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Factors Related to Fatal Single-Vehicle Run-Off-Road Crashes

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16. Abstract

Run-Off-Road crashes cause a large proportion of fatalities and serious injuries to the vehicle occupants. In this study, fatal crashes from the Fatality Analysis Reporting System for passenger vehicles (passenger cars and LTVs) during the period 1991 to 2007 were used to identify the roadway- (*e.g.*, rural/urban nature and curve existence), driver- (*e.g.*, age, gender, drowsy, and alcohol use), environmental- (*e.g.*, weather, lighting condition), and vehicle-related factors (*e.g.*, speeding) associated with the fatal single-vehicle run-off-road crashes.

The results show that the factors driver sleep, drivers with alcohol use, roadway alignment with curve, speeding vehicle, passenger car, rural roadway, high speed limit road, and adverse weather were significant factors related to the high risk of fatal single-vehicle run-off-road crashes. Also, in the adverse weather condition and for the younger drivers, the vehicle speeding would increase the risk of fatal single-vehicle run-off-road crashes by an additional factor.

17. Key Words	18. Distribution Statement
Run-off-road, ROR, Passenger vehicle, Fatal single-vehicle crashes, FARS, Rural, Age, Alcohol, Gender, Driver-related factor, Sleep, Inattention, Over correction, Avoiding	Document is available to the public from the National Technical Information Service www.ntis.gov

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Executive Summary

A vehicle in transport sometimes leaves the travel lane and encroaches onto the shoulder, median, roadside, parking lane, gore, or a separator and hits one or more natural or artificial objects. This event usually involves a single vehicle and is referred to as a run-off-road (ROR) crash. ROR crashes contribute to a large proportion of fatalities and serious injuries to the vehicle occupants in fatal single-vehicle crashes (around 70% of the fatal single-vehicle crashes are ROR crashes).

In this study, the data from the Fatality Analysis Reporting System (FARS) for fatal crashes involving passenger vehicles (passenger cars, vans, pickup trucks, and utility vehicles) during the period 1991 to 2007 were used to identify the roadway-, driver-, environment-, and vehicle-related factors associated with fatal single-vehicle ROR crashes. The data pertaining only to fatal single-vehicle ROR crashes was used; in multiple-vehicle crashes, one vehicle running off the road could result from its collision with other vehicles.

The single-vehicle crashes were categorized into two groups: run-off-road (ROR) crashes and on-road (OR) crashes in which the vehicle remained on the road after the crash. The single-vehicle OR crashes may involve a pedestrian, bicyclist, train, an animal, or it may be an on-road rollover, a vehicle hitting a median divider or falling trees on the roadway, etc. In this report, the descriptive (univariate) analysis of the relationship between selected factors (variables) was conducted to estimate the likelihood of a vehicle involvement in fatal single-vehicle ROR and OR crashes. The impact of these related factors is also assessed by logistic regression procedure in which the OR crashes essentially form one element of the binary outcome of a crash (on-road versus off-the-road). This procedure helps to assess their relative influence as well as estimate the amount of risk each carries in the occurrence of such crashes.

<u>This study only uses data on fatal single-vehicle crashes, and therefore the results of this analysis should not be interpreted to be representative of all police-reported crashes. Also, because the comparisons are made between single-vehicle ROR and OR crashes, it is possible that the factors that differ between these two types of crashes are not necessarily associated solely with these two types of crashes.</u>

The following are some highlights from the analyses conducted in this study.

- Drivers with alcohol use are more likely to be involved in ROR crashes as compared to the sober drivers. Among the drivers with alcohol use (blood alcohol concentration, BAC=.01+ grams per deciliter), 86.5 percent of them were involved in ROR crashes, while among the sober drivers (BAC=0), 58.3 percent of them were involved in ROR crashes.

