INFLUENCES OF VEHICLE SIZE AND MASS AND SELECTED DRIVER FACTORS ON ODDS OF DRIVER FATALITY

Jeya Padmanaban
JP Research
Los Altos, California

ABSTRACT

Research was undertaken to determine vehicle size parameters influencing driver fatality odds, independent of mass, in two-vehicle collisions. Forty vehicle parameters were evaluated for 1,500 vehicle groupings. Logistic regression analyses show driver factors (belt use, age, drinking) collectively contribute more to fatality odds than vehicle factors, and that mass is the most important vehicular parameter influencing fatality odds for all crash configurations. In car crashes, other vehicle parameters with statistical significance had a second order effect compared to mass. In light truck-to-car crashes, "vehicle type-striking vehicle is light truck" was the most important parameter after mass, followed by vehicle height and bumper height, with second order effect. To understand the importance of "vehicle type" variable, further investigation of vehicle "stiffness" and other passenger car/light truck differentiating parameters is warranted.

A two-phase research study was undertaken to determine the relative contribution of vehicle mass and size parameters to driver fatality odds. An exhaustive search for size parameters that might influence fatality odds, independent of mass, in two-vehicle crashes was performed. In Phase 1, the focus was to identify size parameters that influence fatality odds, independent of mass, in fatal crashes. Phase 2 focused on extending the study to identify size parameters influencing fatality odds in all crashes. The analyses were performed for four configurations: front-to-front, front-to-left, front-to-right, and front-to-rear. For each configuration, car-to-car and light truck-to-car crashes were separately analyzed.

The study focused on *struck* driver fatality odds in two-vehicle crashes and excluded rollover crashes. The vehicles included in the analyses were passenger cars and light trucks (including sport utility vehicles, minivans, and pickups) with gross vehicle weight rating less than 10,000 pounds.

BACKGROUND

The primary goals of the two-year project were to use field data to identify and separate the safety effects of size and mass on fatality odds.

During the past 20 years, the relationships between size, mass, and safety have been studied by numerous public and private auto safety research groups, including the Department of Transportation, the Office of Technology Assessment of the United States Congress, the Insurance Institute for Highway Safety, General Motors Research Laboratories, the National Academy of Sciences, and other members of the highway safety research community. All these past studies include one or two size parameters to study the effects of mass versus size on fatality risk.

Evans and Frick (1992) and Evans (2000) explored relationships between mass and size, but used wheelbase as the only size parameter. Evans, however, improved on the earlier report by estimating how adding mass, in the form of a passenger, to a car crashing head-on into another car affects fatality risks to both drivers, thereby distinguishing between the causal roles of mass and size.

NHTSA (1997) focused on exploring relationships between weight and safety by using logistic regression and generalized linear models to establish relationships between weight and other size parameters. The study analyzed weight-safety relationships for several crash modes to estimate the net effect of vehicle weight change on fatality risk. However, this study also examined very few size variables.

Joksch (1998), using NHTSA crash files, attempted to evaluate the fatality rate per driver involved in collisions between two cars and between a car and a light truck for various collision configurations. These studies acknowledge that more sophisticated approaches are warranted to evaluate fatality risk as a function of combinations of several independent variables.

In very recent studies, Evans (2003) addressed the difficulties involved in estimating changes to fatality risk resulting from Corporate Average Fuel Economy (CAFE) standards, and Ross and Wenzel (2002) estimated driver fatality risk by vehicle type and model using Fatality Analysis Reporting System (FARS) calendar year 2000 data for recent model year vehicles (1995-1999). This latter study evaluated the fatality risk to the driver of the vehicle in question and fatality risk to the driver of other vehicles involved in crashes with the vehicle in question. The study acknowledged that separating the contribution of driver characteristics from vehicle design contribution is difficult. The authors updated their study [Ross and Wenzel, 2003] and concluded that some design factors, such as bumper height and stiffness of light trucks and sport utility vehicles (SUVs), could be better predictors of risk than vehicle mass.

Size factors, as distinct from mass, were also discussed in NHTSA testimony before the Senate Committee on Commerce, Science, and Transportation. Speaking on the safety of SUVs, NHTSA Administrator J.W. Runge (2003) addressed the problem of size incompatibility in vehicle-to-vehicle crashes:

> In the fleet of 20 years ago, the primary incompatibility was one of weight. ... However, the arrival of SUVs and increased numbers of pickups has made other incompatibilities important as well — incompatibility in vehicle height and in the alignment of interacting vehicle structures, such as bumpers and chassis frame rails.

