PROBLEMS WITH COMPARING VEHICLE COMPATIBILITY ISSUES IN US AND UK FLEETS

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ABSTRACT

Shifting vehicle feet composition in the United States and United Kingdom, and concerns relating to vehicle compatibility and occupant safety, prompted investigation of the respective mixes of passenger cars and light trucks in two-vehicle collision. Differences between striking and struck vehicle mass for frontal and front-to-driver's side car-to-car and light truck-to-car crashes on US and UK roads are examined, as is US data on relative importance of mass and vehicle size parameters that address geometric compatibility in influencing fatality odds. Findings suggest that significant disparities between vehicle fleets in the two countries warrant further study before direct comparisons between safety experiences are made.

KEY WORDS: compatibility, frontal impacts, side impacts, size, mass

DURING THE PAST 20 YEARS, the relationships between size, mass, and safety have been studied by numerous public and private auto safety research groups in the United States (US) and Europe, 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, Birmingham Automotive Safety Centre (University of Birmingham), the National Academy of Sciences, and other members of the highway safety research community. Some of these studies have suggested altering US vehicle design based on European experience. However, *none* of these studies has explicitly investigated the mass variation in vehicle fleets between the US and the United Kingdom (UK) or provided a comprehensive analysis of the relative influence of size factors such as bumper height, "stiffness", and vehicle mass on fatality odds. At a time when solutions to US safety issues are being examined in light of European road experience, a detailed study of just how transferable this experience is becomes particularly relevant.

In 2001, JP Research, Inc. undertook a two-year, two-phase Size/Mass Effects Study for FreedomCAR, a cooperative effort of the United States Council for Automotive Research (USCAR — an umbrella organization for Ford Motor Company, General Motors Corporation, and DaimlerChrysler Corporation) and the US government. The primary goal of the project was to evaluate and separate the safety effects of size and mass using US field data (Padmanaban, 2003). In 2003, a third phase was outlined for the Size/Mass Effects Study, with the objective of using US field data for an in-depth assessment of the influence of frontal geometric parameters on struck driver's fatality odds. Since then, new studies have emerged, purporting to evaluate vehicle compatibility issues and rendering conclusions on the contribution of "mismatch" of front-end structures between cars and light trucks to increased risks in front-to-front and front-to-left crashes (O'Neill and Kendall, 2004). Studies in the past few years also addressed the results of the US federal New Car Assessment

Program (NCAP) frontal crash tests and the stiffness of heavier cars (Nolan and Lund, 2001; Verma et al, 2003) in terms of increased injury risk to occupants of struck vehicles. Due to differences between European and US vehicles in terms of "vehicle stiffness" and other front structure parameters, this new research parked interest in comparing injury experience and vehicle mix in US and UK crashes to gain valuable insight into the natures of both.

The study reported in this paper does just that. The study had two objectives: 1) to compare the differences in vehicle mix for car-to-car and light truck-to-car crashes on US roads and on UK roads, and 2) to assess the influence of frontal geometric parameters on fatality odds, compared to vehicle mass in two-vehicle US crashes. As part of this study, variations in mass of striking and struck vehicles were examined for frontal and front-to-left (US) and front-to-right (UK) crash configurations. The results obtained using US field data were compared to the results obtained using UK field data. Statistical analyses were then performed using US field data to identify the relative effects of size parameters and vehicle mass in influencing struck driver fatality odds.

METHODOLOGY

First, comprehensive analysis of US and UK crash data was performed to determine differences in the vehicle mix of cars and light trucks (US data on "light trucks" includes sport utility vehicles, minivans, and pickups; UK data includes sport utility vehicles only) involved in crashes in these countries. Second, US crash data was used to examine the relative importance of mass and size parameters influencing fatality odds.

DATA SOURCES. Real-world accident data obtained from the Co-operative Crash Injury Study (CCIS) database in the UK (1992-2002) and the National Automotive Sampling System (NASS) in the US (1988-2002) were used to perform the first part of this study. The CCIS database is maintained by the Transport Research Laboratory and is sponsored by a consortium of Motor Vehicle Manufacturers and the UK Department for Transport (DfT). The database includes only passenger cars that were less than 7 years old at the time of the crash and were towed away to a garage or a vehicle dismantler. The CCIS applies a stratified sampling criterion to select crashes for further investigation. Approximately 80% of serious and fatal and about 10-15% slight injury crashes (according to the UK Government's classification) are investigated. The resulting sample is biased towards more serious injuries. Some 1,500 crashes are investigated annually.

The NASS database, which is maintained by the National Highway Traffic Safety Administration (NHTSA), is a nation-wide representative sample of tow-away crashes investigated in detail by NASS teams consisting of engineers, biomechanical experts, medical personnel, and statisticians. NASS is widely used by NHTSA to examine injury mechanisms, nature of injuries by body region, and other occupant/vehicle and crash related factors. The NASS Crashworthiness Data System (CDS), used for the first part of this study, investigates about 5,000 crashes a year involving passenger cars, light trucks, vans, and utility vehicles. Both the NASS and CCIS data files contain similar types of information on crash type, injury severity, and other pertinent occupant/vehicle factors, which facilitated a direct comparison of US and UK field experience.

The second part of the study was performed using fatal accident data from the US Fatality Analysis Reporting System (FARS) and crash file data from the states of Florida, Maryland, and North Carolina. The FARS database, which was established in 1975, includes all vehicle crashes within the 50 states, the District of Columbia, and Puerto Rico that result in death within 30 days of the crash. The state crash files contain data on both fatal and nonfatal crashes; nonfatal crashes were included in the study so that the influence of size/mass on fatality odds in *all* two-vehicle, nonrollover crashes could be determined.