- Speeding vehicles are more likely to be involved in ROR crashes as compared to the non-speeding vehicles. Among the vehicles that were speeding, 90 percent were involved in ROR crashes, while among vehicles that were not speeding, 59.5 percent were involved in ROR crashes.

- Curved road segments are more likely to be the scene of ROR crashes as compared to the straight roadways. Among the crashes that occurred on curved roads, 90.2 percent of them were ROR crashes, while among those that occurred on straight roadways, 62.1 percent were ROR crashes.

- Rural roads are more likely to be the scene of ROR crashes as compared to the urban roads. Among all crashes that occurred on rural roadways, 80.6 percent of them were ROR crashes, while among the crashes that occurred on urban roadways, 56.2 percent of them were ROR crashes.

- In most cases, the actual vehicle's pre-crash travel speed is unknown. In this analysis the posted speed limit was used as a proxy to a vehicle's travel speed. Among all the crashes that occurred on roadways with posted speed limits of 60 mph and above, 81 percent were in ROR crashes; while among the crashes that occurred on roadways with speed limits less than 60 mph, 69 percent of the vehicles were in ROR crashes. The high speed limit roads are more likely to be the scene of ROR crashes as compared to the low speed limit roads.

- Roadways with fewer lanes (one or two lanes) are more likely to be the scene of ROR crashes as compared to the roadways with three and more lanes (divided or undivided). Among all the crashes that occurred on roadways with fewer lanes, 67.8 percent (divided) and 76.6 percent (undivided) were ROR crashes, while among the crashes that occurred on roads with three and more lanes, 62 percent (divided) and 40 percent (undivided) were ROR crashes.

- ROR crashes are more likely to occur in adverse weather conditions (rain, sleet, snow, fog, fog, and others - smog, smoke, blowing sand, or dust) as compared to good weather conditions (normal or clear). Among the crashes that occurred in adverse weather conditions, 75.5 percent of the crashes were ROR crashes; while among those crashes that occurred in good weather conditions, 70 percent were ROR crashes.

- ROR crashes are more likely to occur during nighttime as compared to the daytime. Among the crashes that occurred during nighttime (8 p.m. – 5:59 a.m.), 74.2 percent were ROR crashes; while among those crashes that occurred during the day time period (6 a.m. – 7:59 p.m.), 66.5 percent were ROR crashes.

- Vehicles with high occupancy (two or more occupants) are more likely to be involved in ROR crashes as compared to the vehicles with drivers alone. Among crashes involving vehicles with the drivers as the only occupants, 68.0 percent were ROR crashes; while among vehicles involved with two or more occupants, 74.8 percent were ROR crashes.

- Vehicles driven by young drivers (age 15 to 24) are more likely to be involved in ROR crashes as compared to other age groups of drivers.

- Vehicles with male drivers are more likely to be involved in ROR crashes as compared to the vehicles with female drivers.

- Drivers with performance-related factors such as sleepiness, inattentiveness, over-correction of the vehicle, or crash-avoiding are more likely to be involved in ROR crashes as compared to other driver-performance-related factors. The percentages of sleepy (91.2%), inattentive (75.4%), over-correction of the vehicle (85.6%), and crash-avoiding (79.8%) drivers involved in fatal single-vehicle ROR crashes are significantly greater ($p < 0.0001$) than the drivers with other performance-related factors that account for 67 percent of ROR crashes.

- Among all passenger vehicles (passenger cars, vans, pickup trucks, and utility vehicles), passenger cars are more likely to be involved in fatal single-vehicle ROR crashes as compared to other passenger vehicle types.

- Logistic regression modeling was used to assess their relative influence as well as estimate the amount of risk each factor carries in the occurrence of such crashes. It shows that the most influential factor in the occurrence of fatal single-vehicle ROR crashes is the driver performance-related factor: sleepy, followed by alcohol use, roadway alignment with curve, vehicle speeding, passenger car, rural roadway, high-speed-limit road, adverse weather, and crash-avoiding. In the adverse weather condition and for the younger drivers (15 to 24 and age 25 to 44), the vehicle speeding would increase the risk of fatal single-vehicle ROR crashes by an additional factor.