All of these studies address the need to examine the relative contribution of size variables, mass, and other nonvehicular factors influencing fatality odds in car-to-car and light truck-to-car crashes. This study does just that. It addresses vehicle crashworthiness and the effect of mass and size on fatality odds, given a crash.

DATA SOURCES

Based on NHTSA's General Estimates System (GES) data files for the years 1990-2000 (including vehicles with model years 1981 and later), an estimated 1.5 million police-reported car-to-car crashes and 1.2 million light truck-to-car crashes occur annually, resulting in approximately 7,500 fatalities. Over 50% of fatalities occurring in these two-vehicle crashes are in front-to-front crashes, 30% are in front-to-left crashes, and 15% are in front-to-right crashes. Consequently, this paper focuses on these three configurations.

FIELD PERFORMANCE DATA. The study was conducted in two phases. In Phase 1, factors influencing fatality odds in severe crashes were examined. In particular, two-vehicle crashes in which *exactly* one driver died were examined using FARS data for the years 1980-1999. Crash data had to include vehicle identification numbers (VINs). VINs were used to identify makes/models and to screen for 1981 and later model vehicles.

The rationale for using crashes in which only one driver died was to isolate the size and mass effects by examining the vehicle attributes for the driver who was killed and the driver who survived in a severe crash. Crashes in which both drivers died were assumed to be extremely severe crashes, providing no information on the influence of vehicle parameters on survivability of drivers and, hence, excluded from the Phase 1 analyses. These extreme crashes accounted for less than 5% of the data.

The findings of the Phase 1 study (i.e., identification of those parameters showing a significant influence on odds of driver fatality in a fatal crash) provided the starting point for Phase 2. In Phase 2, the objective was to identify parameters that influence fatality odds in any crash. Phase 2 used FARS data and state crash file data from Florida (1986-1999), Maryland (1989-1999), and North Carolina (1980-1999). In this phase, nonfatal crashes were included so that the influence of size/mass on fatality odds in *all* two-vehicle, nonrollover crashes could be determined.

VEHICLE PARAMETER DATA

Vehicle Data Sources. Vehicle parameter data for each vehicle included in the study was obtained from various sources including:

- American Automobile Manufacturers' Association (AAMA) specifications (compiled by NHTSA) for major interior and exterior measurements for passenger cars.
- The Gas Truck Index and Import Truck Index for major exterior measurements and some internal dimensions— light trucks only.
- Microsoft's carpoint.msn.com website for major exterior and interior measurements.
- The Environmental Protection Agency (EPA) for interior volume for cars with more than two seats.
- The Canadian Vehicle Specification System (CVS) for major exterior measurements
- The NHTSA New Car Assessment Program (NCAP) Vehicle Test Measurement data for front-end longitudinal distances and frontal impact "average height of force."
- Kelly Blue Book for verifying and filling in wheelbase and curb weight data.

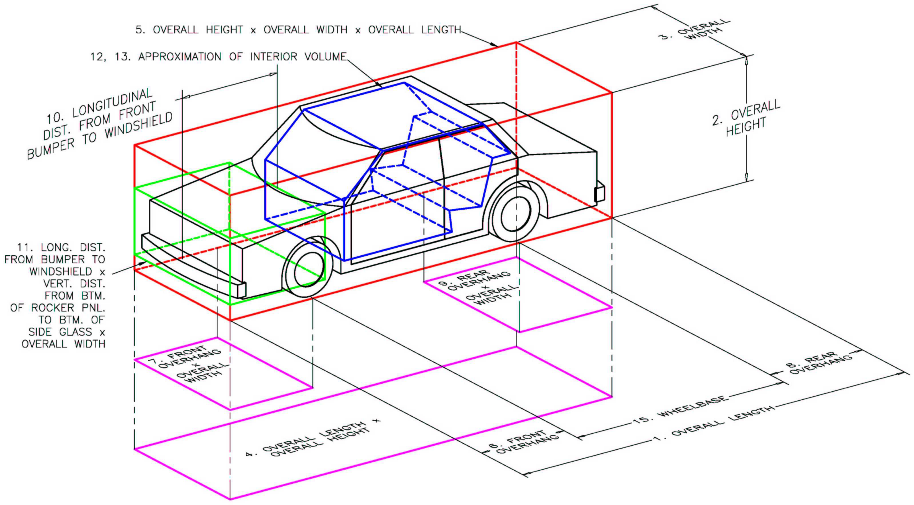
- FARS for wheelbase and curb weight for passenger cars for verifying.
- Bumper height data from a software called “Expert Autostats”, version 4.2W, 4N6XPRT Systems.

Several attempts were made to check for consistency and completeness among various data sources. In addition, USCAR committee representatives for Ford/GM/Chrysler were provided data for their respective vehicles to validate the data used in the study.

