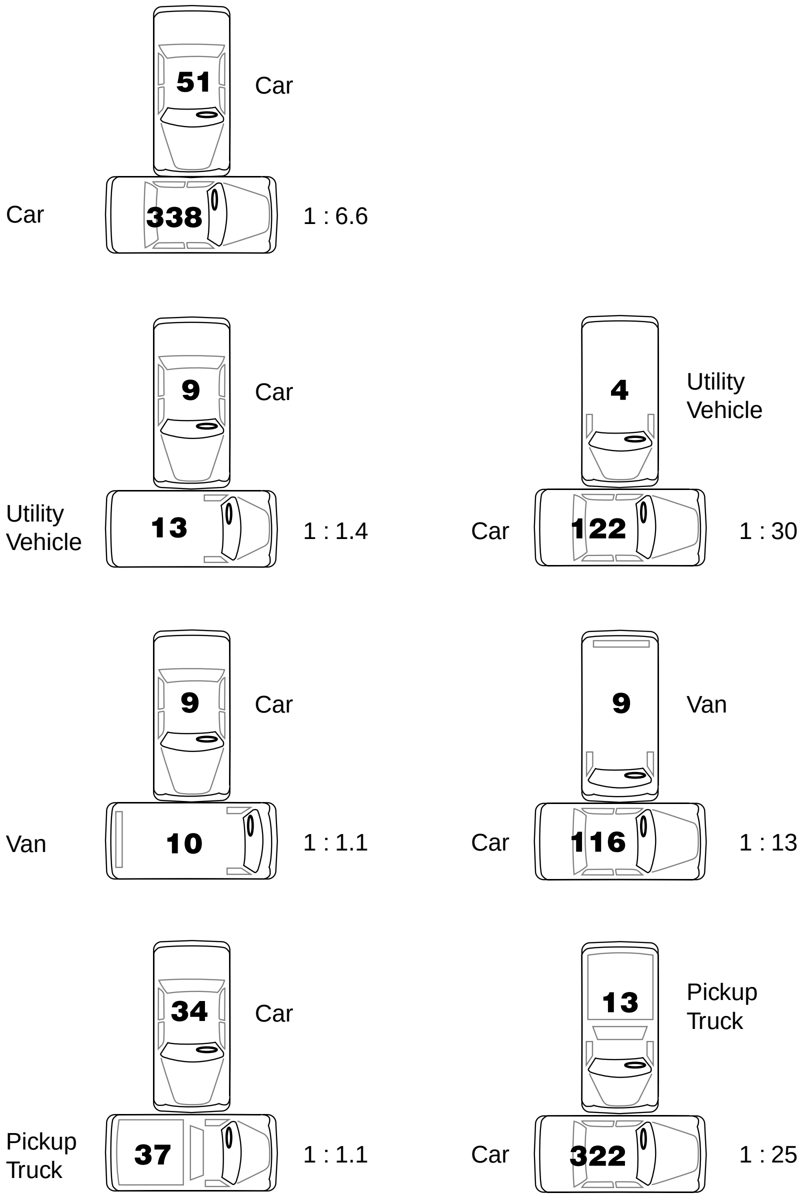

Figure 8-5. Fatalities in front-left collisions between cars and light trucks. Based on FARS data, using only collisions where both drivers were 26 to 55 years old, and no vehicle had an airbag.