1. Introduction

A vehicle in transport sometimes leaves the travel lane and encroaches onto the shoulder, median, roadside, parking lane, gore, or a separator and hits one or more natural or artificial objects. This event usually involves a single vehicle and is referred to as a run-off-road crash. ROR crashes contribute to a large proportion of fatalities and serious injuries to the vehicle occupants in fatal single-vehicle crashes -- around 70 percent of the fatal single-vehicle crashes are ROR crashes. In contrast, there are crashes in which a vehicle remains on the road after the crash and are referred as on-road crashes. The single-vehicle OR crashes may involve a pedestrian, bicyclist, train, an animal, or it may be an on-road rollover, a vehicle hitting a median divider, or falling trees on the roadway, etc. The OR crashes contribute to around 30 percent of the fatal single-vehicle crashes.

The total number of passenger vehicle fatal single-vehicle crashes (bar graph, right label) and the percentage that were ROR crashes (line graph, left label) from 1991 to 2007 are shown in Figure 1. The total numbers of fatal single-vehicle crashes fluctuate over the years 1991 to 2007. However, the percent of ROR crashes shows an upward trend during the same time period (with 68 percent in 1991 and 73 percent in 2007.) *Keeping vehicles on the roadway* is one of the major goals of Strategic Highway Safety Plan.[1 2]