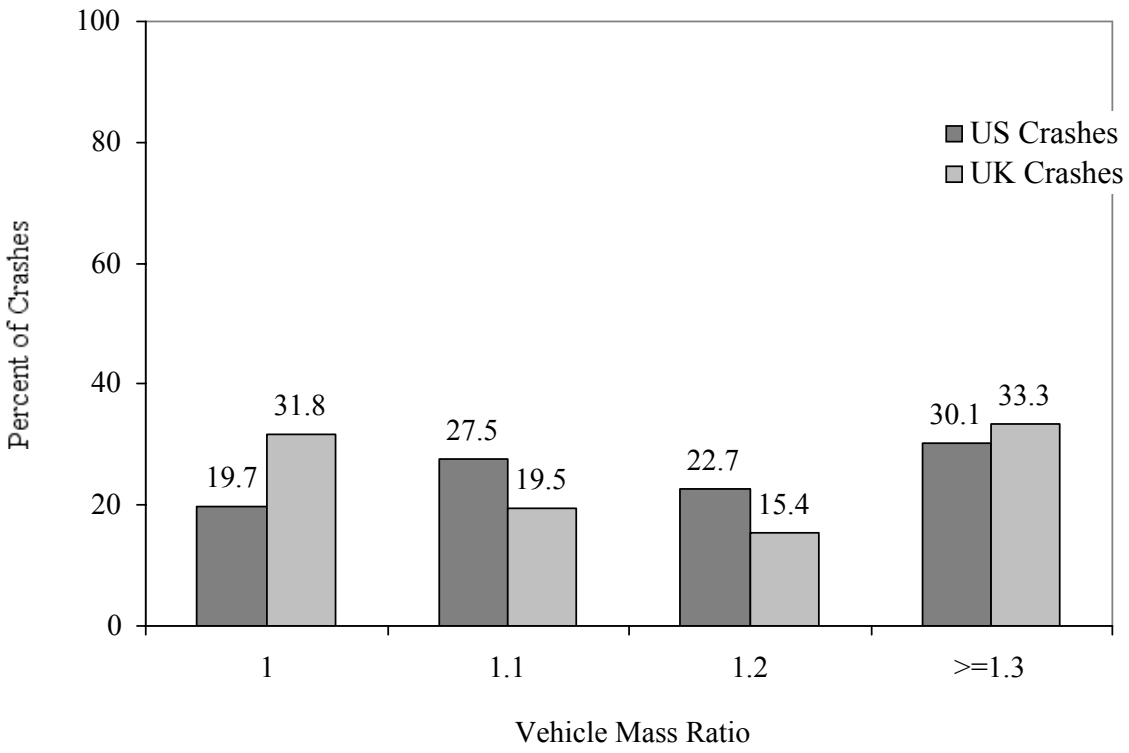
RESULTS

COMPARISON OF VEHICLE MIX IN US AND UK CRASHES. For the years 1988-2002, the US and UK studies focused on two-vehicle crashes involving 1990 or later model year vehicles in car-to-car and light truck-to-car crashes (note that this phrase refers both to the case of a light truck striking a car and that of a car striking a light truck). Analyses were performed for frontal and front-to-driver's side (*left* in US; *right* in UK) crash configurations. The US study included about 1,100 crashes with 326 frontal car-to-car, 284 frontal light truck-to-car, 290 front-to-left car-to-car, and 200 front-to-left light truck-to-car crashes. The UK study included about 1,000 crashes with 820 frontal

car-to-car, 42 frontal sport utility vehicle-to-car, 145 front-to-right car-to-car, and 12 front-to-right sport utility vehicle-to-car crashes.

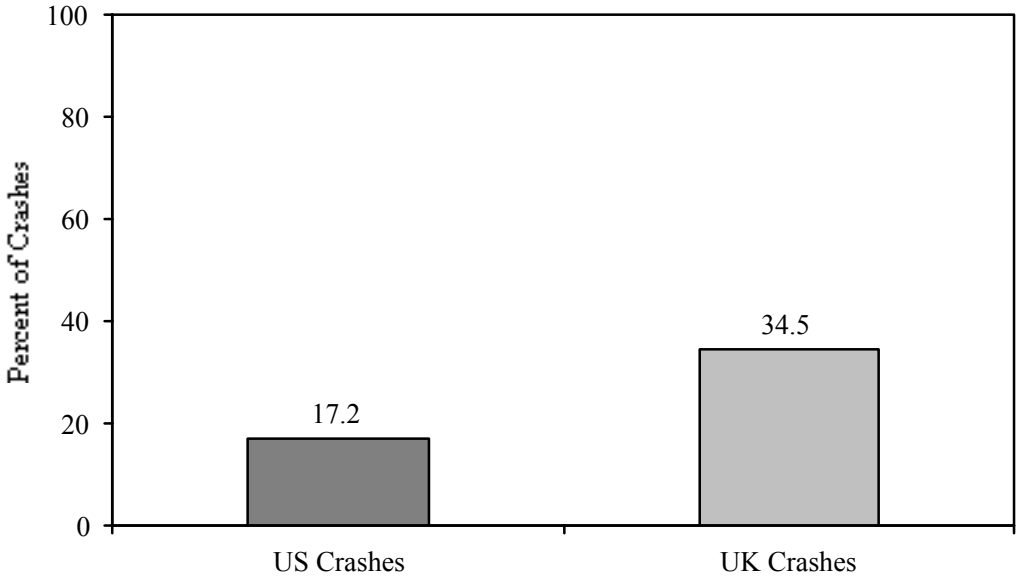
Car-to-Car Crashes. In two-vehicle crashes, vehicle mass ratio was computed as a ratio of striking vehicle mass/ struck vehicle mass. Figure 1 presents comparisons of select vehicle mass ratios for car-to-car frontal crashes in the US and UK. The crashes are grouped into four vehicle mass ratio categories: 1.0 (striking vehicle mass = struck vehicle mass); 1.1 (striking vehicle mass is 10% more than struck vehicle mass); 1.2 (striking vehicle mass is 20% more than struck vehicle mass); and >1.3 (the difference between striking and struck vehicle mass is 30% or greater). In the US, only 20% of car-to-car crashes have a mass ratio of 1.0 (roughly equal mass in striking and struck vehicles); in the UK, the corresponding percentage is 32%. Higher percentages of US crashes were seen for mass ratios of 1.1 and 1.2, indicating that there is a wider mass variation for US crashes compared to UK crashes.