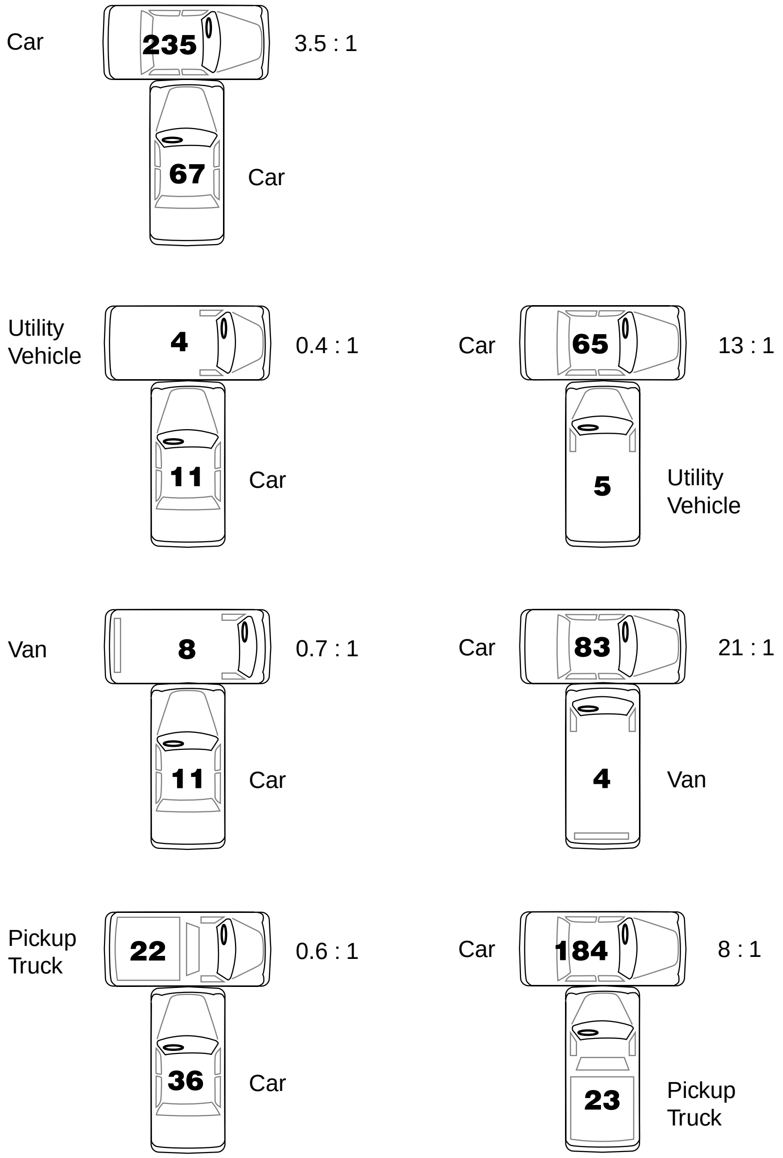

Figure 8-6. Fatalities in front-right collisions between cars and light trucks. Based on FARS data, using only collisions where both drivers were 26 to 55 years old, and no vehicle had an airbag.

Figure 8-7 shows the results. The open circles show the combinations of *riskin* and *riskby* in collisions between cars and the three types of light trucks. Adjustment to a standard age distribution changes the values to the tips of the arrows. These changes are large for light trucks, and very small for cars because car drivers dominate the overall age distribution.

On the straight line through the lower part of the graph, *riskin* and *riskby* are equal. The points for light trucks are well above the line; the point for cars is below the line. The overall pattern agrees with that of Figures 8-2 and 8-3. The *riskby* for light trucks is much higher than for cars, but differences among the three types are relatively small; the *riskin* values for light trucks are lower than that for cars, but for pickup trucks by not much.

