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Report to Congressional Requesters

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# HIGHWAY SAFETY

# Fatalities in Light Trucks and Vans

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**Methodology Division**

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The Honorable Frank R. Lautenberg
Chairman, Subcommittee on Transportation
and Related Agencies
Committee on Appropriations
United States Senate

The Honorable William Lehman
Chairman, Subcommittee on Transportation
and Related Agencies
Committee on Appropriations
House of Representatives

In a letter dated November 21, 1988, and through our subsequent discussions with your staff, you asked us to analyze the National Highway Traffic Safety Administration's (NHTSA's) Fatal Accident Reporting System (FARS) to

- compare passenger-car fatality rates to those for standard pickup trucks, small pickups, standard vans, small vans, and multipurpose vehicles (for example, all-terrain and 4-wheel-drive vehicles); and
- compare the fatality experience for these vehicle types in two, more policy-relevant ways: (1) after statistically controlling (that is, adjusting) for non-vehicle-related factors (for example, driver and roadway variables), and (2) when only those accidents involving rollovers or side-impact collisions are considered.

The analysis in this report complements our earlier assessment of NHTSA's overall strategy for determining if certain Federal Motor Vehicle Safety Standards (FMVSS) should be extended to pickup trucks, vans, and multipurpose vehicles.[1] This report also provides data relevant to the question of whether the risks associated with rollover and side-impact accidents warrant proposed regulations to require crush-resistant roofs and side-impact protection.

[1]U.S. General Accounting Office, Motor Vehicle Safety: Passive Restraints Needed To Make Light Trucks Safer, GAO/RCED-90-56 (Washington, D.C.: November 1989).

Fatality rates for different vehicle types do differ, as table 1 indicates. During 1985 and 1986, there were 206 fatalities for every million passenger cars registered.[2] The fatality rate was lower for small and standard vans and standard pickups, and higher for small pickups and multipurpose vehicles.

**Table 1: Fatality Rates Combining 1985 and 1986 Data**

| Vehicle type | Fatalities | Fatality rate per million registered vehicles |
|---|---|---|
| Standard pickup | 6,799 | 200 |
| Small pickup | 3,928 | 308 |
| Standard van | 1,511 | 140 |
| Small van | 293 | 151 |
| Multipurpose vehicle | 1,639 | 217 |
| Passenger car | 47,789 | 206 |
| **Total** | **61,959** | **207** |

However, differences in fatality rates may not be solely attributable to vehicle type. While vehicle type probably contributes to differences in fatality rates, so do non-vehicle-related factors, such as whether the victim was wearing a seat belt or whether the crash occurred in an urban or rural setting. Unadjusted fatality rates are difficult to interpret because we cannot tell how much of the difference between two rates is due to vehicle-type differences and how much is due to non-vehicle-related factors such as gender of the driver. For example, if men have higher accident rates than women, and if men are more likely to be drivers of certain types of vehicles than others, then a difference in fatality rates may be attributable partly to vehicle type and partly to the gender of the driver.[3] More policy-relevant information can be produced by statistically controlling for such non-vehicle-related factors.

Existing research indicates that a disproportionate share of single-vehicle-accident fatalities involves occupants of light trucks and multipurpose vehicles. For example, the research suggests that the rollover tendencies of light trucks and multipurpose vehicles may be higher as a

[2]For our analysis of highway fatalities we used 1985-86 information from the Fatal Accident Reporting System (FARS), the latest FARS information available at the time we began our study.

[3]Appendix I discusses the relationship between vehicle type and eleven variables representing characteristics of drivers, roadway conditions, and accident circumstances. Highly significant differences exist among vehicle types in the likelihood of their involving a drinking driver, a driver under 25 years old, a male driver, a victim being ejected or wearing a safety belt, an accident occurring on weekends, involving multiple vehicles, occurring on rural or wet or curved roads, or off the road. (See appendix I.)

result of inherent vehicle characteristics, such as a higher center of gravity in relation to vehicle track width. However, because the studies we reviewed have not controlled for the influence of different driver characteristics or vehicle uses, it has not been possible to conclude that higher fatality rates are due to the characteristics of the vehicle, independent of the foregoing confounding influences. Appendix II summarizes the existing research in this area.

In our analysis, we controlled for, or held constant, two sets of non-vehicle-related factors: driver/victim characteristics and roadway/accident characteristics. The driver/victim characteristics included restraint use by fatality (yes or no), sex of driver, age of driver (younger than 25 or 25 and older), and alcohol use by driver (drinking or not). The roadway/accident characteristics we controlled for included multiple-vehicle involvement (whether this factor was present), accident location (on or off the roadway), setting (urban or rural), roadway curvature (straight or curved), and pavement condition (wet or dry).

Because of the Committee's interest in rollover and side-impact collisions, we examined the fatalities associated with each separately. For each type of collision, we separately estimated the effect of driver/victim characteristics and roadway/accident characteristics, and then, having controlled for these effects, we estimated the likelihood of fatalities occurring in each of the six vehicle types. Our full technical report, included as appendix I, describes the statistical analyses we performed and our more detailed findings.

Unfortunately, the information necessary to calculate fatality rates, which are adjusted for each of our control factors, does not exist. While we know the number of registered vehicles within each vehicle type, and therefore can derive general fatality rates as we did in table 1, we do not have the necessary level of detailed "exposure" data to adjust these rates for driver or roadway conditions. We do not know, for example, how many miles small vans are driven by men, or on wet pavement, or by drinking drivers. Without such information, it is impossible to calculate fatality rates for different types of vehicles adjusted for non-vehicle-related fators.

For this reason, we have expressed the results of our analysis not as a comparison of fatality rates for different vehicle types, but rather as the relative odds of a fatality occurring in one particular type of vehicle as opposed to another. For example, 5,401 passenger-car fatalities in our sample involved rollovers, and 28,493 did not. The odds, therefore, of a fatality occurring in a passenger-car accident involving a rollover are .19 (5,401 divided by 28,493). By contrast, 610 fatalities in multipurpose vehicles involved rollovers, while 558 did not. The odds for rollover fatalities in multipurpose vehicles, therefore, are 1.09 (610 divided by 558). By forming an odds ratio between the results of these two calculations, we can conclude that a fatality in a multipurpose vehicle is 5.74 (1.09 divided by .19) times more likely than a fatality in a passenger car to involve a rollover.

These calculations, however, do not account for the possible confounding effect of other variables. For example, they do not take into account the possibility that drivers of multipurpose vehicles may be younger than passenger car drivers, or more liable to have been drinking, or more likely to be male, or less likely to be wearing a safety belt. They also do not consider the possibility that fatal accidents involving multipurpose vehicles may be more likely to take place on dry pavement, or in a rural area, or off the road, or on a curve, or involve only one vehicle. Any of these non-vehicle-related factors, or some combination of them, could account, in whole or in part, for the greater likelihood of rollover fatalities in one type of vehicle than in another.

For this reason, we constructed statistical models which allowed for the possible influence of these factors and recalculated the odds for each vehicle type after adjusting for the non-vehicle-related factors. For these calculations, we used passenger cars as the criterion (or reference) group. Table 2 presents the results of these analyses for fatalities involving rollover accidents—that is, the likelihood, relative to passenger cars, of a fatality occurring in each of five vehicle types. The data are presented (1) before adjustment for non-vehicle-related factors, (2) after adjustment for driver/victim characteristics, and (3) after adjustment for accident/roadway characteristics.

**Table 2: Fatality Likelihood Ratio in Rollover Accidents, Non-Passenger-Car Vehicles Versus Passenger Cars**

| Variables controlled for | Multipurpose vehicle | Standard van | Small van | Small pickup | Standard pickup |
|---|---|---|---|---|---|
| None | 5.74 | 1.89 | 1.21 | 2.73 | 2.47 |
| Driver/victim characteristics | 5.83 | 2.11 | 1.74 | 2.58 | 2.35 |
| Accident/roadway characteristics | 4.59 | 1.99 | 1.88 | 2.25 | 1.76 |

We can conclude that, in all of the special vehicle types we examined, fatalities are more likely than those occurring in a passenger car to have involved a rollover. This tendency is most pronounced for multipurpose vehicles. While adjustments for the influence of driver/victim characteristics or for accident/roadway characteristics affect the magnitude of our estimates somewhat, the differential effect of vehicle type, and the lower likelihood of a fatality occurring in a passenger car than in any of these other vehicle types, persist.

Table 3 presents parallel statistics for fatalities occurring in side-impact accidents. Fatalities in all the non-passenger-car vehicles in our analysis are less likely to have involved a side impact than those occurring in passenger cars. This tendency persists even after adjustment for driver/victim characteristics and for accident/roadway characteristics. Multipurpose-vehicle, standard-van, and pickup fatalities are approximately half as likely, and small van fatalities slightly less than two thirds as likely, to have involved a side impact.