Figure 1. Percent of US and UK Crashes by Vehicle Mass Ratio
Car to Car, Front to Front



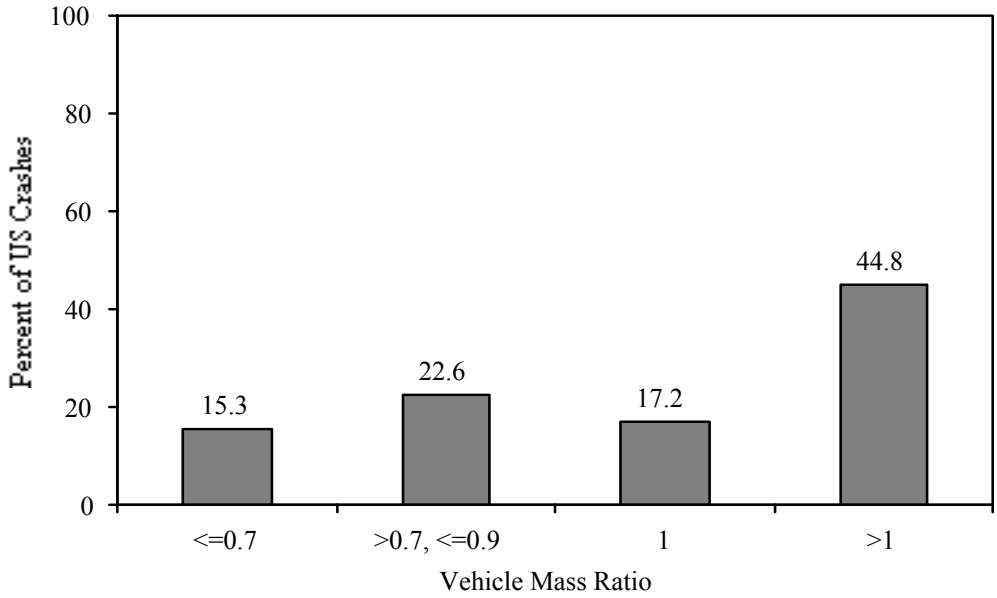
There was insufficient data from the UK files on front-to-right car-to-car crashes for mass ratio greater than 1.0 (>1). Consequently, Figure 2 presents the percent of US and UK crashes with vehicle mass ratio equal to 1.0 for front-to-driver's side crashes. In the US, 17% of front-to-left crashes have a mass ratio of 1.0, while in the UK, 35% of front-to-right crashes have a mass ratio of 1.0. This result is consistent with frontal car crashes, showing a greater mass variation in the US for car-to-car front-to-driver's side crashes, compared to the UK.

Figure 2. Percent of UK and US Crashes Where Vehicle Mass Ratio = 1
Car to Car, Front to-Left (US) / -Right (UK)



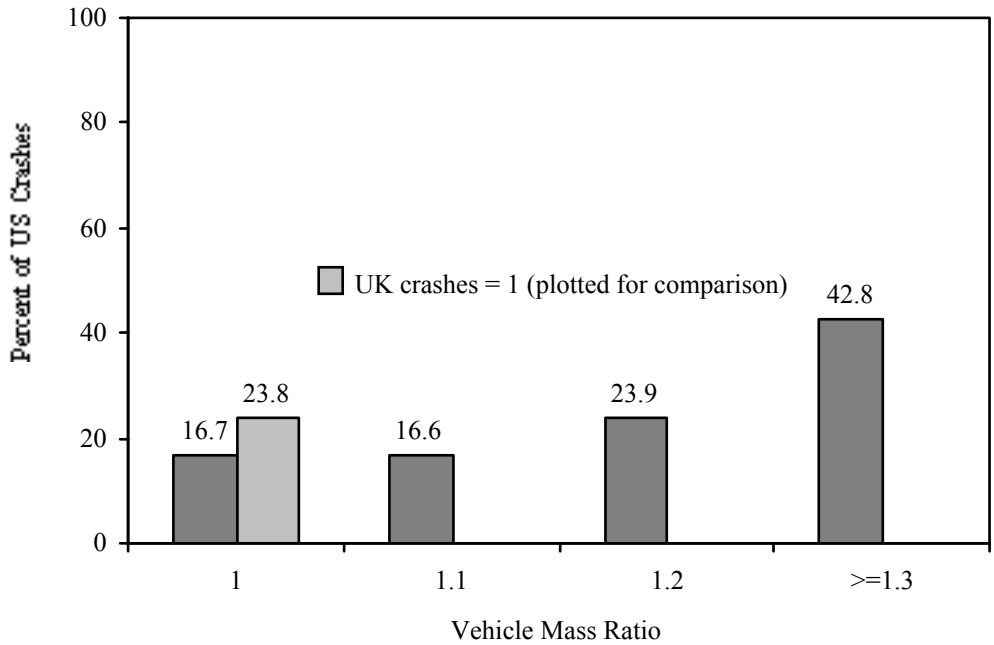
There was enough data in the US files to allow examination of front-to-left crashes by vehicle mass ratio. Figure 2A presents the mass ratio distribution for US car-to-car, front-to-left crashes. The data clearly indicates that in the US there is a wide mass variation even among car-to-car front–to-left crashes.