Size Metrics. Fifteen initial metrics and combinations (Figure 1) were selected on the basis of extensive review of technical literature and engineering judgment. The parameters, and their reasons for selection, are given below:

1. *Overall length*.
2. *Overall height*.
3. *Overall width* (possibly of special interest for side-impact crashes).
4. *Overall length times overall width* gives a rough measure of size in plan view. Since most of the subject crashes are generally two-dimensional in nature, this rectangle seemed likely to be important in crash performance.

Figure 1. Illustration of Initial Size Metrics



5. *Overall length times overall width times overall height* is a volumetric measure of vehicle size. This seemed an obvious choice to characterize size, even though different body configurations occupy different fractions of this bounding box.
6. *Front overhang* is a measure of crush distance ahead of the front axle, which could be relevant to crash energy absorption in frontal impacts.

7. *Front overhang times overall width* is a measure in plan view of the crushable zone ahead of the front axle.
8. *Rear overhang* is a measure of crush distance behind the rear axle, which seems relevant to crash energy absorption in rear impacts.
9. *Rear overhang times overall width* is a measure in plan view of the crushable zone behind the rear axle.
10. *Longitudinal distance from front of bumper to front of base of windshield* is a measure of the length of the front structure of the vehicle and of the distance from the passenger compartment to the very front of the vehicle. This seemed likely to be particularly relevant to frontal impacts.
11. *Longitudinal distance from front of bumper to front of base of windshield, times vertical distance from bottom of side glass to rocker panel, times overall width* gives a volume related to the total size of the vehicle front end. This seemed important for energy absorption or force transmission in frontal impacts.
12. *EPA interior volume* simply provides a defined measure of vehicle "size." (Not generally provided for two-seat cars or light trucks.)
13. *Passenger space available* is the sum of headroom and legroom times the sum of hip room and shoulder room (a possible surrogate for *EPA volume* for light trucks).
14. *Front weight percent* was included to test the intuitive notion that front-heavy vehicles might fare better in frontal impacts and more poorly in rear impacts, and vice versa.
15. *Wheelbase.*

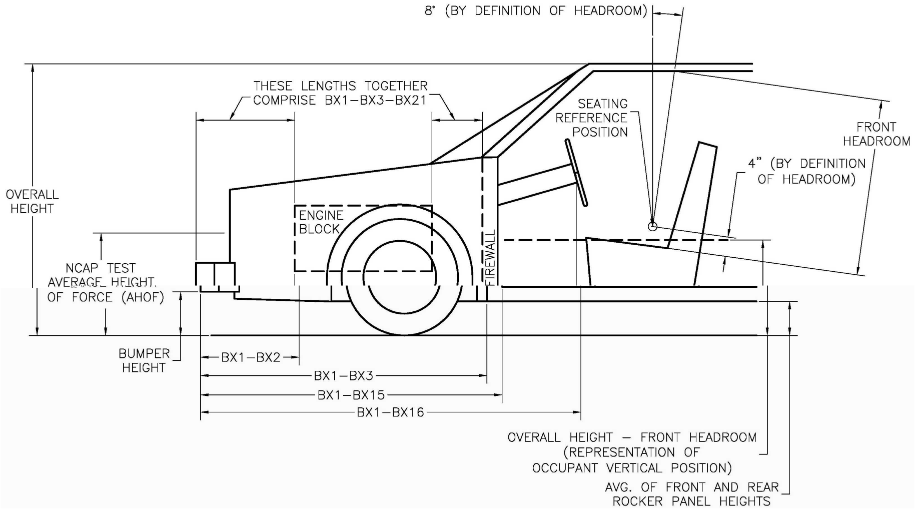
Preliminary analyses used these 15 vehicle parameters. In the course of the project, additional vehicle parameters addressing height compatibility and frontal crush protection that could potentially influence fatality odds in front-to-front and front-to-side impact crashes were included. These were:

1. *Overall height minus Front headroom*.
2. *Average of front and rear rocker panel heights* above the ground.
3. *Average height-of-force results* (NHTSA NCAP barrier crash data).
4. *Front bumper height.*
5. *Rear bumper height.*
6. *Interior width* (average of front hip room and front shoulder room).
7. *Overall width minus Interior width.*
8. *Longitudinal distance from front of vehicle to front of engine* (NCAP BX1-BX2) *times Overall width.*
9. *Longitudinal distance from front of vehicle to firewall underhood* (NCAP BX1-BX3) *times Overall width.*

10. *Longitudinal distance from front of vehicle to left interior of firewall* (NCAP BX1-BX15) *times Overall width.*
11. *Longitudinal distance from front of vehicle to steering column center* (NCAP BX1-BX16) *times Overall width.*
12. *Longitudinal distance from front of vehicle to firewall underhood less length of engine block* (NCAP BX1 – BX3 – BX21) *times Overall width*.