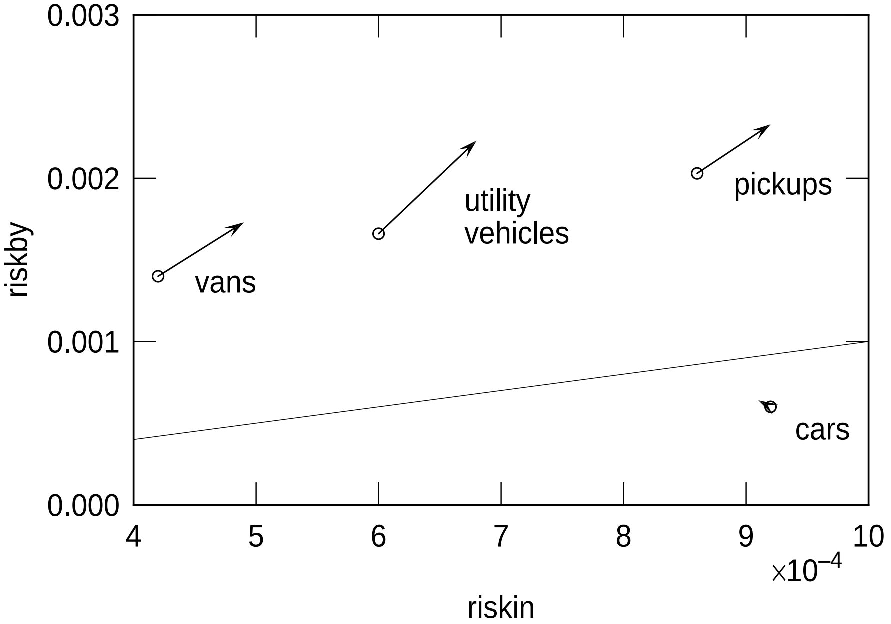

Figure 8-7. *Riskby* versus *riskin* in collisions between cars and light trucks. The open circles show the risks estimated without regard to the victims' ages. The tips of the arrows show how the risks change when they are standardized to a common driver age distribution over all four-vehicle classes. Based on FARS and GES data.

9. CONCLUSIONS

The main finding is that there are clearly differences in aggressivity among car classes, and among cars and light trucks.

The differences of the fatality risks in collisions between cars and light trucks are great, in all impact configurations. They are much larger than can be explained by the weight differences between cars and the three types of light trucks.

Among cars, weight is the critical factor. Heavier cars impose a higher fatality risk on the drivers of other cars than lighter cars. A complement to this effect is that the driver fatality risk in the heavier car is lower. However, the reduction in the fatality risk for the driver of the heavier car is less than the increase of the fatality risk for the driver of the lighter car. Thus, the variation of weight among cars results in a net increase of fatalities in collisions.

A larger car , if everything else is similar, will be heavier than a smaller car. However, some cars are heavier than others of the same size based on wheelbase. It is useful to define the difference between a car’s weight and the average weight of all cars of the same wheelbase as the car’s “overweight.” It was found that overweight showed little or no beneficial effect on the fatality risk (in collisions with other cars as well as in single car collisions) for the driver of the car, but that it tends to increase the fatality risk for drivers of other cars in collisions.

Considering the large effect weight has, “gross” aggressivity, which includes the effect of weight should be distinguished from “net” aggressivity, which remains after removing the effect of weight.

When it was attempted to distinguish the effect of weight, it was noted that there were great differences in the apparent aggressivity of different car models. However, to a large extent these differences appeared random. To separate the random differences from “real” ones, a detailed error analysis that accounts for the complex sampling plan of the General Estimates System is needed.

To make the concept of aggressivity practically useful, empirical (apparent) aggressivity must be related to specific vehicle features or engineering characteristics. One of the more obvious features is bumper height. It was tried to relate bumper height to aggressivity, while controlling for weight. The resulting pattern gave no clear evidence for an effect of bumper height; rather, it suggested greater aggressivity for cars with a sporty image. This would reflect not a physical vehicle effect, but an effect of driver characteristics related to car characteristics.

The only driver characteristics readily available are age and sex. The risk of being killed from a certain injury increases greatly in the higher age groups. Therefore, driver age differences among cars was adjusted. The effect was that apparent relations became smoother or more consistent.

It is concluded that to estimate net aggressivity data and to relate them to specific vehicle characteristics, will require very detailed statistical analyses and careful control for driver characteristics and possibly for environment characteristics. Some of the necessary work has to be exploratory or experimental.