Fig 2A: Percent of US Crashes by Vehicle Mass Ratio
Car to Car, Front to Left



Light Truck-to-Car Crashes. As Figure 3 shows, only 17% of light truck-to-car front-to-front crashes in the US have a mass ratio of 1.0; in the UK, the corresponding percentage (as seen in Figure 3) is 24%. In the US, about 43% of light truck-to-car crashes have a mass ratio of 1.3 or greater. Due to limited data on sport utility vehicles, meaningful comparisons could not be made for higher mass ratios for light truck-to-car UK crashes.

Figure 3. Percent of US Crashes by Vehicle Mass Ratio
Light Truck-to-Car, Front to Front



Once again, a greater variation in mass ratio is seen in US light truck-to-car crashes compared to those in the UK. In general, there were fewer light truck-to-car crashes in the UK CCIS file than in the NASS file. The low incidence of light truck-to-car crashes in the CCIS database reflects the distribution of vehicle body types in the general vehicle population mix in the UK. In the US, currently, 40% of the total vehicle population is light trucks, and this percentage is increasing annually. In the UK, the population of sport utility vehicles is still very small, which in part explains the large differences in crash configurations between the UK and US.

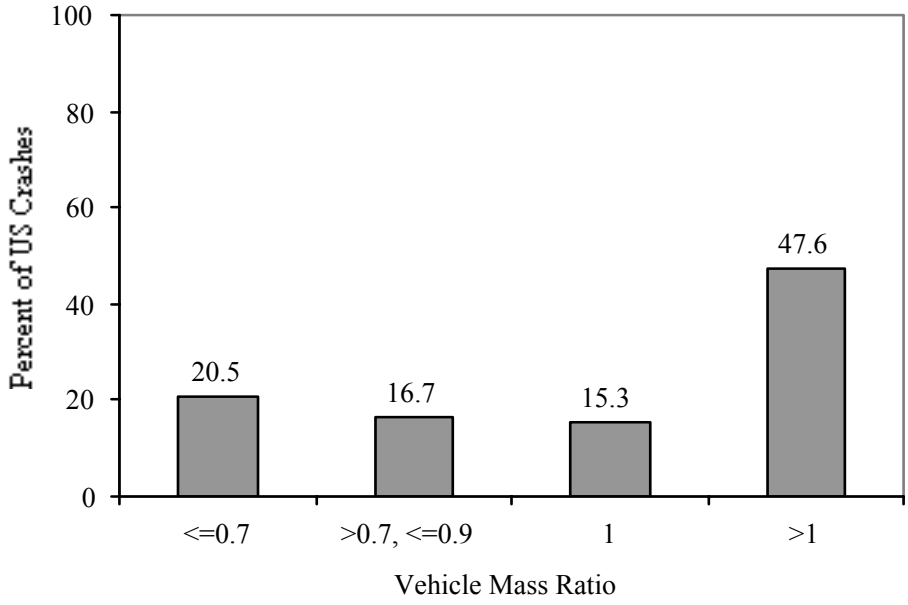
Of all truck-to-car configurations, front-to-front and front-to-left crashes are the predominant ones in terms of frequency and injury severity. Hence, data on differing mass ratios for front-to-left truck-to-car crashes were examined in detail, as seen in Figure 4.

Figure 4 presents the mass ratio distribution for US front-to-left light truck-to-car crashes. The data for front-to-driver's side light truck-to-car crashes shows significant variance in vehicle mass ratios, especially in the US crash data. Only 15% of these crashes have a mass ratio of 1.0 and about 48% of these crashes have a mass ratio >1.0.

The mass variance seen in the US plays an important role in injury outcome for struck drivers in two-vehicle crashes. A detailed discussion of injury risk to US drivers by vehicle mass ratio is presented in subsequent sections.

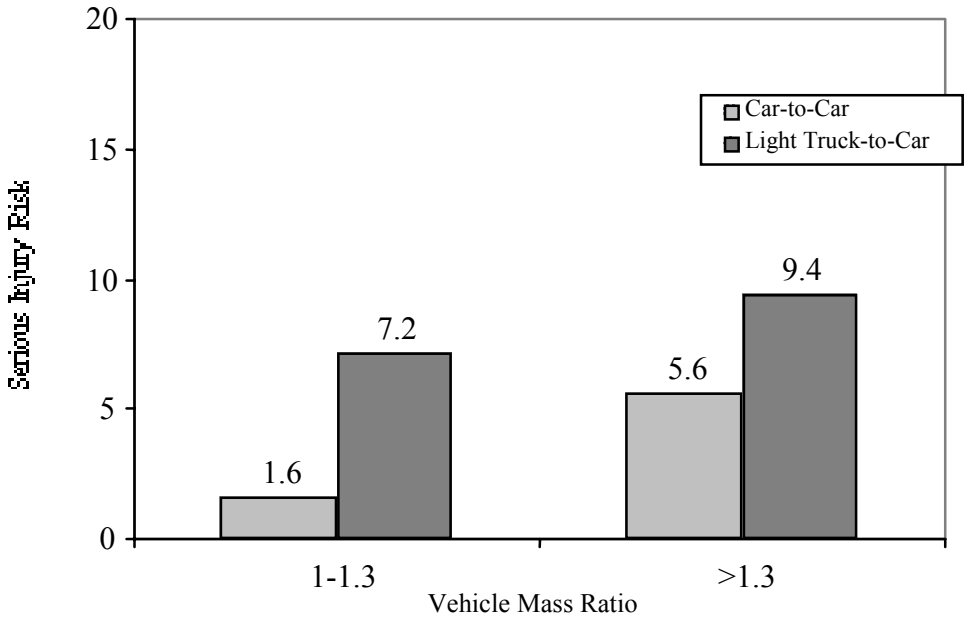
INJURY RISK BY VEHICLE MASS RATIO. Analyses were done to compare injury risk to drivers in US crashes with varying vehicle mass ratios. Specifically, injury risk to occupants in car-to-car and