The first five additional metrics were chosen to address height compatibility. The width parameters were added to address side impacts. The last five metrics were chosen to focus on frontal crush/ protection distances. Figure 2 shows most of these parameters.

Figure 2. Illustration of Additional Size Metrics



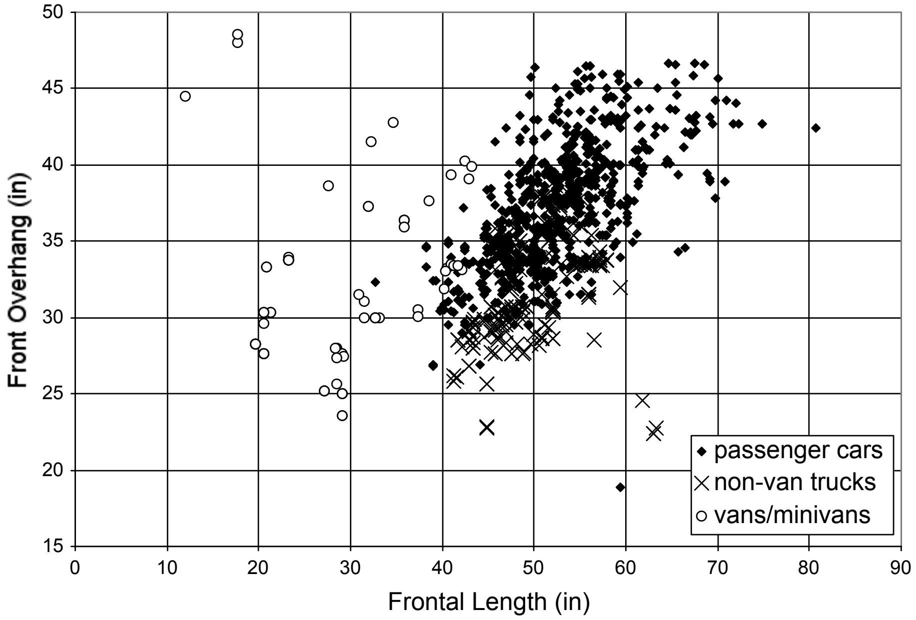
Additional Variables. In addition to vehicle size metrics and mass, driver factors such as belt use, driver drinking, and driver age were included for struck vehicles (to reflect driver vulnerability) and striking vehicles (to represent high-risk drivers). Drinking driver is defined by any police-reported alcohol use or blood alcohol content of at least 0.01%. In Phase 1, these variables were introduced separately for both striking and struck driver. In Phase 2, a high-risk driver variable combining striking driver's belt use/age/drinking was created. The aggressivity index for this variable is derived from three binomial variables (each carrying a value of 0 or 1). Thus, the combination of belted driver / age >26 / not drinking = 0 (low risk), and unbelted driver / age <26 / drinking = 3 (high risk).

METHODOLOGY

The study was performed in two phases that each involved several stages of extensive logistic model building effort in light of engineering interpretation of variables selected by the process. Several logistic models were examined carefully to understand the interactions among size parameters and mass, and the relative contribution of each to odds of fatality. In each phase, logistic models were developed separately for car-to-car and light truck-to-car crashes for four configurations: front-to-front, front-to-left, front-to-right, and front-to-back.

Careful examination of vehicle parameters for the light truck group revealed that, for some size metrics (front overhang/front length), the parameter ranges for vans were distinctly different from those of other light trucks (Figure 3). For this reason, logistic models were developed separately for crashes involving vans and crashes involving pickups and SUVs.

Figure 3. Comparison of Frontal Length and Front Overhang for Cars, Light Trucks, and Vans



PHASE 1 MODELS. The relationships between driver fatality odds and vehicle and driver parameters of striking and struck vehicles were examined using the FARS data set. The striking and struck vehicle's design parameters were entered as ratios (striking vehicle mass / struck vehicle mass) to separate and present the relative importance of striking and struck vehicle design parameters

in the subject crashes. This procedure is consistent with that used in other field studies.

PHASE 2 MODELS. While FARS provides a complete census of national fatalities, there is no data source with sufficient sample size to obtain national estimates of nonfatal drivers involved in crashes. The GES data, maintained by NHTSA is a sample of all police-reported crashes selected from individual state crash files to provide national estimates. However, the sample sizes are small for performing analyses based on individual makes/models. Consequently, to extrapolate the number of nationwide nonfatal crashes, crash data from three states (Florida, North Carolina, and Maryland) was used. Several sensitivity analyses were performed to validate the extrapolation methods used. For the logistic models developed in this phase, striking and struck vehicle parameters were entered separately (instead of as ratios) to determine the relative importance of striking and struck vehicle attributes on driver fatality odds in a crash.