**Table 3: Fatality Likelihood Ratio in Side-Impact Accidents, Non-Passenger-Car Vehicles Versus Passenger Cars**

| Variables controlled for | Multipurpose vehicle | Standard van | Small van | Small pickup | Standard pickup |
|---|---|---|---|---|---|
| None | 0.39 | 0.52 | 0.65 | 0.46 | 0.46 |
| Driver/victim characteristics | 0.42 | 0.53 | 0.60 | 0.50 | 0.50 |
| Accident/roadway characteristics | 0.49 | 0.54 | 0.60 | 0.53 | 0.54 |

The results of our analysis suggest that the increased likelihood of fatal rollover accidents—including fatalities in all five light truck and van vehicle types—may be attributable to the vehicles themselves. This increased likelihood may be due to differences in vehicle configuration (for example, higher center of gravity), as well as to the absence of specific safety standards required for passenger cars. Therefore, in the case of rollovers, our results provide some support for the proposed extension and strengthening of federal standards concerning crush-resistant roofs for all five non-passenger-car vehicle types considered.[4]

Our results do not provide similar evidence for the extension of side-impact standards to those same vehicles. Here our results indicate that fatalities in non-passenger-car vehicles are less likely to involve side impacts than are passenger-car fatalities.

Some cautions need to be applied in interpreting the results of our analysis. First, while we have found that non-passenger-car fatalities are more likely than passenger-car fatalities to involve rollovers, and less

[4]NHTSA is now reviewing comments received from the notice of proposed rule-making.

likely to involve side impacts, we cannot conclude that these differences are the result of differing protections afforded occupants in these types of accidents. (Indeed, our study was not designed to measure such effects.) Such an interpretation is consistent with our findings. However, in the absence of information on nonfatal accidents to parallel our fatality data, this linkage cannot be established.

Second, as we noted earlier, we do not have "exposure" data at the level of detail needed to compute adjusted fatality rates. We do not know, for example, how many miles small vans are driven by men, or on wet pavement, or by drinking drivers. Consequently, we cannot estimate the likelihood that a given number of miles traveled in one type of vehicle by a given driver type will result in a rollover fatality.

Finally, our data do not allow us to estimate the effects of proposed safety features—so that although safety features such as crush-resistant roofs might reduce rollover injuries, without data on vehicles so equipped we cannot estimate the effectiveness of such features.

While the foregoing limitations do not allow us to demonstrate conclusively that changes in specifications for certain vehicles would result in fewer highway fatalities, we believe our analysis offers persuasive evidence that rollover fatalities are more likely, and side-impact fatalities less likely, to occur in non-passenger-car vehicles, and that these tendencies are vehicle-specific and cannot be attributed simply to driver, roadway, or accident characteristics.

We conducted our analysis in Washington, D.C., and Kansas City, Missouri, between August 1988 and July 1990 in accordance with generally accepted government auditing standards. Dr. Probir Roy of the University of Missouri at Kansas City and Dr. Douglas Sloane of the Catholic University of America assisted us in the development and application of our statistical model.

We provided draft copies of this report to officials of NHTSA's National Center for Statistics and Analysis and discussed with them the study results. We incorporated their suggestions as appropriate. We are sending copies to the Secretary of Transportation and other interested parties and will make copies available to others upon request.

If you have any questions or would like additional information, please call me at (202) 275-1854. Major contributors to this report are listed in appendix III.

Eleanor Chelimsky
Assistant Comptroller General

# Contents

## Abbreviations

| | |
|---|---|
| DOT | Department of Transportation |
| FARS | Fatal Accident Reporting System |
| FMVSS | Federal Motor Vehicle Safety Standards |
| GAO | General Accounting Office |
| NCSS | National Crash Severity Study |
| NHTSA | National Highway Traffic Safety Administration |
| UMTRI | University of Michigan Transportation Research Institute |

# The Analysis of FARS Data on Rollovers and Side Impacts: Methodology and Detailed Findings

## Overview

Our analysis of these data involved four interrelated steps.

1. We examined the data for bivariate relationships between vehicle type and rollovers, and between vehicle type and side impacts. We found strong relationships in both cases.

2. We then looked at a series of two-way tables to explore whether certain other variables that measured characteristics of drivers, fatality victims, accidents, and roadways were simultaneously related to both vehicle type and the outcomes of interest (rollovers and side impacts) in such a fashion that they could account for these bivariate relationships. We discovered strong relationships between several of these measures and both rollover and side-impact accidents.

3. We then considered a series of three-way tables that permitted us to control for the relationship between vehicle type and these characteristics, and between these characteristics and rollover and side-impact accidents, before reestimating the relationship between vehicle type and rollovers, and between vehicle type and side impacts.

4. When, in these three-way analyses, the associations of vehicle type with both rollovers and side impacts persisted, we attempted finally to control for certain of these interrelated characteristics simultaneously. The persistence of the initial vehicle type/rollover and vehicle type/side-impact associations even after the introduction of these multivariate controls convinces us that they are not of a spurious nature, or at least are not readily accounted for by the set of control variables we have considered.

The nature and magnitude of these associations, and the techniques we used to test and describe them, are discussed in the following sections.

## Bivariate Relationship Between Rollovers, Side Impacts, and Vehicle Type

Our analysis began with a consideration of the fatal-accident data in table I.1, where the type of vehicle in which the fatality occurred—a six category variable contrasting multipurpose vehicles, standard vans, small vans, small pickups, standard pickups, and passenger cars—is cross-classified by whether the fatality involved a rollover or a side impact. The numbers given in the first two rows in table I.1 represent the number of fatalities, within each vehicle category, that did or did not involve a rollover, or that did or did not involve a side impact. For each of the two accident categories shown in the table, a likelihood ratio chi-square statistic ($L^2$) is given. The large value of this test statistic for both tables indicates that the hypothesis that, among fatalities, rollovers and side impacts are unrelated to vehicle type can be easily rejected. Rollovers and side impacts, in other words, are strongly associated with vehicle type.

**Table I.1: Observed Frequencies of Motor-Vehicle Fatalities Involving Rollovers and Side Impacts, by Vehicle Type, and Odds and Odds Ratios Derived From Them**

| Accident category, odds, and ratio | Multipurpose vehicle | Standard van | Small van | Small pickup | Standard pickup | Passenger car |
|---|---|---|---|---|---|---|
| Rollover[a] | 610 | 275 | 40 | 934 | 1,580 | 5,401 |
| No rollover | 558 | 763 | 171 | 1,806 | 3,345 | 28,493 |
| Odds on rollover | 1.09 | 0.36 | 0.23 | 0.52 | 0.47 | 0.19 |
| Ratio[b] | 5.74 | 1.89 | 1.21 | 2.73 | 2.47 | |
| Side impact[c] | 180 | 202 | 49 | 484 | 857 | 10,708 |
| No side impact | 988 | 836 | 162 | 2,256 | 4,068 | 23,186 |
| Odds on side impact | 0.18 | 0.24 | 0.30 | 0.21 | 0.21 | 0.46 |
| Ratio[b] | 0.39 | 0.52 | 0.65 | 0.46 | 0.46 | |

[a] $L^2 = 1,685.41$, 5 df, $P < .0001$

[b] All ratios are expressed relative to passenger cars—that is, 1.09/0.19 = 5.74, 0.36/0.19 = 1.89, and so on. These odds ratios can be interpreted in a reasonably straightforward fashion: Multipurpose-vehicle fatalities are 5.74 times as likely to have involved a rollover as passenger-car fatalities, standard-van fatalities 1.86 times as likely as passenger-car fatalities to have involved a rollover, and so on.

[c] $L^2 = 816.30$, 5 df, $P < .0001$

The nature of these associations can be described by calculating odds and odds ratios from the observed frequencies in the table. The odds of rollovers (or side impacts) having been involved in these fatalities were calculated for each type of vehicle. For multipurpose vehicles, for example, there were 610 fatalities that involved a rollover and 558 fatalities that did not, so the odds on fatalities involving a rollover in that vehicle type were 610/558 = 1.09. For every multipurpose-vehicle fatality that did not involve a rollover, in other words, there were 1.09 that did. Thus, for every 100 that did not, there were 109 that did. The odds on fatalities involving rollovers in other types of vehicles can be similarly calculated, and the values that result are given in the third row in each of the two accident categories contained in the table. The odds on fatalities involving a rollover were 0.36 for standard vans, 0.23 for small vans, and so on.

To determine how strongly the odds on rollovers or side impacts are associated with vehicle type, we chose passenger cars as the criterion vehicle type and calculated the odds ratios, or relative odds on rollovers being involved in other-vehicle-type fatalities versus fatalities involving passenger cars. These odds ratios are provided in the last row in each of the two accident categories in table I.1. For example, among rollover fatalities, the odds ratio between multipurpose vehicles and passenger cars is 5.74 (1.09/0.19). Similarly, the odds ratios comparing standard vans, small vans, and standard pickups to passenger cars are 1.89 (0.36/0.19), 1.21 (0.23/0.19), 2.73 (0.52/0.19), and 2.47 (0.47/0.19), respectively. These odds ratios can be interpreted directly to mean that, for example, fatalities in multipurpose vehicles are 5.74 times as likely to have involved a rollover as fatalities in passenger cars, fatalities in standard vans 1.89 times as likely to have involved a rollover as passenger-car fatalities, and so on.