Figure 4. Percent of US Crashes by Vehicle Mass Ratio
Light Truck-to-Car, Front to Left



light truck-to-car crashes were compared to evaluate the significance of mass ratios. There was sufficient data available to compare injury risk for the US crashes involving light trucks and cars. Comparable data was *not* readily available to the authors for the UK crashes.

Figure 5. Serious Injury Risk to US Drivers by Vehicle Mass Ratio
Front-to-Front Crashes

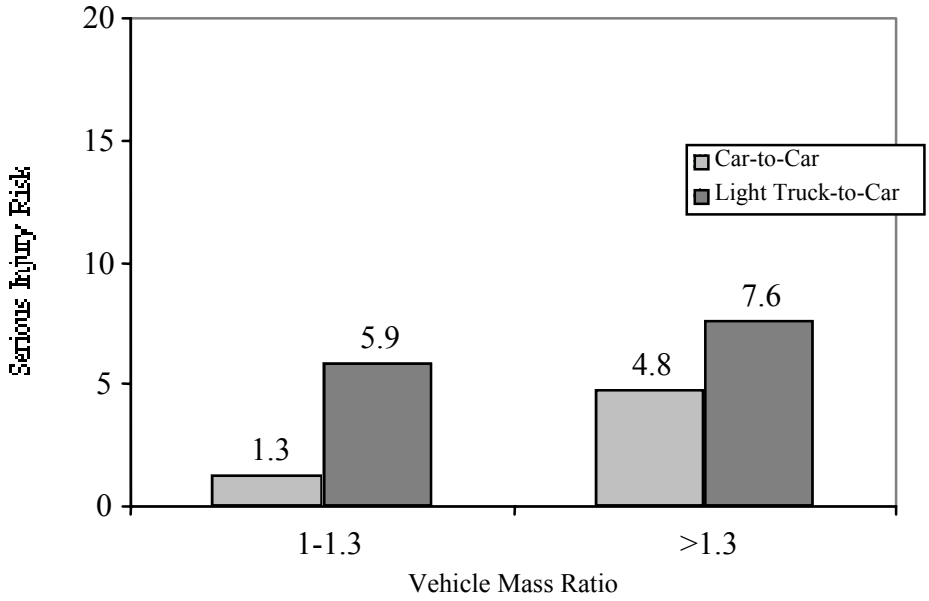


This part of the study focused on front-to-front crashes only, due to the focus of NHTSA NCAP standards and front structure studies on frontal crashes. Figure 5 presents the serious injury risk

MAIS 3 or greater[1]) to US drivers in front-to-front crashes. For both car-to-car and light truck-to-car crashes, the injury risk increases significantly when the mass ratio increases. In addition, the serious injury risk to drivers is much higher in light truck-to-car crashes compared to car-to-car crashes for the same mass ratio group.

Figure 6 presents the serious injury risk for *belted* drivers, which shows a similar trend. While the belted drivers have lower risk of serious injury compared to all drivers, the risk is higher when there is a wider variation between striking and struck vehicle mass.

Figure 6. Serious Injury Risk to *Belted* US Drivers by Vehicle Mass Ratio
Front-to-Front Crashes



VEHICLE COMPATIBILITY RESEARCH

The findings in the first part of this study indicate the importance of addressing vehicle compatibility issues in two-vehicle crashes in the US. An update of the 2003 FreedomCAR Size/Mass Effects Study, reported in a AAAM paper (Padmanaban, 2003), was performed to collect additional vehicle parameter data for the all vehicle groups included in the previous study in order to address vehicle compatibility issues in car-to-car and light truck-to-car crashes. The final models presented in the 2003 study were selected as a starting point for the current study. Statistical analyses were done to examine the relative effect of vehicle size and mass parameters on struck driver fatality odds[2] in two-vehicle crashes. In each crash, mass ratio was calculated as the ratio of striking vehicle mass to the struck vehicle mass. Logistic regression was performed to examine the relative contribution of various vehicle parameters and driver factors to the struck vehicle driver's odds of fatality. The analyses used over 20 years of FARS (1980-2001) and 11 to 20 years of state (Florida, 1986-2001; Maryland, 1989-2000; and North Carolina (1980-1999) data. The analyses were based on over 50,000 fatal crashes from FARS and 1.8 million non-fatal crashes for the three states.

The 2003 JP Research study concluded that, in two vehicle crashes, the driver age, driver belt use, and "driver drinking status" for the struck vehicle were highly significant in influencing the fatality odds. In addition, the driver age and belt use for striking vehicle (representing striking vehicle driver aggressivity) were significant.

[1] The AIS (Abbreviated Injury Scale) was developed by the American Medical Association and the Association for the Advancement of Automotive Medicine to measure threat to life in an accident. MAIS refers to the *most severe* injury sustained in a crash. The scale ranges from 0 for no injury to 6 for maximum/untreatable.
[2] The struck vehicle was defined as the vehicle with fatality.