MODELING ODDS OF FATALITY. Odds of fatality is a measure of association which explains how much more likely it is for someone to die in a crash with the presence of a particular factor (old age, for example) compared to the absence of the same factor.

For each configuration, the dependent variable is the logarithm of the odds ratio. For example, if ‘p’ is the probability the struck driver is killed, then:

$$\text{Odds of struck driver fatality} = p/(1-p),$$

and so the dependent variable is:

$$\text{logodds} = \ln(p/(1-p)).$$

The logistic models were developed to predict the odds of fatality for the struck driver only. For example, in front-to-left collisions, the fatality odds are modeled for the left-struck driver only.

Overall model fit parameters, p-value, and standard error for the coefficients of the selected variables were examined carefully to understand the relationship between mass, size, and fatality odds. Automated stepwise algorithms from the SAS statistical analysis program (SAS Institute, 2001) were used to select variables. The results were then examined carefully to select the best statistical models based on statistical and engineering interpretation of findings. The relative contribution of each variable to odds of fatality (a measure derived from SAS standardized estimates) and the relative explanatory power of variables to model fit (a measure derived from contributions of each variable as calculated by the Wald Chi square statistic) were examined to understand the importance of each explanatory variable in the logistic models.

Finally, in a step taken to address collinearity problems (which occur when there is some correlation among the independent variables in a regression model), several combinations of variables were run to examine the interaction between size variables and mass. Model fits, changes in the magnitude of standard errors of mass coefficients, and the estimated correlation matrix were some of the results examined to address the interaction between mass and size metrics. When two variables were correlated, logistic models with one and both variables were run to select better model fits and to evaluate their contamination effect on mass coefficients.

RESULTS

PHASE 1 RESULTS. The study included 18,175 car-to-car fatal crashes and 21,980 light truck-to-car fatal crashes in which only one driver died. The factors influencing *struck* driver fatality odds are discussed in detail in subsequent sections.

Car-to-Car Crashes. Belt use/driver age (struck driver) and mass ratio were important primary variables affecting fatality odds in all crash configurations. The driver factors collectively explain about 60-80% of variation in odds of fatality. Mass ratio contributes about 20% to explaining the variation in odds of fatality in each configuration.

The size parameters had a second order effect on fatality odds compared to car mass in fatal crashes. Table 1 presents the variables that were shown to be significant (Chi-square significance at 0.05 level), along with their relative contribution to fatality odds.

The relative contribution was calculated based on standardized estimates produced by the logistic model. The relative contribution of a variable, k, is:

$$\frac{\text{Standardized Estimate of variable k}}{\Sigma_i\,(\text{Standardized Estimate of variable i})} \times 100$$

The results in tables indicate the relative importance of each variable. For example, Table 1 shows that, in frontals, mass ratio is almost five times as important as front overhang x width ratio in influencing fatality odds.

Table 1. Relative Contribution of Factors to Fatality Odds (%)
Car-to-Car, Fatal Crashes

Variables	Front-Front	Front-Left (fatal driver struck on the left)	Front-Right (fatal driver struck on the right)
Driver Factors			
Belt use	22	23	25
Age	36	48	39
Drinking	5	9	3
Female			7
Total Driver Factors	**63**	**80**	**74**
Vehicle Parameters			
Mass ratio	**19**	**21**	**20**
(Front overhang x width) ratio	**4**		
(Front axle to windshield distance) ratio	**3**		
Wheelbase ratio	**2**		
Bumper height ratio	**1**		
Airbag presence (benefit to struck driver)	**3**		

NOTE: Percentages given in all tables are rounded, when applicable.

Airbags were significant in reducing fatality odds in front-to-front crashes, and front overhang x width, front axle to windshield distance, and bumper height showed up as significant size parameters. However, none of these size parameters were as important as mass in influencing fatality odds in car-to-car crashes.

Light Truck-to-Car Crashes. In light truck-to-car crashes, cases in which the struck vehicle is a car and cases in which the struck vehicle is a light truck were both included. Most of the driver fatalities in these crashes (about 80%) were in cars. A variable called “vehicle type-struck vehicle is car or light truck (striking vehicle is light truck or car)” is included to address the crash compatibility between cars and light trucks. Table 2 presents the light truck-to-car results with the relative contribution of each factor to fatality odds.