APPENDIX A. THE SMOOTHING TECHNIQUE USED

The purpose of smoothing is to describe empirical data that cannot be adequately approximated by simple analytical functions of the independent variables. Though this technique works, in principle, with any number of independent variables, the technique was applied in this study only to the case of two variables.

Let z_i be the value of the dependent variable, and x_i and y_i those of the independent variables at data point *i*. The process of smoothing calculates for a number of grid points *j* with coordinates ξ_j and η_j the smoothed values ζ_j . The technique used in "kernel smoothing" which uses a weight function $w(d_{ij})$, where d_{ij} is a measure of a distance between an observation *i* and grid point *j*. The weight function is so defined that it is largest for a distance zero between grid point and observation, and declines with increasing distance.

The procedure fits a separate linear regression to each grid point, using the weight functions. This means that the model fits the data points near the grid points best, the remote ones possibly not well. The value of this linear function at the grid point is the smoothed value. This procedure is repeated for each grid point, resulting in smoothed values for each grid point. In the case of two independent variables, the resulting smoothed function can be represented as a surface in a three-dimensional space by connecting the smoothed values with grid lines.

As weight function, the Gaussian kernel was used:

$$w_{ij} = \exp\left\{-\left(\frac{x_i - \xi_j}{a}\right)^2 - \left(\frac{y_i - \eta_j}{b}\right)^2\right\} \qquad \text{(A-1)}$$

where *a* x *b* are the size of the "window": the larger *a* or *b*, the wider the range in x_i or y_i over which the data points have a large weight.

When fitting a model, several choices are available: The density of the grid, the exponent and the size of the window. The orientation of the window can be varied; this was investigated, but not used. Usually experimenting can be done to determine which values eliminate variations that are likely to be noise, but still retain features of the surface that may reflect real effects. Though statistical criteria to deal with the first aspect can be developed, they are cumbersome, and were not used. The procedure can be refined in many aspects, but this did not appear productive in our context.

The results of the smoothing are shown as surfaces, formed by connecting the smoothed values at the grid points along the grid lines. The width of the lines is proportional to the number of cases in each cell; if the line was too narrow to be printable, it was printed as a dotted line.

APPENDIX B CAR FAMILIES

The family code is based on the FARS make/model codes for one of its members. If a body style is given, only cars of that body style are included in the family. If a body style has a negative sign , then cars of that body style are excluded from the family. Body type “u” indicates unibody, and “f” frame. Minimum and maximum bumper height are over the members of the family in the covered model years. Wheelbase (WB) and length are in inches, weight in pounds, and bumper height in centimeters. An asterisk indicates missing information.

Table B-1. Definition of car families, and typical characteristics for vehicles in each family