The two full sets of odds ratios provided in table I.1 indicate that all non-passenger-car fatalities are more likely than passenger-car fatalities to have involved a rollover (by factors ranging from 1.21 to 5.74), and all non-passenger-car fatalities are less likely than passenger-car fatalities to have involved a side impact (by factors ranging from 0.65 to 0.39). Differences in the odds on rollovers are most pronounced between multipurpose vehicles and trucks versus passenger cars, as are differences in the odds on side impacts. The value of the chi-square statistics associated with these differences assures us that they are due to more than sampling variability or chance.

## Bivariate Relationships Between Vehicle Type and Selected Driver, Victim, and Accident Characteristics

The fact that these strong associations of vehicle type with rollovers and side impacts are not attributable to chance or random fluctuations does not necessarily imply that they are not spurious, or that they cannot be accounted for by other variables with which both vehicle type and rollovers or side impacts are jointly associated. It may be, for example, that the more pronounced tendency for multipurpose-vehicle fatalities (relative to passenger-car fatalities) to involve rollovers results from the fact that multipurpose vehicles are more apt to be driven by males, and males are more likely to be involved in rollovers. Alternatively, drinking drivers may be more likely to be involved in rollovers or side impacts than nondrinking drivers, and certain vehicle-type fatalities may be more apt to involve drinking drivers.

To gain a preliminary impression of the extent to which certain characteristics may be jointly related to vehicle type, and to rollovers and side impacts, we examined the simple paired associations between a number of driver, victim, and accident characteristics and vehicle type, and between these characteristics and rollovers and side impacts. The crosstabulations between these characteristics and vehicle type are presented in table I.2, while the crosstabulations with rollovers and side impacts can be found in tables I.3 and I.4.

**Table I.2: Observed Frequencies of Motor Vehicle Fatalities Involving Selected Characteristics, by Vehicle Type and Odds and Odds Ratios Derived From Them**

| Characteristic, odds, and ratio | Multipurpose vehicle | Standard van | Small van | Small pickup | Standard pickup | Passenger car |
|---|---|---|---|---|---|---|
| Male[a] | 984 | 884 | 152 | 2,348 | 4,478 | 23,395 |
| Female | 184 | 154 | 59 | 392 | 447 | 10,499 |
| Odds on male | 5.35 | 5.74 | 2.58 | 5.99 | 10.02 | 2.23 |
| Ratio | 2.40 | 2.57 | 1.16 | 2.69 | 4.50 | |
| Under 25[b] | 428 | 238 | 26 | 1,041 | 1,523 | 12,363 |
| 25 and over | 740 | 800 | 185 | 1,699 | 3,402 | 21,531 |
| Odds on under 25 | 0.58 | 0.30 | 0.14 | 0.45 | 0.61 | 0.57 |
| Ratio | 1.01 | 0.53 | 0.25 | 0.79 | 1.07 | |
| Drinking[c] | 602 | 378 | 55 | 1,304 | 2,464 | 13,398 |
| No drinking | 566 | 660 | 156 | 1,436 | 2,461 | 20,496 |
| Odds on drinking | 1.06 | 0.57 | 0.35 | 0.91 | 1.00 | 0.65 |
| Ratio | 1.63 | 0.88 | 0.54 | 1.40 | 1.54 | |
| No Restraint[d] | 1,026 | 935 | 150 | 2,533 | 4,706 | 28,989 |
| Restraint | 142 | 103 | 61 | 207 | 219 | 4,905 |
| Odds on no restraint | 7.23 | 9.08 | 2.46 | 12.24 | 21.49 | 5.91 |
| Ratio | 1.22 | 1.54 | 0.42 | 2.07 | 3.64 | |
| Ejection[e] | 726 | 374 | 62 | 1,142 | 1,918 | 8,066 |
| No ejection | 442 | 664 | 149 | 1,598 | 3,007 | 25,828 |
| Odds on ejection | 1.64 | 0.56 | 0.42 | 0.71 | 0.64 | 0.31 |
| Ratio | 5.29 | 1.81 | 1.35 | 2.29 | 2.06 | |
| Multi-vehicles[f] | 354 | 533 | 143 | 1,161 | 1,883 | 19,345 |
| Single vehicle | 814 | 505 | 68 | 1,579 | 3,042 | 14,549 |
| Odds on multi-vehicles | 0.43 | 1.06 | 2.10 | 0.74 | 0.62 | 1.33 |
| Ratio | 0.32 | 0.80 | 1.58 | 0.56 | 0.47 | |
| Weekend[g] | 707 | 529 | 102 | 1,478 | 2,691 | 17,919 |
| Weekday | 461 | 509 | 109 | 1,262 | 2,234 | 15,975 |
| Odds on weekend | 1.53 | 1.04 | 0.94 | 1.17 | 1.20 | 1.12 |
| Ratio | 1.37 | 0.93 | 0.84 | 1.04 | 1.07 | |
| Rural[h] | 880 | 719 | 135 | 2,094 | 3,924 | 22,274 |
| Other | 288 | 319 | 76 | 646 | 1,001 | 11,620 |
| Odds on rural | 3.06 | 2.25 | 1.78 | 3.24 | 3.92 | 1.92 |
| Ratio | 1.59 | 1.17 | 0.93 | 1.69 | 2.04 | |

(continued)

| Characteristic, odds, and ratio | Multipurpose vehicle | Standard van | Small van | Small pickup | Standard pickup | Passenger car |
|---|---|---|---|---|---|---|
| Off-road[i] | 663 | 433 | 62 | 1,328 | 2,668 | 14,154 |
| Other | 505 | 605 | 149 | 1,412 | 2,257 | 19,740 |
| Odds on off-road | 1.31 | 0.72 | 0.41 | 0.94 | 1.18 | 0.72 |
| Ratio | 1.82 | 1.00 | 0.57 | 1.31 | 1.64 | |
| Curved road[j] | 411 | 262 | 54 | 971 | 1,654 | 9,878 |
| Other | 757 | 776 | 157 | 1,769 | 3,271 | 23,996 |
| Odds on curved road | 0.54 | 0.34 | 0.34 | 0.55 | 0.51 | 0.41 |
| Ratio | 1.32 | 0.83 | 0.83 | 1.33 | 1.23 | |
| Wet road[k] | 195 | 232 | 40 | 466 | 838 | 7,389 |
| Other | 973 | 806 | 171 | 2,274 | 4,087 | 26,505 |
| Odds on wet road | 0.20 | 0.29 | 0.23 | 0.20 | 0.21 | 0.28 |
| Ratio | 0.71 | 1.04 | 0.82 | 0.71 | 0.75 | |

[a] $L^2 = 1,680.49$, 5 df, $P < .0001$

[b] $L^2 = 203.46$, 5 df, $P < .0001$

[c] $L^2 = 321.95$, 5 df, $P < .0001$

[d] $L^2 = 604.24$, 5 df, $P < .0001$

[e] $L^2 = 1,437.06$, 5 df, $P < .0001$

[f] $L^2 = 1,048.03$, 5 df, $P < .0001$

[g] $L^2 = 35.67$, 5 df, $P < .0001$

[h] $L^2 = 540.53$, 5 df, $P < .0001$

[i] $L^2 = 393.85$, 5 df, $P < .0001$

[j] $L^2 = 104.96$, 5 df, $P < .0001$

[k] $L^2 = 104.93$, 5 df, $P < .0001$

**Table I.3: Observed Frequencies in the Cross-Classifications of Rollovers, With Selected Characteristics and Odds and Odds Ratios Derived From Them**

| Characteristic | Rollover | No rollover | Odds on rollover | Odds ratio |
|---|---|---|---|---|
| Male[a] | 6,936 | 25,305 | 0.27 | 1.42 |
| Female | 1,904 | 9,831 | 0.19 | |
| Under 25[b] | 4,020 | 11,599 | 0.35 | 1.75 |
| 25 and over | 4,820 | 23,537 | 0.20 | |
| Drinking[c] | 5,183 | 13,018 | 0.40 | 2.35 |
| No drinking | 3,657 | 22,118 | 0.17 | |
| No restraint[d] | 8,373 | 29,966 | 0.28 | 3.11 |
| Restraint | 467 | 5,170 | 0.09 | |
| Ejection[e] | 6,293 | 5,995 | 1.05 | 11.67 |
| No ejection | 2,547 | 29,141 | 0.09 | |
| Multi-vehicles[f] | 725 | 22,694 | 0.03 | 0.05 |
| Single vehicle | 8,115 | 12,442 | 0.65 | |
| Weekend[g] | 5,221 | 18,205 | 0.29 | 1.38 |
| Weekday | 3,619 | 16,931 | 0.21 | |
| Rural[h] | 7,100 | 22,926 | 0.31 | 2.21 |
| Other | 1,740 | 12,210 | 0.14 | |
| Off-road[i] | 7,207 | 12,101 | 0.60 | 8.57 |
| Other | 1,633 | 23,035 | 0.07 | |
| Curved road[j] | 4,021 | 9229 | 0.44 | 2.32 |
| Other | 4,819 | 25,907 | 0.19 | |
| Wet road[k] | 1,074 | 8,086 | 0.13 | 0.45 |
| Other | 7,766 | 27,050 | 0.29 | |