For light truck-to-car fatal crashes, the logistic models once again show driver factors (belt use, driver age, drinking) and mass ratio to be the primary variables contributing to driver fatality odds. In addition, “vehicle type-striking vehicle is light truck” contributed significantly to fatality odds.

The “vehicle type” variable was shown to be significant even after controlling for mass, bumper height, and height of cars and light trucks. This result indicates that there are other design parameters, such as “stiffness,” that could contribute to fatality odds in a light truck-to-car crash. Other factors such as rail height/crumple zone that differentiate cars and light trucks might also contribute to fatality odds in a crash involving cars and light trucks. Limited data was available for some of these vehicle parameters. To date, none of the size metrics examined was as important as mass in influencing fatality odds.

Table 2. Relative Contribution of Variables to Fatality Odds (%) Light Truck-to-Car, Fatal Crashes

Variables	Front-Front	Front-Left (fatal driver struck on the left)	Front-Right (fatal driver struck on the right)
Driver Factors			
Belt use	18	28	28
Age	29	32	34
Drinking	4	11	6
Female	2		
Total Driver Factors	**53**	**71**	**68**
Vehicular Parameters			
Mass ratio	**27**	**17**	**22**
Vehicle type	**10**	**9**	**11**
Vehicle height ratio	**5**		
(Front axle to windshield distance) ratio			
Bumper height ratio			
Airbag presence (benefit to struck driver)	**2**		

PHASE 2 RESULTS. The state crash data files used for the study provided a total of 1.1 million crashes for the study period. Of these crashes, 60% involved two cars, 10% involved a car and a van, and 30% involved a car and a light truck that is not a van. Since most (approximately 90%) of the crashes involve car-to-car or light truck-to-car (no vans), the results discussed in detail are for crashes that do not involve vans.

Car-To-Car Crashes. The relative contributions of factors selected by logistic models as being significant are presented in Table 3. The relative contribution of variables to fatality odds (standardized estimates) and relative explanatory power of variables to logistic models (Wald Chi-square) indicate once again that driver factors (belt use, age, drinking, and aggressivity) are important in all configurations. As in Phase 1, mass was the most important vehicle parameter, contributing approximately 20-30% to the variation in fatality odds in car crashes. The collective effect of size parameters on fatality odds in any crash is 8-9%.

Table 3. Relative Contribution of Variables to Fatality Odds (%) Car-to-Car, All Crashes

Variables	Front-Front	Front-Left (fatal driver struck on the left)	Front-Right (fatal driver struck on the right)
Driver Factors			
Belt use	20	16	20
Driver age	18	28	19
Drinking	9	7	9
Striking high-risk driver	15	13	11
Total Driver Factors	**62**	**64**	**59**
Vehicle Parameters			
Mass	**21**	**23**	**29**
Vehicle age	**2**	**4**	**3**
Front axle to windshield distance	**7**	**4**	**5**
Occupant relative vertical position		**4**	**4**
Bumper height	**2**		
Airbag presence (benefit to struck driver)	**5**		

As indicated earlier, the "striking high-risk driver" variable is a combination of belt use/drinking/driver age for the striking driver, representing the driver's "risky behavior."

In both Phases, in front-to-front crashes, the size metrics bumper height and front axle to windshield distance showed up as significant parameters with second order effect compared to mass. Airbags reduced fatality odds in front-to-front crashes.
In Phase 2, an additional size metric, "occupant relative vertical position," showed up as significant for the driver impacted on the left or right.

Light Truck-to-Car Crashes. The results were consistent between the two phases. Table 4 presents the relative contribution of factors to fatality odds. Once again, driver factors (belt use, driver age, drinking) and high-risk striking driver were important factors influencing fatality odds. Of the vehicle parameters examined, "vehicle type-striking vehicle is light truck" was important in influencing fatality odds after mass in all the three configurations. Vehicle height, bumper height, and front axle to windshield were significant in different configurations, with second order effect compared to mass.

Table 4. Relative Contribution of Variables to Fatality Odds (%) Light Truck-to-Car, All Crashes

Variables	Front-Front	Front-Left (fatal driver struck on the left)	Front-Right (fatal driver struck on the right)
Driver Factors			
Belt use	19	14	21
Age	13	19	13
Drinking	8	6	7
Striking high-risk driver	13	9	9
Total Driver Factors	**53**	**48**	**50**
Vehicle Parameters			
Mass	**22**	**20**	**29**
Vehicle age	**2**	**4**	**2**
Vehicle type	**9**	**15**	**15**
Vehicle height (benefit to struck driver)		**8**	
Front axle to windshield distance	**6**		
Bumper height		**1**	**2**
Airbag presence (benefit to struck driver)	**6**		

In all crashes, mass still contributed about 20-30% to variation in fatality odds. "Vehicle type-striking vehicle is light truck" was significant even after controlling for mass and vehicle height. Data on "stiffness," "rail height," and other differences between light trucks and cars needs to be explored further.