Family code	Make code	Model code		Model year range		Body style	WB	Body type	Weight	Length	Bumper ht.	
											min	max
122-020-05	22	020	Pontiac Grand Prix	88	96		107.5	u	3244	194.9	29.6	36
122-020-05	21	020	Olds Cutlass Supreme	88	96		107.5	u	3303	192.2	25.9	35.6
122-020-05	20	020	Chevy Lumina	90	96		107.5	u	3314	200.9	32.9	34
122-020-05	20	036	Chevy Monte Carlo	95	96		107.5	u	*	200.7	*	*
122-020-05	18	020	Buick regal	88	96		107.5	u	3240	193.9	26.8	35.8
122-018-05	22	018	Pontiac Grand Am	92	96		103.4	u	2711	186.9	21.6	23.8
122-018-05	21	021	Olds Achieva	92	96		103.4	u	2763	187.9	21.9	22.5
122-018-05	20	019	Chevy Corsica/Beretta	87	96		103.4	u	2700	183.4	20.6	32.3
122-018-05	18	018	Buick Skylark	92	96		103.4	u	2761	189	23.4	24.4
122-018-04	22	018	Pontiac Grand Am	85	91		103.4	u	2567	177.5	21.6	23.8
122-018-04	21	018	Olds Calais	86	91		103.4	u	2527	178.8	19.6	38
122-018-04	18	018	Buick Skylark	86	91		103.4	u	2573	180.1	23.4	24.4
120-035-04	38	032	Isuzu Impulse	90	93		96.5	u	2536	166.1	22.4	22.5
120-035-04	20	035	Chevy-geo storm	90	93		96.5	u	2394	164	21.6	22.6
120-034-05	53	034	Suzuki Swift	89	96		93.1	u	1900	161.2	18.3	21.6
120-034-05	20	034	Chevy Geo Metro	89	96		93.1	u	1851	151.4	20	21.8
120-032-05	49	032	Toyota Corolla	94	96		97	u	2355	172	21.5	21.5
120-032-05	20	032	Chevy-Geo Prism	93	96		97.1	u	2358	173	17.5	17.5
120-032-04	49	032	Toyota Corolla	86	93	-2	95.7	u	2355	172	21.5	21.5
120-032-04	20	032	Chevy-Geo Prism/Nova	89	92		95.7	u	2358	173	17.5	17.5
120-031-04	38	031	Isuzu I-Mark	87	90		94.5	u	2067	160.2	20.1	20.1
120-031-04	20	031	Chevy-geo spectrum	86	89		94.5	u	1867	160.2	20.6	24.6
120-016-05	22	016	Pontiac Sunbird	84	94		101.2	u	2340	178.2	21.6	24.2
120-016-05	21	016	Olds Fairness	82	88		101.2	u	2341	176.2	28.8	29
120-016-05	20	016	Chevy Cavalier	82	94		101.2	u	*	182.3	24.5	26.5
120-016-05	19	016	Cadillac Cameroon	82	88		101.2	u	2635	177.8	25.3	29.1
120-013-04	22	013	Pontiac T-1000	81	87		94.3	u	2059	161.9	32.3	32.5
120-013-04	20	013	Chevy Chevette	77	87		94.3	u	2022	161.9	32.3	32.5
120-009-05	22	009	Pontiac Firebird	93	96		101.1	u	3467	195.6	13	13
120-009-05	20	009	Chevy Camera	93	96		101.1	u	3258	193.2	13	13
120-009-04	22	009	Pontiac Firebird	82	92		101	u	3467	195.6	13	13
120-009-04	20	009	Chevy Camera	82	92		101	u	3258	193.2	13	13
120-002-05	22	002	Pontiac Safari	87	89	06	115.9	f	3985	220.5	*	*
120-002-05	22	002	Pontiac Parisienne	83	86		115.9	f	3985	220.5	*	*
120-002-05	21	002	Olds Custom Cruiser	81	92	06	115.9	f	4076	217.5	25.4	31.2