The original study examined over 40 vehicle parameters for all the vehicles included and found "vehicle mass ratio" and a vehicle parameter for the distance between Front Axle and Windshield (FAW) to be significant in influencing driver fatality odds. Consequently, the logistic models for the current study included all these driver and vehicle parameters that were significant in influencing fatality odds. To address frontal compatibility, bumper height, overall vehicle height, and "vehicle stiffness" were included as additional variables in the current study.

DATA SOURCES. Data on bumper height, which was collected for over 97% of the vehicles included in the study, was obtained from Expert Autostats. Autostats uses data provided by manufacturers brochures, supplemented as needed by its own measurements of undamaged vehicles. Bumper height measures are made from the ground to the top of the front bumper, and data is rounded to the nearest inch. In cases of a curved bumper, the foremost point (first contact point with a vertical surface) on the front bumper is used. For a variable height bumper (as is used on the front end on most current sport utility vehicles), the height of bumper that covers the most width is chosen.

Vehicle stiffness data was obtained from NHTSA. Stiffness values used by NHTSA are derived by analysis of the force-deflection curves from frontal barrier impact tests. NHTSA's stiffness value is the slope of the longest straight line (with a minimum length of 75mm) that begins within the first 200mm of crush that fits the data with an R-squared value greater than 0.95.

LOGISTIC MODEL VARIABLES. The variables included in this expanded analysis were:

- Log ((striking vehicle mass)/(struck vehicle mass))
- Bumperhtdiff = (striking-struck vehicle bumper height)
- Airbag presence for struck vehicle
- Struck driver belt use
- Struck driver age = $(\text{driver age})^{1.5}$
- Struck driver drinking
- Strikdriverbeltage: Introduced to reflect striking driver aggressivity, this variable was derived based on driver age and belt use for the striking driver.
  - Equals 0 if the driver age >25 and belted
  - Equals 2 if the driver age <=25 and unbelted
  - Equals 1 if the driver age >25 and unbelted
  - Equals 1 if the driver age <=25 and belted
- Striking vehicle FAW
- Struck vehicle FAW
- Struck vehicle log stiffness
- Striking vehicle log stiffness
- Struck vehicle age.

The results showed that, of all the vehicle parameters examined, vehicle mass ratio was the most important vehicle parameter influencing struck driver's fatality odds in car-to-car and light truck-to-car crashes. Other vehicle parameters, such as stiffness or bumper height, had a second order effect in influencing fatality odds of struck driver. In light truck-to-car front-to-left crashes, vehicle overall height was significant after vehicle mass ratio. In addition, the product term stiffness x bumper height was used for light truck-to-car front-to-left crashes. This product term provided a better logistic model fit than including these vehicle parameters separately.

The logistic models were run using standard statistical analysis software (SAS) packages. A rigorous analysis was performed to select variables that were statistically significant at p-value of 0.01. Several iterations of the logistic models were run to examine the interaction among variables, and the final logistic models were chosen based on examination of overall model fit, standard errors of coefficients and correlation among variables, and statistical significance of variables included in the study. Sensitivity analyses were performed to test the stability of logistic models and validity and consistency of final results. The goodness of fit and other statistical criteria (checking interaction among factors, inclusion/exclusion of factors, different forms of variables) used to assess the logistic models showed consistent results.

COMPATIBILITY RESULTS. Figures 7 through 10 show the relative contribution of key variables to the odds of struck driver fatality for car-to-car and light truck-to-car crashes with a

stepwise entry level value of p = 0.01. The relative contribution is calculated based on the standardized estimates of coefficients associated with each variable included in the logistic model.

Analyses of mass and size parameter effects reveals that, for car-to-car and light truck-to-car crashes, mass ratio is still the most important vehicle parameter influencing fatality odds of a driver. In light truck-to-car crashes, vehicle stiffness and bumper height seem to have a significant, second order effect in influencing fatality odds, and vehicle mass ratio seems to be the most important vehicle parameter influencing fatality odds. In these crashes, the struck vehicle being stiffer reduces fatality odds for that driver; and the striking vehicle being stiffer increases the odds fatality for the struck driver. In front-to-left (driver-side) light truck-to-car crashes, vehicle mass ratio and vehicle height have similar effect, while the product term (bumper height and stiffness) has a significant, yet second order effect.

All the analyses performed showed the importance of vehicle mass ratio over any other size parameters in influencing fatality odds for struck drivers in two-vehicle crashes.

Figure 7. Relative Contribution of Variables to Odds of Fatality
Car-to-Car, Front-to-Front Crashes (p = 0.01)