The results are consistent with those of the Phase1 study on fatal crashes**.** Of all the vehicle parameters studied, mass was the most important factor influencing fatality odds.

DISCUSSION

USE OF STATE CRASH FILES. For this study, the state crash files provided more than 1.5 million records of nonfatal drivers in two-vehicle crashes. These files have been typically relied upon by NHTSA and other auto safety researchers to perform rollover analyses and investigations of relative risk of subject and peer vehicles to support NHTSA's defect investigation programs, crashworthiness analyses, and safety standards effectiveness assessments.

This study included a few selected driver factors (belt use, drinking, driver age, gender) based on published technical literature addressing the importance of these factors. Other factors such as road type/weather are not coded with consistent definitions among various states and hence could not be included in the study.

Over-Reporting of Belt Use in State Crash Files. The state crash files, which rely largely on self-report to determine whether belts were in use, suffer from over-reporting of belt use for uninjured occupants. Data obtained from observational studies by state, sponsored by NHTSA (2000), was examined to address the nature of over reporting of belt use in state files. The state police-reported belt use was higher for nonfatal occupants, compared to observational surveys. However, there were no inherent biases in favor of or against specific makes/models in terms of belt use. A correction factor based on survey data was used to account for effects of belt use over-reporting, and the results of subsequent analyses were compared with logistic models developed using state-reported belt use. Both these analyses rendered the same conclusions in terms of relative importance of factors influencing fatality odds.

Reporting of Alcohol Involvement in State Crash Files. As with belt use, alcohol involvement tends to be better reported for fatalities than for surviving drivers. Again, however, no biases have been observed that would affect the use of this driver factor for the purposes of determining effects of vehicle size and mass.

Missing Data in State Crash Files. Only the states which have more complete, reliable data on alcohol and VINs were included in the study. These states have 5-10% missing data on alcohol reporting. Sensitivity analyses were performed by developing logistic models for each state individually and the results were compared. The logistic models remained robust.

Use of State Crash Files Instead of GES Data. Another data source, GES, is maintained by NHTSA and is a collection of police-reported crash data obtained from individual states. GES obtains its data from a nationally representative sample (approximately 45,000 crashes) selected from 6 million police-reported crashes which occur annually. However, the use of GES data is limited and cannot be relied upon to compare injury experience of specific makes/models of cars and light trucks. In addition, GES data contains the same strengths and weaknesses of each individual state crash file (by virtue of the fact it is derived from police reports) and it does not provide any additional benefit to this study. To date, the NHTSA studies addressing vehicle compatibility issues have typically used state crash files to address the relative importance of factors influencing fatality risk.

AREAS FOR FURTHER INVESTIGATION. In addition to bumper height and overall vehicle height, the influence of average height of force (ahof, derived from NHTSA's NCAP results) was investigated for car-to-car crashes. Logistic models were developed including ahof in each configuration. The data sets were reduced by half due to the limited availability of ahof data for the vehicles included in the study. Still, preliminary analyses indicate that a striking vehicle's ahof is at least as important as bumper height for crashes involving cars (no light trucks). However, car mass is still much more important than ahof. For the crashes involving light trucks, ahof was available for only 40% of the data. More data on ahof for light trucks is needed to understand the relative influence of ahof.

The distance between front axle and windshield shows up to be a statistically significant size parameter in different configurations in Phases 1 and 2. Since it is not consistently showing up for the same configurations between Phases 1 and 2, and it has a much smaller, second order, effect compared to vehicle mass in influencing fatality odds, further research is warranted to understand the physical significance (if any) of this metric.

In light truck-to-car crashes, the variable "vehicle type-striking vehicle is light truck" (struck vehicle is car) shows up strongly even after controlling for mass, bumper height, and vehicle height. Several combinations of mass, vehicle height, and "vehicle type" were run to understand the interaction among these three variables. Careful examination of model fits and standard errors showed that the combination of mass and "vehicle type" was the best statistical model for front-to-front crashes, and the combination of "vehicle type," mass, and vehicle height was the best statistical model for front-to-left crashes. The noted effect of "vehicle type" could mean that there are parameters — such as frame rail height, chassis construction, and/or "stiffness" of light trucks (as hypothesized by Nusholtz, *et al.*, 2003) — that have an influence (in addition to those of mass, bumper height, and vehicle height) on the odds of fatality. In front-to-left crashes involving a car and a light truck, "vehicle type" might, for example, represent the difference between body-on-frame (85% of light trucks) and unitized body (88% of cars) construction. Once again, additional data on ahof, frame rails, and/or "stiffness" would provide a better understanding of differentiated effects between cars and light trucks.