[a] $L^2 = 155.03$, 1 df, $P < .0001$

[b] $L^2 = 467.43$, 1 df, $P < .0001$

[c] $L^2 = 1{,}337.67$, 1 df, $P < .0001$

[d] $L^2 = 668.95$, 1 df, $P < .0001$

[e] $L^2 = 9{,}382.12$, 1 df, $P < .0001$

[f] $L^2 = 10{,}088.64$, 1 df, $P < .0001$

[g] $L^2 = 149.91$, 1 df, $P < .0001$

[h] $L^2 = 791.57$, 1 df, $P < .0001$

[i] $L^2 = 6{,}599.96$, 1 df, $P < .0001$

[j] $L^2 = 1{,}176.16$, 1 df, $P < .0001$

[k] $L^2 = 557.04$, 1 df, $P < .0001$

**Table I.4: Observed Frequencies in the Cross-Classifications of Side Impacts, With Selected Characteristics and Odds and Odds Ratios Derived From Them**

| Characteristic | Side impact | No side impact | Odds on side impact | Odds ratio |
|---|---|---|---|---|
| Male[a] | 8,595 | 23,646 | 0.36 | 0.73 |
| Female | 3,885 | 7,850 | 0.49 | |
| Under 25[b] | 4,338 | 11,281 | 0.38 | 0.95 |
| 25 and over | 8,142 | 20,215 | 0.40 | |
| Drinking[c] | 4,283 | 13,918 | 0.31 | 0.66 |
| No drinking | 8,197 | 17,578 | 0.47 | |
| No restraint[d] | 10,392 | 27,947 | 0.37 | 0.63 |
| Restraint | 2,088 | 3,549 | 0.59 | |
| Ejection[e] | 2,740 | 9,548 | 0.29 | 0.26 |
| No ejection | 9,740 | 21,948 | 0.44 | |
| Multi-vehicles[f] | 8,542 | 14,967 | 0.57 | 2.33 |
| Single vehicle | 4,028 | 16,529 | 0.24 | |
| Weekend[g] | 6,267 | 17,159 | 0.37 | 0.86 |
| Weekday | 6,213 | 14,337 | 0.43 | |
| Rural[h] | 7,801 | 22,225 | 0.35 | 0.70 |
| Other | 4,679 | 9,271 | 0.50 | |
| Off-road[i] | 3,882 | 15,426 | 0.25 | 0.46 |
| Other | 8,598 | 16,070 | 0.54 | |
| Curved road[j] | 3,060 | 10,190 | 0.30 | 0.68 |
| Other | 9,420 | 21,306 | 0.44 | |
| Wet road[k] | 3,290 | 5,870 | 0.56 | 1.56 |
| Other | 9,190 | 25,626 | 0.36 | |

[a] $L^2 = 172.67$, 1 df, $P < .0001$

[b] $L^2 = 4.37$, 1 df, $P = .037$

[c] $L^2 = 363.75$, 1 df, $P < .0001$

[d] $L^2 = 228.29$, 1 df, $P < .0001$

[e] $L^2 = 319.99$, 1 df, $P < .0001$

[f] $L^2 = 1{,}493.97$, 1 df, $P < .0001$

[g] $L^2 = 65.20$, 1 df, $P < .0001$

[h] $L^2 = 263.39$, 1 df, $P < .0001$

[i] $L^2 = 1{,}185.38$, 1 df, $P < .0001$

[j] $L^2 = 267.09$, 1 df, $P < .0001$

[k] $L^2 = 312.75$, 1 df, $P < .0001$

Nearly all these crosstabulations reveal highly significant relationships, as indicated by the chi-square statistics associated with them. These tables also present the magnitude of this relationship as odds and odds ratios. These ratios can be interpreted as in table I.1. For example, the driver of a multipurpose vehicle involved in a fatality was 2.39 (5.35/2.23) times more likely to have been male than the driver of a passenger car involved in a fatality.[1] A rollover fatality was 1.42 (0.27/0.19) times more likely to have involved a male driver than a female driver.[2] A detailed interpretation of each of these relationships appears unnecessary, but in general these crosstabulations indicate the following:

1. Among vehicle fatalities, each of the following variables bears a significant relationship to vehicle type, to rollovers, and to side impacts: sex of driver, age of driver, whether the driver was drinking, whether the victim was using restraints, whether an ejection occurred, whether multiple vehicles were involved, whether the fatalities occurred on weekends, or on rural roads, or off-road, or on curved or wet roads.

2. Fatalities involving multipurpose vehicles, and both types of pickups, were more likely than passenger-car fatalities to have involved a male driver, a drinking driver, no restraint use, and an ejection, and more likely to have occurred off-road or on rural roads or curved stretches of roads. They were less likely, at the same time, to have involved multiple vehicles and wet roads and, in the case of pickups at least, a driver under the age of 25. Fatalities occurring in both types of van were also more likely than passenger-car fatalities to have involved a male driver and an ejection, but, unlike multipurpose vehicle and truck fatalities, they were less likely than passenger-car fatalities to have involved a drinking driver, or to have occurred off-road, or on a curved road. (See table I.2.)

3. Fatalities involving rollovers were more likely to have involved a male driver, a driver under age 25, a drinking driver, no restraint use, and an ejection, and they were also more likely to have occurred on weekends, on rural roads, on curved roads, or off road. Fatalities involving rollovers were, at the same time, less likely to have involved multiple vehicles or wet roads. Fatalities involving side impacts were, conversely, more likely to have involved multiple vehicles or wet roads, but less likely to have involved male drivers, younger drivers, drinking drivers, no restraint use, and ejection, or an accident that occurred off-road, on the weekend, or on a curved or wet road. (See tables I.3 and I.4.)

[1] See table I.2.

[2] See table I.3.

Given the significance and magnitude of the associations of these characteristics, both with vehicle type and with the outcomes of interest (rollovers and side impacts), we concluded that it was necessary to control for them in analyzing the association of vehicle type with rollovers and side impacts. In other words, we attempted first to identify the portion of the bivariate relationship between vehicle type and rollover or side impact that could be accounted for by the relationship between the personal and accident-related characteristics we considered, and then we attempted to determine if vehicle type significantly added to our understanding of the likelihood of rollovers or side impacts.

We did this by constructing and analyzing a series of three-way tables in which vehicle type was cross-classified by rollover and one control variable at a time, and a similar set of tables for side impact and one control variable at a time. While we do not provide all of these three-way tables in this report, table I.5 presents the results of fitting selected hierarchical models to the rollover tables, and table I.6 contains the results of fitting similar models to the side-impact tables.

**Table I.5: Likelihood-Ratio Chi-Square ($L^2$) Values Associated With Several Hierarchical Models Fitted to Three-Way Tables in Which Rollovers Are Cross-Classified by Vehicle Type and Selected Characteristics**

| | Chi-square values | | |
|---|---|---|---|
| Control variable | [VC] [R] 11 degrees of freedom | [VC] [CR] 10 degrees of freedom | [VC] [CR] [VR] 5 degrees of freedom |
| Sex of driver | 1,748.23 | 1,593.20 | 31.11 (.98) |
| Age of driver | 2,231.33 | 1,763.90 | 12.71 (.99) |
| Drinking | 2,876.09 | 1,538.41 | 26.72 (.99) |
| Restraint use | 2,226.74 | 1,557.79 | 6.05 (.99) |
| Ejection | 10,097.19 | 715.07 | 47.68 (.99) |
| Multi-vehicles | 11,066.65 | 978.02 | 62.63 (.99) |
| Weekend | 1,819.83 | 1,669.92 | 2.30 (.99) |
| Rural road | 2,306.24 | 1,514.67 | 11.16 (.99) |
| Off-road | 8,177.50 | 1,577.54 | 190.21 (.98) |
| Curved road | 2,802.58 | 1,626.42 | 11.75 (.99) |
| Wet road | 2,211.57 | 1,654.54 | 33.33 (.99) |

Models are denoted, following convention, by the underlying marginals of the three-way tables they fit: V = vehicle type; R = rollover; C = the third (control) variable in each table (for example, sex, age, and so on). All models are described in detail in the text.

Numbers in parentheses next to the chi-square values for the third model fitted to each table indicate the proportion of the variation in the odds on the fatality involving a rollover that is accounted for by that model.

**Table I.6: Likelihood-Ratio Chi-Square ($L^2$) Values Associated With Several Hierarchical Models Fitted to Three-Way Tables in Which Side Impacts Are Cross-Classified by Vehicle Type and Selected Characteristics**

| | Chi-square values | | |
|---|---|---|---|
| Control variable | [VC] [S] 11 degrees of freedom | [VC] [CS] 10 degrees of freedom | [VC] [CS] [VS] 5 degrees of freedom |
| Sex of driver | 888.21 | 715.56 | 1.90 (.99) |
| Age of driver | 830.53 | 826.15 | 5.13 (.99) |
| Drinking | 1,117.37 | 753.62 | 3.54 (.99) |
| Restraint use | 991.21 | 762.92 | 14.77 (.98) |
| Ejection | 1,018.95 | 698.96 | 22.86 (.98) |
| Multi-vehicles | 2,067.83 | 573.86 | 11.54 (.99) |
| Weekend | 880.29 | 815.09 | 5.09 (.99) |
| Rural road | 1,007.87 | 744.48 | 8.20 (.99) |
| Off-road | 1,895.79 | 710.41 | 23.01 (.99) |
| Curved road | 1,063.36 | 796.27 | 9.37 (.99) |
| Wet road | 1,098.39 | 785.64 | 7.33 (.99) |

Models are denoted, following convention, by the underlying marginals of the three-way tables they fit: V = vehicle type; S = side impact; C = the third (control) variable in each table (for example, sex, age, and so on). All models are described in detail in the text.