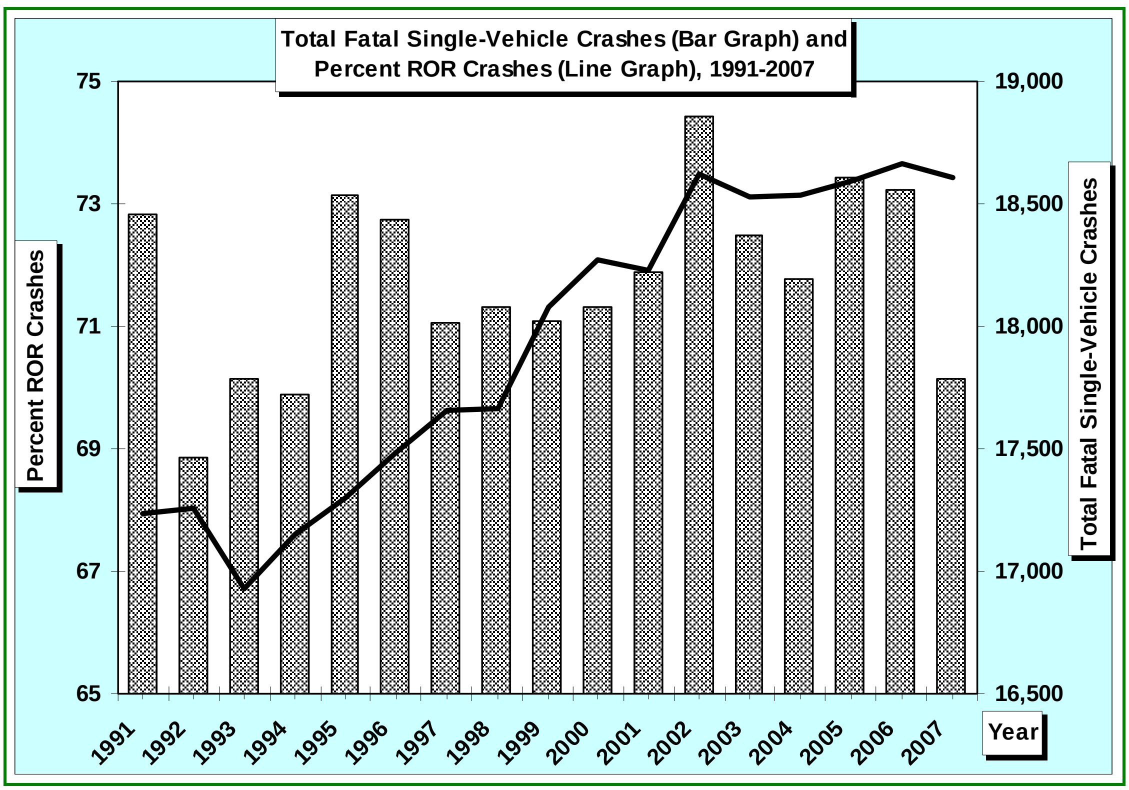

Figure 1. Total Passenger Vehicle Fatal Single-Vehicle Crashes (Bar Graph) and the Percent of ROR Crashes (Line Graph), 1991-2007 (FARS 1991-2007).

The reasons for an ROR crash are varied and include avoiding a vehicle, object, or an animal in the travel lane; over-correction during the operation of the vehicle; inattentive driving due to distraction, fatigue, sleep, or alcohol; the effects of weather on pavement conditions; and traveling too fast through a curve. There are also a number of roadway design factors (*e.g.*, travel lanes that are too narrow, substandard curves) that can increase the probability that a driver error may result into an ROR crash. [2-6]

This study aims to identify the roadway factors (*e.g.*, rural/urban nature and curve existence), driver factors (*e.g.*, age, gender, sleepy, and alcohol use), environmental factors (*e.g.*, weather, lighting condition), and vehicle-related factors (*e.g.*, speeding) associated with the fatal single-vehicle ROR crashes. The analyses on the relationship between selected factors (variables) and the likelihood of fatal single-vehicle ROR and OR crashes are presented.

The study is focused only on fatal crashes, that is, a crash that involve a motor vehicle in transport traveling on a traffic way customarily open to the public and resulting in the death of a person (occupant of a vehicle or a non-motorist) within 30 days of the crash. Therefore, the results presented in this study can not be generalized to the entire crash population. Also, because the comparisons are made between single-vehicle ROR and OR crashes, it is possible that the factors that differ between these two types of crashes are not necessarily associated solely with these two types of crashes.

The outline of this report is as follows: Section 2 presents the data and the method used in this report. Section 3 presents the descriptive (univariate) statistics through the percentage frequency distributions of fatal single-vehicle ROR versus fatal single-vehicle OR crashes by various roadway-, environment-, occupant- and vehicle-related factors. Section 4 assesses their relative influence as well as estimates the amount of risk each factor carries in the occurrence of such crashes using logistic regression. The conclusions are presented in Section 5.

2. Data and Methodology

The data used in this study comes from the Fatality Analysis Reporting System for fatal crashes during the period 1991 to 2007. All analyses in this report pertain to fatal single-vehicle ROR crashes that involve passenger vehicles, including cars, vans, pickup trucks, and utility vehicles with gross vehicle weight ratings under 10,000 lbs.

In this study, the fatal single-vehicle crashes were categorized into two groups: ROR crashes and OR crashes in which the vehicles were still on the road after the crash.[†] The descriptive (univariate) analysis of the relationship between selected factors (variables) was conducted to estimate the likelihood of a vehicle involvement in fatal single-vehicle ROR and OR crashes. The chi-square test is used to assess the differences in percentages between groups, and is statistically significant at $\alpha = 0.05$ significance level when $p < 0.05$. The impact of these related factors is also assessed by logistic regression procedure in which the OR crashes essentially form one element of the binary outcome (on-road versus off- road). This procedure helps to assess their relative influence as well as estimate the amount of risk each carries in the occurrence of such crashes.

[†] For the designation of ROR and OR crash, refer to FARS Analytical Reference Guide 1975-2006, DOT HS 810 605, May 2006.