Family code	Make code	Model code		Model year range		Body style	WB	Body type	Weight	Length	Bumper ht. min	max
120-002-05	20	002	Chevy Caprice	91	96		115.9	f	3388	214.1	24.9	26.4
120-002-05	18	004	Buick Roadmaster	91	96		115.9	f	4123	215.8	26.9	44.7
120-002-05	18	002	Buick estate wagon	86	90	06	115.9	f	4123	220.5	33	33
119-014-05	19	014	Cadillac Seville	92	96		111	u	3771	204.4	23.1	23.1
119-014-04	19	014	Cadillac Seville	86	91		108	u	3391	188.4	31.7	31.8
119-005-05	21	005	Olds Tornado	86	92		108	u	3322	201	35.9	39.2
119-005-05	19	005	Cadillac Eldorado	92	96		108	u	3727	202.2	24.1	25.4
119-005-05	18	005	Buick Riviera	86	93		108	u	3417	187.2	32.4	50.9
118-020-04	22	020	Pontiac Grand Prix	78	87		108.1	f	3244	194.9	29.5	36.4
118-020-04	21	020	Olds Cutlass Supreme	78	87		108.1	f	3303	192.2	31.7	33.1
118-020-04	20	010	Chevy Monte Carlo	78	89		108.1	f	3170	200.4	31.9	34.6
118-020-04	18	020	Buick Regal	78	87		108.1	f	3240	193.9	29.6	29.6
118-007-05	22	017	Pontiac 6000	82	91		104.8	u	2983	188.8	30.2	30.2
118-007-05	21	017	Olds Cutlass Ciera	82	96		104.9	u	2808	190.3	30.4	30.6
118-007-05	20	017	Chevy Celebrity	82	90		104.9	u	2809	190.8	35.6	36.2
118-007-05	18	007	Buick Century	86	96		104.9	u	3107	189.1	24.3	24.4
118-005-05	21	022	Olds Aurora	95	96		113.8	u	3967	205	23.2	23.2
118-005-05	18	005	Buick Riviera	95	96		113.8	u	3762	207.2	24.1	24.1
118-003-05	21	003	Olds Ninety-Eight	91	96		110.8	u	3503	205.8	27.1	27.7
118-003-05	18	003	Buick Park Avenue	91	96		110.8	u	3494	205.3	24	25.7
118-003-05	18	003	Buick Electra	85	90	-6	110.8	u	3494	205.3	23.1	37.2
118-002-05	22	002	Pontiac Bonneville	87	96		110.8	u	3599	200.6	21	35.6
118-002-05	21	002	Olds Delta 88	86	96	-6	110.8	u	3417	200.4	24.5	29.5
118-002-05	18	002	Buick Lesabre	86	96	-6	110.8	u	3443	200	22.4	51
114-031-04	14	031	Mercury Capri	91	94		94.7	u	2411	166.1	23.9	24
113-005-05	13	005	Lincoln Continental	88	94		109	u	3621	205.6	22.6	27.7
113-002-04	13	005	Lincoln Continental	84	87		108.5	u	3765	200.7	*	*
113-002-04	13	002	Lincoln MarkVII	84	92		108.5	u	3715	202.8	34.5	37.8
113-001-05	13	001	Lincoln Towncar	90	96		117.4	f	4055	218.9	34.5	37.8
113-001-04	13	001	Lincoln Towncar	80	89		117.3	f	3993	219	32.8	32.8
112-035-05	14	037	Mercury Mystique	95	96		106.5	u	*	183.9	22	22
112-035-05	12	035	Ford Contour	95	96		106.5	u	*	183.9	20.7	20.7
112-018-05	41	018	Mazda mx6	94	96		102.9	u	2652	181.5	*	*
112-018-05	12	018	Ford Probe	93	96		102.9	u	2788	178.7	*	*
112-018-04	41	018	Mazda mx6	88	93		99	u	2616	181.5	*	*
112-018-04	12	018	Ford Probe	89	92		99	u	2715	178.7	*	*
112-017-04	14	017	Mercury Sable	86	95		106	u	*	192.2	23.1	40
112-017-04	12	017	Ford Taurus	86	95		106	u	*	190	24.6	34.6
112-016-05	12	016	Ford Crown Victoria	80	96		114.4	f	3805	212.4	34.7	37.6
112-015-05	14	015	Mercury Topaz	84	94		99.9	u	2584	176.7	24.6	38.2
112-015-05	12	015	Ford Tempo	84	94		99.9	u	2605	176.7	24.6	38.2
112-013-05	41	035	Mazda Protege	90	94	04	98.4	u	2192	161.8	*	*
112-013-05	14	036	Mercury Tracer	91	96		98.4	u	2442	170.9	21.5	21.9
112-013-05	12	013	Ford Escort	92	96		98.4	u	2396	170.9	21.5	21.6
112-013-04	41	035	Mazda 323	86	89		94.5	u	2192	161.8	*	*
112-013-04	14	036	Mercury Tracer	88	90		94.2	u	2442	166.8	23.9	23.9
112-013-04	14	013	Mercury Lynx	86	87		94.2	u	2442	166.8	36.9	39.1
112-013-04	12	013	Ford Escort	86	91		94.2	u	2396	170.9	22.8	39.1
112-006-04	14	006	Mercury Marquis	83	86		105.6	u	2941	196.5	34.1	35
112-006-04	12	006	Ford LTD	83	86		105.6	u	2842	196.5	34.1	35
112-004-05	14	004	Mercury Cougar	89	96		113	u	3589	200.8	31.8	37.6
112-004-05	13	002	Lincoln Mark VIII	93	96		113	u	3768	206.9	32.5	32.5
112-004-05	12	004	Ford T-bird	89	96		113	u	3545	200.3	31.8	36.8
112-003-05	12	003	Ford Mustang	94	96		101.3	u	3259	181.5	23.3	25