Numbers in parentheses next to the chi-square values for the third model fitted to each table indicate the proportion of the variation in the odds on the fatality involving a side impact that is accounted for by that model.

Three models were fitted to all tables. The first was the logit-specified model of independence, which asserts that in each table rollovers or side impacts are unrelated to either vehicle type or the control variable present. This model can be readily rejected in every case, as could have been anticipated from our two-way results. The independence model, moreover, is substantially and significantly improved upon by the second model we fit to the data, which asserts that the control variables (but not vehicle type) are associated with rollovers and side impacts. (Note the significant reduction in chi-square values from the first to the second columns of numbers in tables I.5 and I.6, which correspond to these two models.) Additionally, the third model fitted to each of the tables—which allows vehicle type to be related to rollovers and side impacts after controlling for the association of each control variable with both vehicle type and these outcomes—significantly improves upon the second model. This implies that the associations of vehicle type with rollovers and side impacts persist after individual controls are introduced.

While this third model does not, in every case, provide a reasonable fit to the data (indicating the presence of significant three-way interactions), this is not surprising given the large sample being used

**Table I.7: Odds Ratios Indicating the Association of Vehicle Type With Rollovers and Side Impacts, Before and After Controlling for Selected Characteristics** (One at a Time)

| | Rollover | | |
|---|---|---|---|
| Control variable | Multipurpose vehicle | Standard van | Small van |
| None | 5.74 | 1.89 | 1.21 |
| Driver's sex | 5.64 | 1.85 | 1.23 |
| Driver's age | 5.93 | 2.08 | 1.44 |
| Drinking | 5.55 | 1.99 | 1.40 |
| Restraint use | 5.84 | 1.85 | 1.40 |
| Ejection | 3.21 | 1.53 | 1.08 |
| Multi-vehicle | 4.64 | 1.92 | 1.88 |
| Weekend | 5.68 | 1.92 | 1.25 |
| Rural road | 5.59 | 1.88 | 1.25 |
| Off-road | 6.08 | 2.14 | 1.74 |
| Curved road | 5.81 | 2.01 | 1.28 |
| Wet road | 5.71 | 1.92 | 1.21 |

(approximately 44,000). A better indicator of whether this third model provides an adequate account of the associations present in the table can be obtained by determining how much of the variation in the odds on rollovers or side impacts it accounts for. This can be computed by dividing the difference between the chi-square value for the baseline model and the chi-square value for the third (main effect) model by the baseline model chi-square. For the three-way table involving rollovers, vehicle type, and sex of driver, for example, this calculation yields 0.98 [(1748.23 - 31.11)/1748.23]. Ninety-eight percent of the variation in rollovers, across the joint categories of vehicle type and driver sex, is accounted for by this model, which posits independent main effects of vehicle type on rollovers. In other words, the model stipulates an effect of vehicle type that is the same for both male and female drivers and an effect of sex that is the same for all vehicle types. Therefore, there is no compelling reason to take account of the significant three-way interaction that is present in this table. The same is true for the other three-way tables as well, inasmuch as in every case our main effect model accounts for better than 98 percent of the variation in each.

| Rollover | | Side impact | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Small pickup | Standard pickup | Multipurpose vehicle | Standard van | Small van | Small pickup | Standard pickup |
| 2.73 | 2.47 | 0.39 | 0.52 | 0.65 | 0.46 | 0.46 |
| 2.66 | 2.41 | 0.41 | 0.54 | 0.66 | 0.48 | 0.48 |
| 2.75 | 2.61 | 0.39 | 0.51 | 0.64 | 0.46 | 0.45 |
| 2.63 | 2.34 | 0.41 | 0.52 | 0.62 | 0.48 | 0.47 |
| 2.61 | 2.32 | 0.40 | 0.53 | 0.62 | 0.48 | 0.47 |
| 2.09 | 2.01 | 0.45 | 0.54 | 0.67 | 0.49 | 0.48 |
| 2.39 | 1.89 | 0.48 | 0.54 | 0.60 | 0.51 | 0.52 |
| 2.73 | 2.49 | 0.40 | 0.52 | 0.65 | 0.46 | 0.46 |
| 2.58 | 2.31 | 0.41 | 0.53 | 0.65 | 0.48 | 0.48 |
| 2.85 | 2.23 | 0.43 | 0.52 | 0.60 | 0.48 | 0.49 |
| 2.66 | 2.46 | 0.40 | 0.51 | 0.65 | 0.47 | 0.46 |
| 2.68 | 2.44 | 0.40 | 0.52 | 0.66 | 0.47 | 0.46 |

We can use the expected frequencies under this model for each table and derive from them, as before, the odds on rollovers and side impacts, and the ratios of these odds (again with passenger cars as the criterion vehicle type) across vehicle type. The results of these calculations are provided in table I.7, which also provides the initial odds ratios (that is, those calculated in table I.1, prior to controls).

As table I.7 indicates, the odds ratios after adjusting for the effect of the individual control variables are not substantially different from the ratios derived without controls. Only the control for whether the victim was ejected alters appreciably our estimate of the relationship between vehicle type and rollovers, and even there sizable differences among vehicle types remain. For side impacts, no control variable, taken by itself, does much to alter our conclusion about the sizable differences between vehicle types.

**Table I.8: Likelihood-Ratio Chi-Square Values and Other Characteristics Associated With Hierarchical Models Fitted to the Six-Way Tables Formed by Cross-Classifying Rollovers and Side Impacts With Vehicle Type and Selected Driver/Victim Characteristics**

| Model | Marginals fitted |
|---|---|
| 1 | [SADRV] [Z] |
| 2 | [SADRV] [SADRZ] |
| 3 | [SADRV] [SADRZ] [VZ] |
| 4 | [SADRV] [SADRZ] [SVZ] |
| 5 | [SADRV] [SADRZ] [AVZ] |
| 6 | [SADRV] [SADRZ] [DVZ] |
| 7 | [SADRV] [SADRZ] [RVZ] |
| 8 | [SADRV] [SADRZ] [SVZ] [DVZ] |

## Hierarchical Models With Simultaneous Controls for Driver/ Victim and Roadway/ Accident Characteristics

It may be that while no control variable greatly attenuates the initial relationships we found when we consider them serially, they do so when we consider them simultaneously. Unfortunately, the contingency table approach demanded by the categorical nature of independent variables, combined with the small number of fatalities for certain vehicle types (especially small vans), does not permit us to build and analyze tables in which all control variables are considered at once. We were able, however, to control for certain of these variables in blocks, by exploring two pairs of six-way tables in which rollovers, and then side impacts, were cross-classified by vehicle type and certain characteristics of drivers and victims, and then by vehicle type and certain characteristics of accidents and roadways.

Table I.8 provides information about various hierarchical models fitted to the two six-way tables in which rollovers and side impacts are cross-classified by vehicle type and by the following characteristics of drivers and victims: sex of driver, age of driver, whether the driver had been drinking, and whether the victim was using restraints.[3]

[3]After analysis of the interrelationships of the control variables and consultation with NHTSA researchers, we decided to omit ejection from our control variables for these models. Restraint use is highly correlated with ejection. The use of both control variables simultaneously would result in numerous empty or sparse cells. More substantively, ejection can itself be considered a function of vehicle type and therefore could introduce a spurious control into our analysis of the effect of vehicle type.

| Rollover | | | | Side Impact | | | |
|---|---|---|---|---|---|---|---|
| Degrees of freedom | $L^2$ | P | Proportion of variation explained | Degrees of freedom | $L^2$ | P | Proportion of variation explained |
| 93 | 3,766.99 | < .0001 | .00 | 93 | 1,371.23 | < .0001 | .00 |
| 78 | 1,605.31 | < .0001 | .57 | 78 | 737.02 | < .0001 | .46 |
| 73 | 128.72 | < .001 | .97 | 73 | 99.75 | .021 | .93 |
| 68 | 103.09 | .004 | .97 | 68 | 98.32 | .009 | .93 |
| 68 | 120.39 | < .001 | .97 | 68 | 91.34 | .031 | .93 |
| 68 | 99.90 | .007 | .97 | 68 | 97.23 | .012 | .93 |
| 68 | 126.68 | < .001 | .97 | 68 | 84.41 | .086 | .94 |
| 63 | 80.24 | .070 | .98 | | | | |

S = driver's sex; A = driver's age; D = drinking driver; R = restraint use; V = vehicle type; Z = rollover or side impact

The first model fitted to both tables was again the logit-specified model of independence, which allows vehicle type to be related to each of the control variables (that is, driver/victim characteristics) in the table but asserts that rollovers and side impacts are independent of both vehicle type and all of these controls. The large values of chi-square associated with this model suggest that it does not fit the data acceptably, and because it posits that the odds on rollovers and side impacts are the same across all of the joint categories of the factors in the table, it does not account for any of the variation in those odds. Model 2, which allows all factors except for vehicle type to be related in an unconstrained or interactive fashion with rollovers and side impacts, improves significantly upon this first model and accounts for 57 and 46 percent, respectively, of the variation in the odds on rollovers and side impacts.