3. Factors Related to Fatal Single-Vehicle ROR Crashes

In this section, a descriptive (univariate) approach is used to identify the roadway-, driver-, environment-, and vehicle-related factors (variables) that may have strong association with the fatal single-vehicle ROR crashes. Based on other studies, several variables were considered that include the curvature of the road, roadway function class (rural/urban), number of lanes, posted speed limit, weather and lighting conditions, age, gender, and alcohol use by the driver.[7] [8] [9] [10] [11]

3.1 Environment-Related Factors

The environment-related factors examined in the study are roadway alignment, roadway function class, number of lanes, posted speed limit, weather, and lighting conditions.

3.1.1 Road Environment

Road Alignment

Roadway alignment plays a significant role in the occurrence of ROR crashes. Figure 2 shows the percentage frequency distributions of passenger vehicles involved in fatal single-vehicle ROR and OR crashes by road alignment (curved or straight).

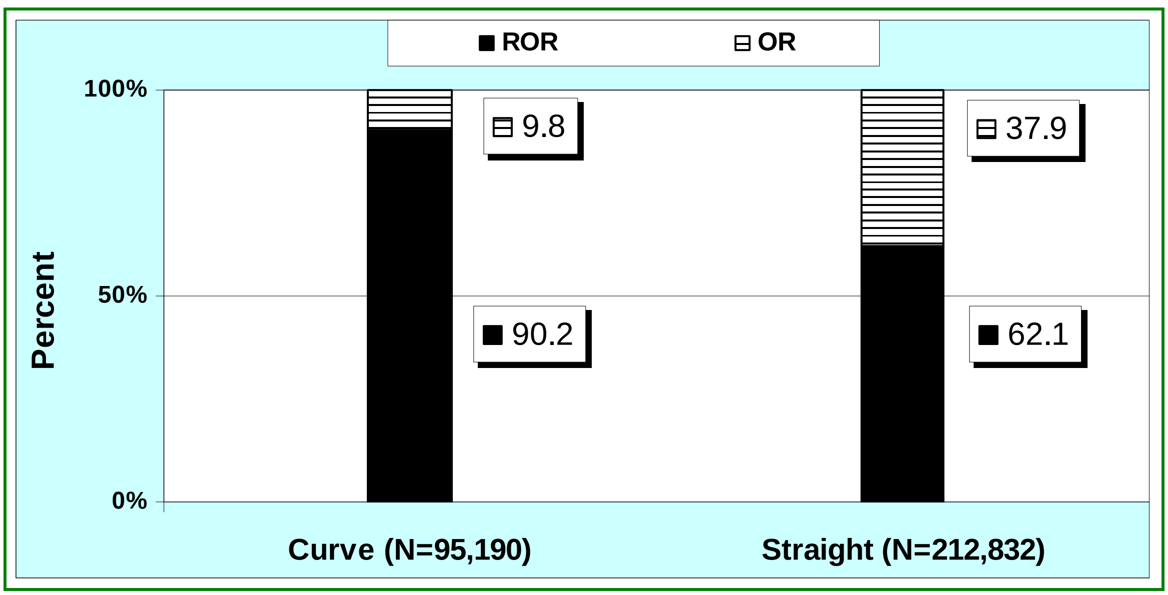

Figure 2. Percentage Frequency Distributions of Fatal Single-Vehicle ROR and OR Crashes by Road Alignment (FARS 1991-2007).

The statistics show that among all fatal single-vehicle crashes that occurred on the curved roads, 90.2 percent were ROR crashes, while among crashes that occurred on straight roadways, 62.1 percent were ROR crashes. In contrast, the occurrence of OR crashes are more frequent on straight roadways. A χ^2 test shows that the difference between two percentages is statistically significant (p <0.0001,) thereby indicating that the curved road segments are more likely to be the scene of ROR crashes as compared to the straight roadways. Improving roadway design (*e.g.*, flattening curves, signing or the more general curve delineation) could reduce the likelihood of ROR crashes.