Family code	Make code	Model code		Model year range		Body style	WB	Body type	Weight	Length	Bumper ht. min	max
112-003-04	14	031	Mercury Capri	79	86		100.5	u	2887	179.3	*	52.5
112-003-04	12	003	Ford Mustang	86	93		100.5	u	3139	179.6	38.6	52.5
110-441-05	52	442	Mitsubishi Expo-LRV	92	94	06	99.2	u	2751	168.6	*	*
110-441-05	10	441	Eagle Summit Wagon	92	96	06	99.2	u	2820	168.5	25	26.1
110-441-05	09	441	Plymouth Vista	92	94	06	99.2	u	2512	168.5	25	26.1
110-044-04	46	044	Renault Medallion	88	89		102.3	u	2518	183.2	23.1	23.1
110-044-04	10	044	Eagle Medallion	88	89		102.3	u	2518	183.2	23	23
110-037-05	52	037	Mitsubishi Eclipse	95	96		98.8	u	*	*	*	*
110-037-05	10	037	Eagle Talon	95	96		98.8	u	2813	172.2	13.5	14.7
110-037-04	52	037	Mitsubishi Eclipse	90	94		97.2	u	2669	172.8	*	*
110-037-04	10	037	Eagle Talon	90	94		97.2	u	2660	172.2	13.5	14.7
110-037-04	09	037	Plymouth Laser	90	94		97.2	u	2669	172.8	18	20.1
110-034-05	52	035	Mitsubishi Mirage	94	96	04	98.4	u	2193	172.2	*	*
110-034-05	10	034	Eagle Summit	93	96	04	98.4	u	2198	174	19.5	20.5
110-034-05	07	034	Dodge Colt	94	94	04	98.4	u	2195	174	*	*
110-034-04	52	035	Mitsubishi Mirage	89	93	04	96.7	u	2193	170.1	*	*
110-034-04	10	034	Eagle Summit	89	92	04	96.7	u	2198	170	19.5	20.5
109-008-04	09	008	Plymouth Turismo	86	87	03	96.6	u	2170	174.8	29.6	29.6
109-008-04	07	008	Dodge Charger	86	87	03	96.6	u	2328	172.8	29.6	29.6
109-007-04	09	07	Plymouth Caravelle	86	88		103.3	u	2548	185.1	30.1	30.1
109-007-04	07	014	Dodge 600	85	88		103.3	u	2557	185.2	30.1	30.1
109-004-04	09	004	Plymouth Gran Fury	83	89		112.7	u	3470	205.7	35.1	35.1
109-004-04	07	007	Dodge Diplomat	82	89		112.7	u	3493	204.6	35.1	35.1
107-040-04	10	040	Eagle Premier	88	92		106	u	3032	192.8	37	37.1
107-040-04	07	040	Dodge Monaco	90	92		106	u	3060	192.8	37.1	37.1
107-039-05	52	039	Mitsubishi 3000gt	91	96	02	97.2	u	2726	180.5	*	*
107-039-05	07	039	Dodge Stealth	91	96	02	97.2	u	2728	180.5	19.4	24.7
107-034-05	52	035	Mitsubishi Mirage	94	96	03	96.1	u	2193	172.2	*	*
107-034-05	10	034	Eagle Summit	93	96	02	96.1	u	2198	174	20.5	20.5
107-034-05	07	034	Dodge Colt	94	94	02	96.1	u	2195	174	*	*
107-034-04	52	035	Mitsubishi Mirage	85	93	03	93.9	u	2193	172.2	*	*
107-034-04	10	034	Eagle Summit	92	92	03	93.9	u	2198	174	20.5	20.5