More importantly, model 3 improves significantly upon model 2. After controlling for the associations of the driver/victim characteristics with vehicle type, and the associations of driver/victim characteristics with rollovers and side impacts, model 3 allows an association of vehicle type with rollovers and side impacts. The significant improvement of model 3 on model 2 implies that the vehicle type/rollover and vehicle type/side-impact associations persist even after controlling for these characteristics simultaneously.

Model 3 does not, strictly speaking, fit the data acceptably in either of these two tables ($P < .05$)—that is, a statistically significant amount of variation due to interactions among the control variables, vehicle type, and the outcome variable remains to be explained. Nevertheless, it does account for the large bulk of the variation in the odds on rollovers (97 percent) and side impacts (93 percent).

Further analysis indicates that securing a model for rollovers that fits the data acceptably requires the inclusion of interactions between sex of driver, vehicle type, and rollovers, and between drinking driver, vehicle type, and rollovers.[4] For side impacts, an acceptable fit of model to data is achieved by allowing an interaction between restraint use, vehicle type, and side impact.[5] We will discuss the nature of these interactions below, after discussing the implications of model 3. However, it should be noted here that these interactions do not account for much of the variation in rollovers or side impacts, nor even much of that variation which is directly attributable to vehicle type.

To reestimate the association of vehicle type with rollovers and side impacts after these simultaneous controls, we can calculate the expected frequencies under the third model fitted to the data in each of the four tables considered and derive from them the odds and odds ratios as before.

Tables I.9 through I.11 contain an example of this procedure for a model of the effect of vehicle type on rollovers, after controlling for the effect of our driver/victim characteristics. In multivariate tables of this nature, we can calculate odds within categories of vehicle type and within categories in the joint distribution of the four other variables being controlled for. For multipurpose-vehicle fatalities, for example, among accidents involving male drivers under 25 who were drinking and not using restraints, the odds on rollovers having been involved were 2.047 (135.70/66.30). For passenger-car fatalities, the odds on rollovers having occurred for that same group defined by that specific combination of control categories was 0.351 (1206.71/3438.29).

[4]Note that models 4 and 6, which include these interactions one at a time, improve significantly on model 3, and that model 8, which includes both interactions, improves significantly on both models 4 and 6.

[5]Model 7 fits the data acceptably ($P < .05$) and significantly improves on model 3.

As in our previous example, the odds ratio indicating the greater likelihood of rollovers for multipurpose-vehicle fatalities relative to passenger-car fatalities is obtained by dividing the former odds by the latter. For this case, the odds ratio of multipurpose vehicles to passenger cars is 5.83 (2.047/0.351). Odds on rollovers can similarly be obtained for other vehicle types, and ratios contrasting those odds can be obtained by using the passenger-car odds as the criterion.[6]

[6]The odds ratios relative to passenger cars calculated from this model remain the same for each vehicle type across each category of the control variables, since this constraint is specified in the model. These odds ratios would vary somewhat across categories in models that allow for vehicle-type/control-variable interactions.

**Table I.9: Expected Frequencies Under the Main-Effect Model for the Six-Way Table in Which Rollovers Are Cross-Classified by Vehicle Type and Driver/Victim Characteristics**

| Sex | Age | Drinking | Restraint used |
|---|---|---|---|
| Male | Under 25 | Yes | No |
| | | | Yes |
| | | No | No |
| | | | Yes |
| | 25 and over | Yes | No |
| | | | Yes |
| | | No | No |
| | | | Yes |
| Female | Under 25 | Yes | No |
| | | | Yes |
| | | No | No |
| | | | Yes |
| | 25 and over | Yes | No |
| | | | Yes |
| | | No | No |
| | | | Yes |

| | Odds on rollover | | | | | |
|---|---|---|---|---|---|---|
| Rollover | Multipurpose vehicle | Standard van | Small van | Small pickup | Standard pickup | Passenger car |
| Yes | 135.70 | 38.76 | 1.89 | 223.02 | 345.92 | 1,206.71 |
| No | 66.30 | 52.24 | 3.11 | 245.98 | 420.08 | 3,438.29 |
| Yes | 11.20 | 0.48 | 0.00 | 4.47 | 3.64 | 41.21 |
| No | 12.80 | 1.52 | 0.00 | 11.53 | 10.36 | 274.79 |
| Yes | 63.56 | 35.13 | 3.09 | 136.36 | 191.40 | 655.46 |
| No | 48.44 | 73.87 | 7.91 | 234.64 | 362.60 | 2,913.54 |
| Yes | 7.78 | 1.10 | 0.13 | 4.43 | 4.10 | 36.46 |
| No | 15.22 | 5.90 | 0.87 | 19.57 | 19.90 | 415.54 |
| Yes | 184.80 | 93.26 | 11.57 | 271.54 | 592.67 | 1,177.16 |
| No | 116.20 | 161.75 | 24.43 | 385.46 | 926.33 | 4,316.84 |
| Yes | 11.70 | 3.08 | 0.88 | 9.48 | 10.79 | 62.08 |
| No | 12.30 | 8.92 | 3.12 | 22.52 | 28.21 | 380.92 |
| Yes | 98.13 | 63.78 | 8.56 | 144.58 | 284.69 | 634.25 |
| No | 161.87 | 290.22 | 47.44 | 538.42 | 1,167.31 | 6,101.75 |
| Yes | 8.51 | 5.11 | 3.08 | 10.87 | 11.44 | 81.99 |
| No | 29.49 | 48.89 | 35.92 | 85.13 | 98.56 | 1,658.01 |
| Yes | 9.85 | 2.31 | 0.83 | 28.20 | 26.88 | 285.93 |
| No | 4.15 | 2.69 | 1.17 | 26.80 | 28.12 | 702.07 |
| Yes | 0.53 | 0.00 | 0.25 | 1.34 | 0.31 | 13.56 |
| No | 0.47 | 0.00 | 0.75 | 2.66 | 0.69 | 69.44 |
| Yes | 25.42 | 6.96 | 1.45 | 34.33 | 36.91 | 367.94 |
| No | 18.58 | 14.04 | 3.55 | 56.67 | 67.09 | 1,569.06 |
| Yes | 2.03 | 0.33 | 0.09 | 1.44 | 0.60 | 20.51 |
| No | 5.97 | 2.67 | 0.91 | 9.56 | 4.40 | 352.49 |
| Yes | 18.84 | 4.32 | 1.58 | 28.09 | 26.12 | 275.06 |
| No | 12.16 | 7.68 | 3.42 | 40.91 | 41.88 | 1,034.94 |
| Yes | 2.12 | 0.21 | 0.36 | 0.49 | 0.46 | 13.36 |
| No | 2.88 | 0.79 | 1.64 | 1.51 | 1.54 | 105.64 |
| Yes | 25.70 | 17.97 | 5.22 | 32.94 | 41.67 | 466.50 |
| No | 36.30 | 70.03 | 24.78 | 105.06 | 146.33 | 3,843.50 |
| Yes | 4.14 | 2.20 | 1.00 | 2.42 | 2.42 | 62.83 |
| No | 14.86 | 21.80 | 12.00 | 19.58 | 21.58 | 1,316.17 |

**Table I.10: Odds Derived From the Main-Effect Model for the Six-Way Table in Which Rollovers Are Cross-Classified by Vehicle Type and Driver/Victim Characteristics**

| Sex | Age | Drinking | Restraint used |
|---|---|---|---|
| Male | Under 25 | Yes | No |
| | | | Yes |
| | | No | No |
| | | | Yes |
| | 25 and over | Yes | No |
| | | | Yes |
| | | No | No |
| | | | Yes |
| Female | Under 25 | Yes | No |
| | | | Yes |
| | | No | No |
| | | | Yes |
| | 25 and over | Yes | No |
| | | | Yes |
| | | No | No |
| | | | Yes |

| Rollover | Odds on rollover: Multipurpose vehicle | Standard van | Small van | Small pickup | Standard pickup | Passenger car |
|---|---|---|---|---|---|---|
| Yes<br>No | 2.047 | 0.742 | 0.608 | 0.907 | 0.823 | 0.351 |
| Yes<br>No | 0.875 | 0.316 | N/A | 0.388 | 0.351 | 0.150 |
| Yes<br>No | 1.312 | 0.476 | 0.391 | 0.581 | 0.528 | 0.225 |
| Yes<br>No | 0.511 | 0.186 | 0.149 | 0.226 | 0.206 | 0.088 |
| Yes<br>No | 1.590 | 0.577 | 0.474 | 0.704 | 0.640 | 0.273 |
| Yes<br>No | 0.951 | 0.345 | 0.282 | 0.421 | 0.382 | 0.163 |
| Yes<br>No | 0.606 | 0.220 | 0.180 | 0.269 | 0.244 | 0.104 |
| Yes<br>No | 0.289 | 0.105 | 0.086 | 0.128 | 0.116 | 0.049 |
| Yes<br>No | 2.373 | 0.859 | 0.709 | 1.052 | 0.956 | 0.407 |
| Yes<br>No | 1.128 | N/A | 0.333 | 0.504 | 0.449 | 0.195 |
| Yes<br>No | 1.368 | 0.496 | 0.408 | 0.606 | 0.550 | 0.234 |
| Yes<br>No | 0.340 | 0.124 | 0.099 | 0.151 | 0.136 | 0.058 |
| Yes<br>No | 1.549 | 0.563 | 0.462 | 0.687 | 0.624 | 0.266 |
| Yes<br>No | 0.736 | 0.266 | 0.220 | 0.325 | 0.299 | 0.126 |
| Yes<br>No | 0.708 | 0.257 | 0.211 | 0.314 | 0.285 | 0.121 |
| Yes<br>No | 0.279 | 0.101 | 0.083 | 0.124 | 0.112 | 0.048 |