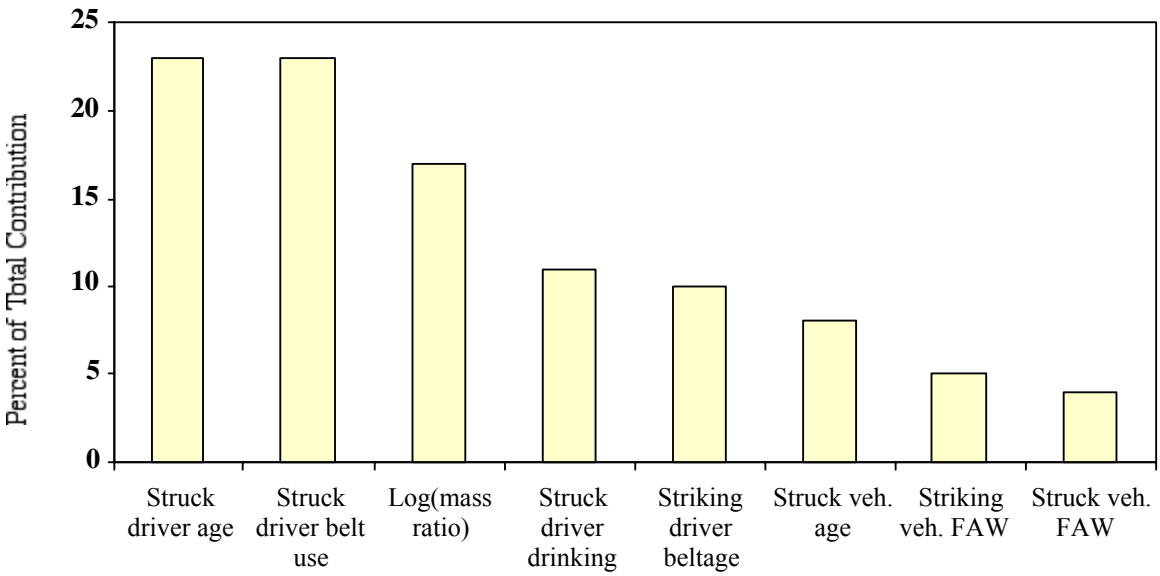


Figure 8. Relative Contribution of Variables to Odds of Fatality
Car-to-Car, Front-to-Left Crashes (p = 0.01)

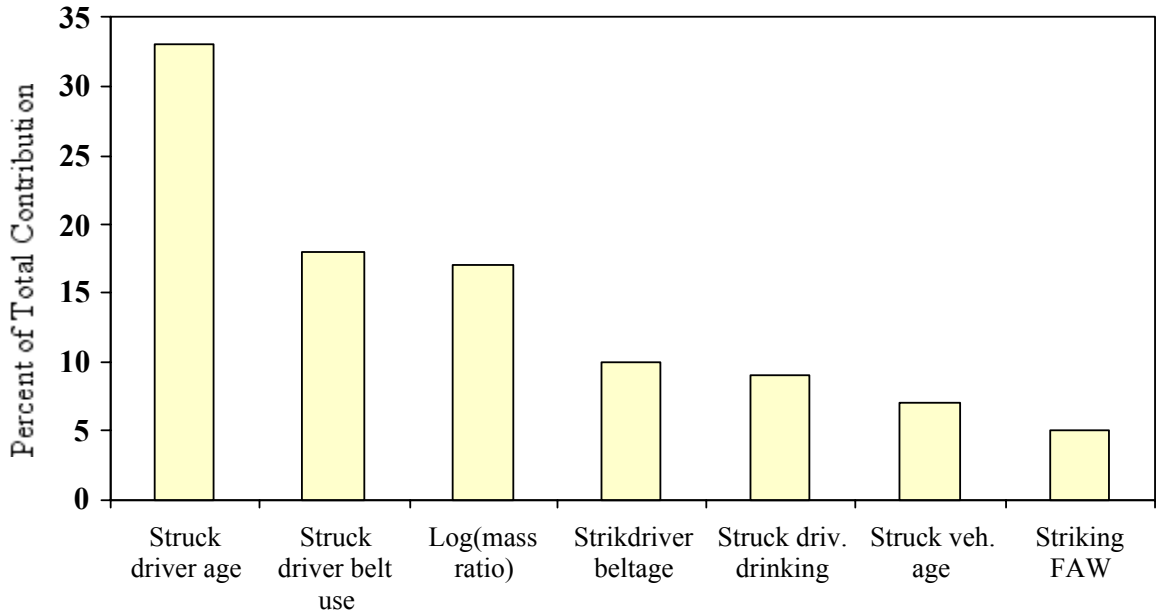


Figure 9. Relative Contribution of Variables to Odds of Fatality
Light Truck-to-Car, Front-to-Front Crashes (p = 0.01)