107-034-04	07	034	Dodge Colt	86	91		93.4	u	2195	174	*	*
107-020-05	09	020	Plymouth Neon	95	96		104	u	2320	171.8	21.6	21.9
107-020-05	07	020	Dodge Neon	95	96		104	u	2274	171.8	21.6	21.9
107-019-05	09	019	Plymouth Acclaim	89	95		103.3	u	2781	181.2	25.7	25.9
107-019-05	07	019	Dodge Spirit	89	95		103.3	u	2779	181.2	25.7	25.9
107-019-05	07	016	Dodge Lancer	86	89		103.1	u	2654	180.4	25.3	26.8
107-019-05	06	016	Chrysler Lebaron	89	94	04	103.5	u	2922	182.7	25.6	26.8
107-019-05	06	017	Chrysler Lebaron-gts	85	88	05	103.1	u	3083	180.4	26.8	26.8
107-018-04	07	018	Dodge Dynasty	88	93		104.5	u	3046	192	23.9	29.6
107-017-05	09	017	Plymouth Sundance	87	94		97.2	u	2636	171.9	24.2	25.1
107-017-05	07	017	Dodge Shadow	87	94		97.2	u	2659	171.9	24	25.1
107-015-04	07	015	Dodge Daytona	86	93		97	u	2612	175	21.3	34.9
107-015-04	06	015	Chrysler Laser	84	86		97	u	2606	175	25.8	25.8
107-011-04	09	011	Plymouth Reliant(K)	86	89		100.3	u	2458	178.6	29.9	29.9
107-011-04	07	011	Dodge Aries(K)	86	89		100.3	u	2458	178.6	29.9	29.9
107-008-04	09	008	Plymouth Horizon	86	90	05	99.1	u	2105	163.2	36.6	36.6
107-008-04	07	008	Dodge Omni	86	90	05	99.1	u	2100	163.2	36.6	36.6
107-004-05	07	004	Dodge Viper	92	96		96.2	f	3457	175.1	*	*
106-044-05	07	043	Dodge Stratus	95	96		108	u	3043	186	15.5	16.3
106-044-05	06	044	Chrysler Cirrus	95	96		108	u	2911	186	15.4	16.5
106-043-05	07	042	Dodge Avenger	95	96		103.7	u	2832	186.9	17.1	17.1
106-043-05	06	043	Chrysler Sebring	95	96		103.7	u	2867	187.4	17.1	19.8

Family	Make	Model		Model year		Body	WB	Body	Weight	Length	Bumper ht.	
code	code	code		range		style		type			min	max
106-041-05	10	041	Eagle Vision	93	96		113	u	3318	201.6	36.2	36.2
106-041-05	07	041	Dodge Intrepid	93	96		113	u	3350	201.7	23.9	23.9
106-041-05	06	041	Chrysler Concorde	93	96		113	u	3377	202.8	25	25
106-041-05	06	042	Chrysler lhs	94	96		113	u	3483	207.4	27.1	27.1
106-017-05	06	016	Chrysler Lebaron	82	94	-4	100.3	u	3010	184.8	25.3	25.7
106-017-05	06	017	Chrysler Lebaron-gts	89	95	01	100.6	u	3010	184.8	25.3	25.7
106-017-05	06	017	Chrysler Lebaron-gtc	89	95	02	100.6	u	3010	184.8	25.3	25.7
101-009-04	10	398	Eagle Eagle	86	89	06	109.3	u	3502	183.2	41.7	41.8
101-009-04	01	007	AMC Concord	pre-86	pre-86		108	u	2891	185	*	*