**Table I.11: Odds Ratios Derived From the Main-Effect Model for the Six-Way Table in Which Rollovers Are Cross-Classified by Vehicle Type and Driver/Victim Characteristics**

| Sex | Age | Drinking | Restraint used |
|---|---|---|---|
| Male | Under 25 | Yes | No |
| | | | Yes |
| | | No | No |
| | | | Yes |
| | 25 and over | Yes | No |
| | | | Yes |
| | | No | No |
| | | | Yes |
| Female | Under 25 | Yes | No |
| | | | Yes |
| | | No | No |
| | | | Yes |
| | 25 and over | Yes | No |
| | | | Yes |
| | | No | No |
| | | | Yes |

| Rollover | Odds ratios relative to passenger cars: Multipurpose vehicle | Standard van | Small van | Small pickup | Standard pickup |
|---|---|---|---|---|---|
| Yes<br>No | 5.83 | 2.11 | 1.74 | 2.58 | 2.35 |
| Yes<br>No | 5.83 | 2.11 | N/A | 2.58 | 2.35 |
| Yes<br>No | 5.83 | 2.11 | 1.74 | 2.58 | 2.35 |
| Yes<br>No | 5.83 | 2.11 | 1.74 | 2.58 | 2.35 |
| Yes<br>No | 5.83 | 2.11 | 1.74 | 2.58 | 2.35 |
| Yes<br>No | 5.83 | 2.11 | 1.74 | 2.58 | 2.35 |
| Yes<br>No | 5.83 | 2.11 | 1.74 | 2.58 | 2.35 |
| Yes<br>No | 5.83 | 2.11 | 1.74 | 2.58 | 2.35 |
| Yes<br>No | 5.83 | 2.11 | 1.74 | 2.58 | 2.35 |
| Yes<br>No | 5.83 | N/A | 1.74 | 2.58 | 2.35 |
| Yes<br>No | 5.83 | 2.11 | 1.74 | 2.58 | 2.35 |
| Yes<br>No | 5.83 | 2.11 | 1.74 | 2.58 | 2.35 |
| Yes<br>No | 5.83 | 2.11 | 1.74 | 2.58 | 2.35 |
| Yes<br>No | 5.83 | 2.11 | 1.74 | 2.58 | 2.35 |
| Yes<br>No | 5.83 | 2.11 | 1.74 | 2.58 | 2.35 |
| Yes<br>No | 5.83 | 2.11 | 1.74 | 2.58 | 2.35 |

**Table I.12: Likelihood-Ratio Chi-Square Values and Other Characteristics Associated With Hierarchical Models Fitted to the Six-Way Tables Formed by Cross-Classifying Rollovers and Side Impacts With Vehicle Type and Selected Accident/Roadway Characteristics**

| Model | Marginals fitted |
|---|---|
| 1 | [RMCWV] [Z] |
| 2 | [RMCWV] [RMCWZ] |
| 3 | [RMCWV] [RMCWZ] [VZ] |
| 4 | [RMCWV] [RMCWZ] [RVZ] |
| 5 | [RMCWV] [RMCWZ] [MVZ] |
| 6 | [RMCWV] [RMCWZ] [CVZ] |
| 7 | [RMCWV] [RMCWZ] [WVZ] |
| 8 | [RMCWV] [RMCWZ] [MVZ] [CVZ] |

The results of such calculations can be summarized by the odds ratios provided in table I.11. After controls were introduced for these driver/victim characteristics, multipurpose-vehicle fatalities remained more than five times as likely as passenger-car fatalities to have involved a rollover. Both types of pickups, and standard vans as well, were more than twice as likely as passenger cars to have involved a rollover, and small vans were almost twice as likely.

When we fitted a series of models involving roadway and accident characteristics to our rollover and side-impact data, we reached conclusions about the preferred models similar to those derived from our driver/victim models. Table I.12 presents a summary of these hierarchical models.

As Table I.12 shows, for both the rollover and side-impact data, model 2 improves significantly on model 1, and model 3 improves significantly on model 2. Moreover, model 3 accounts for the great bulk of the variation in rollovers (99 percent) and side impacts (97 percent) and, in the case of side impacts, it fits the data acceptably and is not improved on significantly by models 4 through 7, which include interaction terms. For the rollover table, none of the models (including three-way

| Rollover | | | | Side impact | | | |
|---|---|---|---|---|---|---|---|
| Degrees of freedom | $L^2$ | P | Proportion of variation explained | Degrees of freedom | $L^2$ | P | Proportion of variation explained |
| 94 | 12,148.64 | < .0001 | .00 | 94 | 2,716.21 | < .0001 | .00 |
| 79 | 986.70 | < .0001 | .92 | 79 | 597.01 | < .0001 | .78 |
| 74 | 177.19 | < .0001 | .99 | 74 | 93.27 | .05 | .97 |
| 69 | 167.83 | < .0001 | .99 | 69 | 85.29 | .05 | .97 |
| 69 | 117.37 | < .001 | .99 | 69 | 82.59 | .10 | .97 |
| 69 | 165.11 | < .0001 | .99 | 69 | 85.87 | .05 | .97 |
| 69 | 170.17 | < .0001 | .99 | 69 | 87.10 | .05 | .97 |
| 64 | 106.40 | < .001 | .99 | | | | |

Note: R = rural road; M = multi-vehicle accident; C = curved road; W = wet road; V = vehicle type; Z = rollover or side impact

interactions) fit the data, which implies the existence of significant higher order—that is, four-way or five-way—interactions. Given the large proportion of variation explained by the models we have considered, however, it seems reasonable to assume that such interactions are substantively trivial in spite of their statistical significance.[7]

A summary of the odds ratios obtained from each of our four preferred models is presented in table I.13. We have already presented a detailed interpretation of the odds ratios for rollover models considering driver/victim characteristics. We found similar results when we controlled for accident/roadway characteristics, although controlling for this set of characteristics does diminish our estimate of the differences between all type of vehicles (with the exception of small vans) and passenger cars. These associations persist, however, and remain quite sizable even after introducing these controls.

[7] Among the models provided in table I.12 for the rollover data, it would appear that the only three-way interaction of any importance is the one involving multi-vehicles, vehicle type, and rollovers, inasmuch as model 5, which includes that interaction, improves significantly on model 3 and is not itself improved on by model 8, which includes another interaction that had appeared significant in the absence of this one. This interaction will be discussed but caution must be applied in interpreting it. In spite of its statistical significance—which is achieved rather easily in working with samples of this size—it accounts for very little of the variation in the odds on rollovers.

**Table I.13: Odds Ratios Describing the Associations of Vehicle Type With Rollovers and Side Impacts, After Controlling for Driver/Victim Characteristics and Accident/Roadway Characteristics** (Derived From Main-Effects Models)

| | Ratios of odds on rollovers, relative | | |
|---|---|---|---|
| Variables controlled for | Multipurpose vehicle | Standard van | Small van |
| Driver/victim characteristics | 5.83 | 2.11 | 1.74 |
| Accident/roadway characteristics | 4.59 | 1.99 | 1.88 |

The association of vehicle type with side impacts also persists after we control for either the driver/victim or accident/roadway characteristics. Multipurpose-vehicle, standard-van, and pickup fatalities are only roughly half as likely as passenger-car fatalities to have involved a side impact, and small-van fatalities are slightly less than two thirds as likely.

## Higher Order Interactions

The odds ratios estimating these associations of interest that are presented in table I.13 were derived from models that constrain those associations to be equally large across all categories of the control variables employed. As we noted, however, there is some evidence of certain interactions present. The nature of those interactions is demonstrated in tables I.14 and I.15, where we have reestimated odds ratios using interaction models.