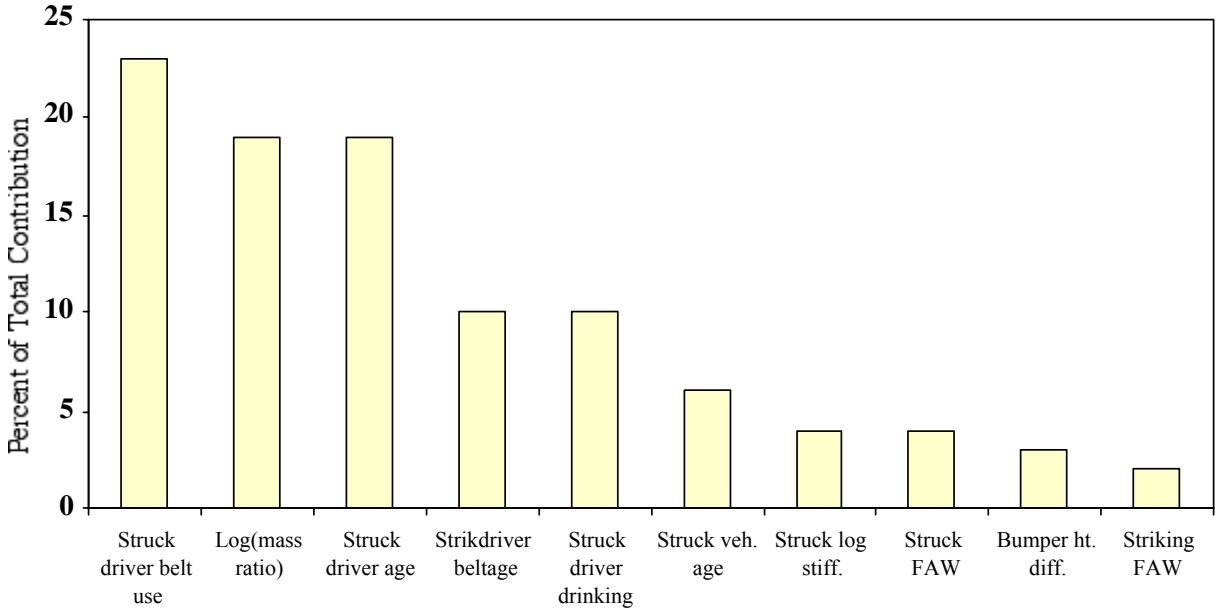
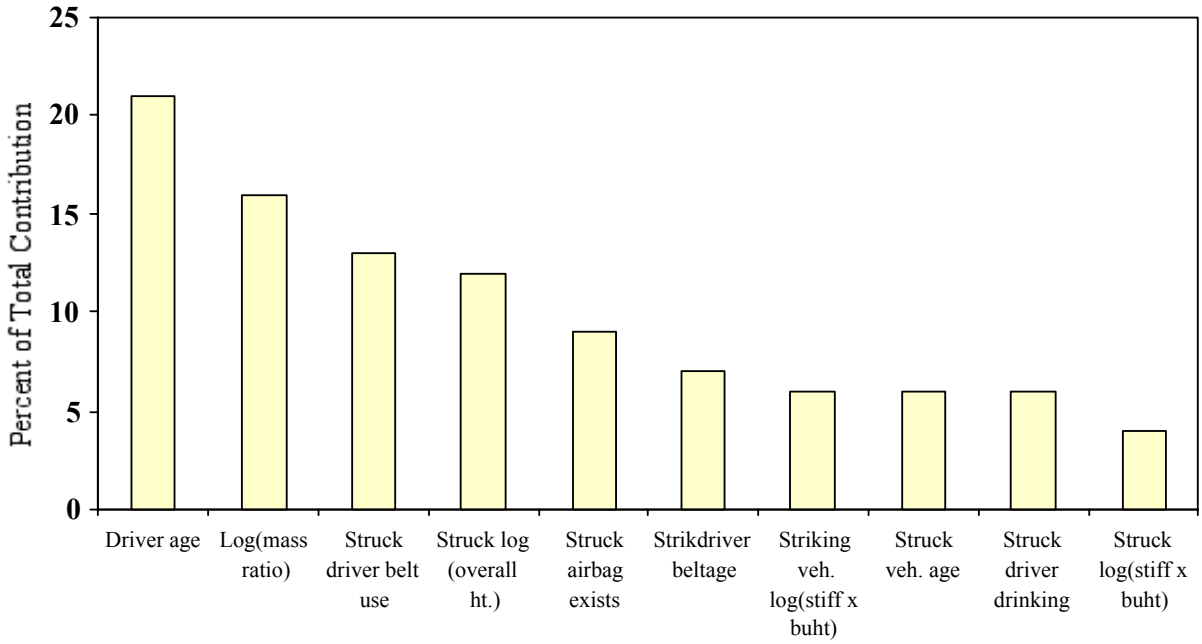


Figure 10. Relative Contribution of Variables to Odds of Fatality
Light Truck-to-Car, Front-to-Left Crashes (p = 0.01)



DISCUSSION and CONCLUSIONS

Recently, there have been several vehicle compatibility discussions by the safety research community on the relative importance of vehicle mass, stiffness, and geometry influencing occupant injuries in US and UK crashes. While some of the NHTSA and IIHS studies have addressed compatibility issues and concluded vehicle geometry to be an important parameter influencing fatality risk, these studies suffer from limited crash data (FARS data for a couple of years) or lack of proper control for other confounding driver factors such as belt use and driver age/ gender.

Our study is comprehensive in that it attempted to identify the relative importance of mass, geometry, and stiffness by examining over 60 vehicle parameters and confounding driver factors. The study showed that driver factors such as belt use and driver age have a significant effect on the fatality odds of the struck driver; hence, any studies comparing fatality rates by vehicle types (full-sized vans, pickups, utility vehicles, cars) must take into account the differences in belt use and age among drivers of these vehicle types. Studies have shown, for example, that belt use is low for pickup drivers and high for minivan drivers. When the driver factors are properly accounted for (as was done in our study), vehicle mass is seen to have a much more pronounced effect compared to stiffness and geometry, which seem to have a second order effect.

Significant disparities in the vehicle fleet involved in crashes in the two countries warrant further study before making direct comparisons between safety experiences in the US and UK. While there is not much data on light truck crashes in the UK (due primarily to there not being many sport utility vehicles on UK roads, compared to the number on US roads), preliminary examination of car-to-car crash data shows that there is a much wider variance of vehicle mass in two-vehicle frontal crashes in the US for car-to-car (for mass ratio <1.3) compared to the UK. There is also a lower percentage of equal-mass (i.e., mass ratio =1) light truck-to-car frontal crashes in the US, compared to the UK. In front-to-left crashes, there is a lower percentage of equal-mass car-to-car crashes in the US, compared to the UK. The wider mass variance influences severe injury risk to all drivers and belted drivers, and the injury risk increases with higher mass ratio.

A comprehensive statistical analysis of US car-to-car and light truck-to-car, front-to-front and front-to-left, crashes shows that vehicle mass is the most important vehicle parameter influencing struck driver fatality odds and that other size variables, such as bumper height and vehicle stiffness, have a second order effect.

ACKNOWLEDGEMENT

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The data were collected by teams from the Birmingham Automotive Safety Centre of the University of Birmingham; the Vehicle Safety Research Centre at Loughborough University; and the Vehicle & Operator Services Agency of the DfT. Further information on CCIS can be found at http://www.ukccis.org .

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