CONCLUSIONS. Research was undertaken to examine the effect of mass and size parameters on fatality odds in fatal and all crashes. An exhaustive search for size parameters was made, and data on any available vehicle parameter was collected. Logistic regression analyses show that anything that contributes significantly to "equalizing" the masses of the passenger vehicle fleet, such as a reduction in the weight of light trucks to bring them closer in weight to cars, will enhance safety. The following additional conclusions were reached for struck-driver fatality odds in two-vehicle crashes:

- Driver factors (belt use, driver age, drinking) and vehicle mass are the dominant variables influencing driver fatality odds. Of all vehicle parameters, mass is the most important factor influencing odds of driver fatality.
- In car-to-car fatal crashes, none of the vehicle size parameters selected by logistic models as statistically significant contribute as strongly to driver fatality odds as does vehicle mass. In front-to-front crashes, front overhang x width, front axle to windshield distance, wheelbase, and bumper height are significant but have a second order effect compared to mass. In side-impact fatal crashes, mass was the only vehicle parameter that was significant.
- In car-to-car all crashes, similar conclusions were reached about the contribution of driver factors, size, and vehicle mass. Again, the size metrics that showed up in front-to-front crashes (front axle to windshield distance and bumper height) and side-impact crashes (driver relative vertical position) as significant had a second order effect on driver fatality odds compared to mass.
- In light truck-to-car crashes, "vehicle type-striking vehicle is light truck" (struck vehicle is car) was important, after mass, in all crash types. In left side-impact crashes, vehicle height, bumper height, and "vehicle type" are significant.
- In addition to mass, vehicle height, and bumper height, "vehicle type" seems to influence fatality odds in light truck-to-car crashes. Data on "stiffness," frame rails, and other frontal crush properties of light trucks and cars needs to be examined to understand the relative contributions of these factors to fatality odds in crashes involving cars and light trucks.
- Preliminary analyses with the limited data available on NHTSA's NCAP measurement, ahof, seem to indicate that, for car-to-car crashes, ahof is at least as important as bumper height, and that both these factors have a second order effect on driver fatality odds compared to mass.
- Bumper height, when it showed up as significant, proved to have a second order effect on fatality odds.

ACKNOWLEDGEMENTS

The author thanks the United States Council for Automotive Research (USCAR) — an umbrella organization for Ford Motor Company, General Motors Corporation, and DaimlerChrysler Corporation — for funding this project.

REFERENCES

Evans, L. “Causal Influence of Car Mass and Size on Driver Fatality Risk.” *American Journal of Public Health,* Vol. 91, 1076-81; July 2001.

Evans, L. “CAFE — Why It Is So Difficult to Estimate Its Effect on Traffic Fatalities and Fuel Use.” *TRB 2003 Annual Meeting*, Washington, D.C.; January 15, 2003.

Evans, L. and Frick, M. “Car Size or Car Mass: Which Has Greater Influence on Fatality Risk?” *American Journal of Public Health*, Vol. 82, No. 8; August 1992.

Joksch, H. “Fatality Risks in Collisions Between Cars and Light Trucks.” UMTRI, DOT HS 808 802; October 1998.

National Highway Traffic Safety Administration. “Relationship of Vehicle Weight to Fatality and Injury Risk in Model Year 1985-93 Passenger Cars and Light Trucks.” NHTSA Summary Report Number DOT HS 808 569; April 1997.

National Highway Traffic Safety Administration. “NOPUS [National Occupant Protection Use] Survey,” 2000.

Nusholtz, G., *et al.*. “Estimation of the Effects of Vehicle Size and Mass on Crash-Injury Outcome through Parameterized Probability Manifolds.” SAE conference; March 2003.

Ross, M. and Wenzel, T. “Analysis of Traffic Deaths by Vehicle Type and Model.” Report No. LBNL-49675 (T021), US DOE; March 2002.

Ross, M. and Wenzel, T. “Are SUVs Safer Than Cars? An Analysis of Risk by Vehicle Type and Model.” *TRB 82nd Annual Meeting,* Washington, DC; January 15, 2003.

Runge, J.W. “The Honorable Jeffrey W. Runge, M.D., Administrator, NHTSA, Before the Committee on Commerce, Science, and Transportation, United States Senate.” Statement for House Hearing on SUV Safety, US Senate; February 26, 2003.

SAS Institute. “SAS System for Windows.” Release 8.02, TS Level 02MO, SAS Institute Inc., Cary, NC; 2001.