**Table I.14: Odds Ratios Describing Interactions of Vehicle Type With Other Characteristics on Rollovers**

| | Ratios of odds on rollovers, relative to passenger cars | | | | |
|---|---|---|---|---|---|
| Categories of interacting variables | Multipurpose vehicle | Standard van | Small van | Small pickup | Standard pickup |
| Male drivers, drinking | 4.75 | 1.50 | 1.35 | 2.27 | 2.31 |
| Male drivers, not drinking | 6.95 | 2.43 | 2.47 | 2.60 | 2.22 |
| Female drivers, drinking | 5.27 | 2.38 | 0.79 | 3.40 | 2.90 |
| Female drivers, not drinking | 7.72 | 3.87 | 1.45 | 3.89 | 2.79 |
| Multi-vehicle accident | 9.74 | 4.13 | 2.28 | 3.14 | 2.88 |
| Single-vehicle accident | 3.87 | 1.68 | 1.82 | 2.14 | 1.65 |

| to passenger cars | | Ratio of odds on side impacts, relative to passenger cars | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Small pickup | Standard pickup | Multipurpose vehicle | Standard van | Small van | Small pickup | Standard pickup |
| 2.58 | 2.35 | 0.42 | 0.53 | 0.60 | 0.50 | 0.50 |
| 2.25 | 1.76 | 0.49 | 0.54 | 0.60 | 0.53 | 0.54 |

We noted, for example, that it appeared that the vehicle type/rollover association interacted with sex of driver, whether the driver was drinking, and whether multiple vehicles were involved. This can be seen in the odds ratios presented in tables I.14, and I.15, as can the interaction of vehicle type with rollovers and side impacts. For all types of non-passenger cars relative to passenger cars, differences in the odds on fatalities involving rollovers appear to be more pronounced when drivers were female, when drivers were not drinking, and when multiple vehicles were involved. Also, non-passenger car/passenger car differences in the odds on side impacts were more pronounced when restraints were used than when they were not.

**Table I.15: Odds Ratios Describing Interactions of Vehicle Type With Other Characteristics on Side Impacts**

| | Ratio of odds on side impacts, relative to passenger cars | | | | |
| --- | --- | --- | --- | --- | --- |
| Categories of interacting variables | Multipurpose vehicle | Standard van | Small van | Small pickup | Standard pickup |
| No restraint use | 0.43 | 0.59 | 0.56 | 0.50 | 0.51 |
| Restraint use | 0.37 | 0.22 | 0.68 | 0.47 | 0.39 |

As discussed previously, however, the improvement in our understanding of rollovers or side impacts afforded by these models, while statistically significant, is slight. In only one case—that of female drivers of small vans who had been drinking—is the odds ratio to passenger cars reversed. This anomaly should be considered a statistical artifact of the small number of small vans, and particularly of this subcategory of small-van fatalities, in our sample.[8]

[8]Only ten of the nearly 44,000 cases in our sample fall into this subcategory.

# Results of Prior Research

Researchers appear to agree that a disproportionate share of the single-car-accident fatalities occurring on our nation's streets and highways involve occupants of small trucks and multipurpose vehicles. While study results suggest that the rollover tendencies of small trucks and multipurpose vehicles may reflect vehicle characteristics—such as a high center of gravity in relation to vehicle track width—every study cautions that various characteristics of drivers and vehicle use may affect the results. Because these factors have not been considered in previous research, researchers have not been able to conclude that higher fatality rates are due to inherent characteristics of these vehicles.

To determine what research has been done on the subject of light-truck, van, and multipurpose-vehicle safety, we searched the National Highway Traffic Safety Administration (NHTSA), Department of Transportation (DOT), University of Michigan Transportation Research Institute (UMTRI), and GAO libraries for research on highway safety, with specific emphasis on studies dealing with fatalities. These libraries collectively contain most of the research in the highway safety area. We identified over one hundred research citations pertaining to small truck and van safety, motor vehicle safety standards, and the extension of those standards to small trucks and vans.

We reviewed all identified research to determine its relevance to our analysis—specifically, to identify those studies that compared fatality experience by vehicle type and/or by vehicle type and type of impact (side impact or rollover). We found eight studies comparing the fatality experience of small trucks, vans, and multipurpose vehicles to that of passenger cars, with emphasis on type of impact.

Although most of the studies based their results on the type of vehicle involved in the accident (adjusted to reflect vehicle exposure), none of the studies accounted for the amount and type of use each vehicle type received—that is, annual number of miles driven in total or for specific purposes. Of the eight studies, four used registration data for the exposure measurement; one used vehicle production data combined with scrap-rate information as a proxy for estimating the number of vehicles in use; one limited itself to toll roads for which accurate exposure rates, using miles traveled, could be obtained; and two used no measure of exposure, basing their results on investigations of samples of vehicles involved in accidents.

- light truck occupant-injury rates in multi-vehicle crashes were generally lower than passenger car occupant-injury rates in multi-vehicle crashes;
- light trucks have higher rollover and occupant-ejection rates than do passenger cars, which creates a greater potential for injuries to their occupants as compared to occupants of passenger cars; and lastly,
- light trucks as striking vehicles were found to have a greater tendency to injure occupants of the struck vehicle—that is, they appear to be more "aggressive" than passenger cars.

## A Further Look at Utility Vehicle Rollovers, 1984

This study was a follow-up to a 1981 report by Reinfurt, et al., that analyzed the relative involvement in rollover crashes of utility vehicles (also referred to as jeeps), pickup trucks, and passenger cars, using crash data from North Carolina (1973-78), Maryland (1974-78), and the Fatal Accident Reporting System (1978-79). The highlight of the results of the earlier study was that smaller vehicles generally had higher rates of rollover involvement than larger vehicles.[3]

This follow-up study examined more recent crash data for North Carolina (1979-82) that included several additional utility-vehicle models for which data were previously inadequate or nonexistent.[4] Also, this report estimated vehicle-specific mileage exposure from newly available data. As was found in the earlier study, rollovers occurred approximately ten times as often in single-vehicle crashes as in multi-vehicle crashes. Among the vehicle groups, utility vehicles had, by a considerable margin, the highest involvement rate in single-vehicle rollover crashes; pickups and cars were equally involved in single-vehicle rollover crashes, at a rate of involvement that was considerably lower than that for utility vehicles. In addition, the study found that utility vehicles had serious or fatal driver injury rates that were approximately three times higher than the rates for pickups or passenger cars.

The authors stressed that, as indicated by earlier literature, track width and center of gravity of a vehicle are very important factors with respect to rollovers.[5] Utility vehicles have a higher center of gravity and

[3]D. W. Reinfurt, et al., A Comparison of the Crash Experience of Utility Vehicles, Pickup Trucks, and Passenger Cars (Chapel Hill, N.C.: The University of North Carolina Highway Safety Research Center and the Washington, D.C., Insurance Institute for Highway Safety, 1981).

[4]D. W. Reinfurt, et. al., A Further Look at Utility Vehicle Rollovers (Chapel Hill, N.C.: The University of North Carolina Highway Safety Research Center, 1984, 1985).

[5]See J. W. Garrett, "A Study of Rollover in Rural United States Automobile Accidents," Society of Automotive Engineers, Paper No. 680772, 1969.

## Side Impacts: An Analysis of Light Trucks, Intrusion, and Injury in FARS and NCSS Data, 1982

In this report, side impacts of light trucks were studied using 1979 FARS data and data from NCSS.[7] Vehicle types included within the light-truck category were pickups, small vans, and large station wagons.

Study results indicated that 12.5 percent of the fatalities in light trucks resulted from side impacts. Within the light-truck category, pickups accounted for nearly 85 percent of the light truck side-impact fatalities, and small vans accounted for only 13.5 percent.

The study further disclosed that there is a high correlation between intrusion into the passenger compartment and serious injury in side-impacted vehicles. However, the authors stressed that it is not clear whether the correlation is due to the intrusion by itself or to the greater impact severity associated with the intrusion.

## Comparison of Truck and Passenger-Car Accident Rates on Limited-Access Facilities, 1981

In this study, vehicles were classified into three broad categories—passenger cars, light trucks, and heavy trucks.[8] Vehicles were classified into three broad categories—passenger cars, light trucks, and heavy trucks. The study conducted a nationwide survey of 1976 through 1978 accident rates for 34 limited-access facilities. These included 21 toll expressways and turnpikes and 13 bridges and tunnels for which accurate exposure rates using vehicle miles traveled could be obtained. The results showed that the fatal-accident rate for light trucks on expressways was significantly greater than that for passenger cars. On the average, light trucks were involved in 2.35 times more fatal accidents than were passenger cars for the same distance traveled.

## Recent Trends in Van and Small Truck Safety, 1979

This study examined whether small truck and van safety had been compromised due to the exclusion of these vehicle types from certain Federal Motor Vehicle Safety Standards (FMVSS).[9] For its exposure measurement, the study used vehicle production data combined with scrap-rate information to estimate the number of vehicles in use. Using data from the 1977 FARS data base, the study found that pickup trucks

[7] R. E. Scott, Side Impacts: An Analysis of Light Trucks, Intrusion, and Injury in FARS and NCSS Data (Ann Arbor: The University of Michigan Transportation Research Institute, 1982).

[8] W.E. Myers, "Comparison of Truck and Passenger-Car Accident Rates on Limited-Access Facilities," Transportation Research Record, 808 (1981), pp. 48-55.

[9] J. O'Day and R. Kaplan, "Recent Trends in Van and Small Truck Safety," Society of Automotive Engineers Technical Paper, 1979.

# Major Contributors to This Report

## Program Evaluation and Methodology Division, Washington, D.C.

Michael J. Wargo, Director
Richard T. Barnes, Assistant Director
Roy R. Jones, Project Manager
Dale Harrison, Project Advisor
Robert E. White, Project Advisor

## Kansas City Regional Office

David E. Ashley, Regional Manager Representative
Denise M. Wempe, Deputy Project Manager
Donald L. Ficklin, Computer Analyst
Thomas M. Cook, Project Staff
Kimberli S. Hagberg, Project Staff

United States
General Accounting Office
Washington, D.C. 20548

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