<u>Roadway Function Class</u>

It is also of interest to see if the roadway function class makes a difference in the occurrence of ROR crashes. Figure 3 shows the percentage frequency distributions of passenger vehicles involved in fatal single-vehicle ROR and OR crashes by roadway function (rural or urban).

In fatal single-vehicle crashes, among those that occurred on rural roads, 80.6 percent were ROR crashes, while among those that occurred on urban roadways, 56.2 percent were ROR crashes. In contrast, the occurrence of OR crashes were more frequent on urban roadways. A χ^2 test shows that the difference between two percentages of ROR crashes is statistically significant (p <0.0001.) This shows that the rural roads are more likely to be the scene of ROR crashes as compared to the urban roads.

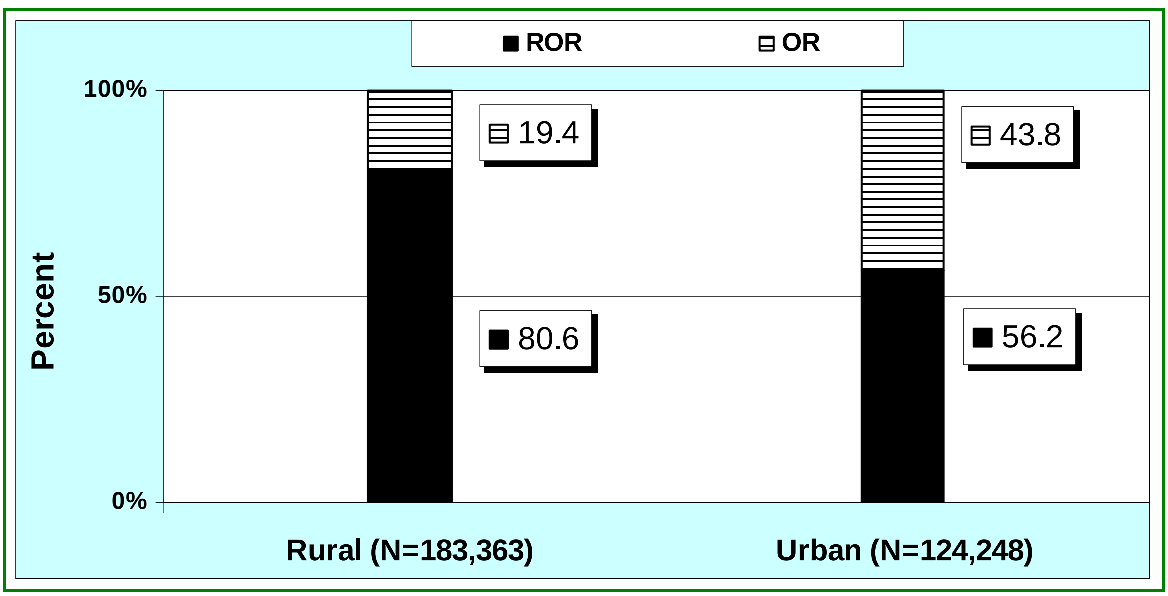

Figure 3. Percentage Frequency Distributions of Fatal Single-Vehicle ROR and OR Crashes by Roadway Function (FARS 1991-2007).

Road Posted Speed Limit

In most cases, the actual vehicle's pre-crash travel speed is unknown. In this analysis the posted speed limit was used as a proxy to a vehicle's travel speed. Figure 4 shows the percentage frequency distributions of passenger vehicles involved in fatal single-vehicle ROR and OR crashes by posted speed limits (< 60 mph and 60+ mph).

Among fatal single-vehicle crashes that occurred on roadways with posted speed limits of 60 mph and above, 81 percent were ROR crashes, while among the crashes that occurred on roadways with posted speed limits less than 60 mph, 69 percent were ROR crashes. A χ^2 test shows that the difference between these two percentages is statistically significant (p <0.0001). This in turn shows that the high speed limit roads are more likely to be the scene of ROR crashes as compared to the low speed limit roads.

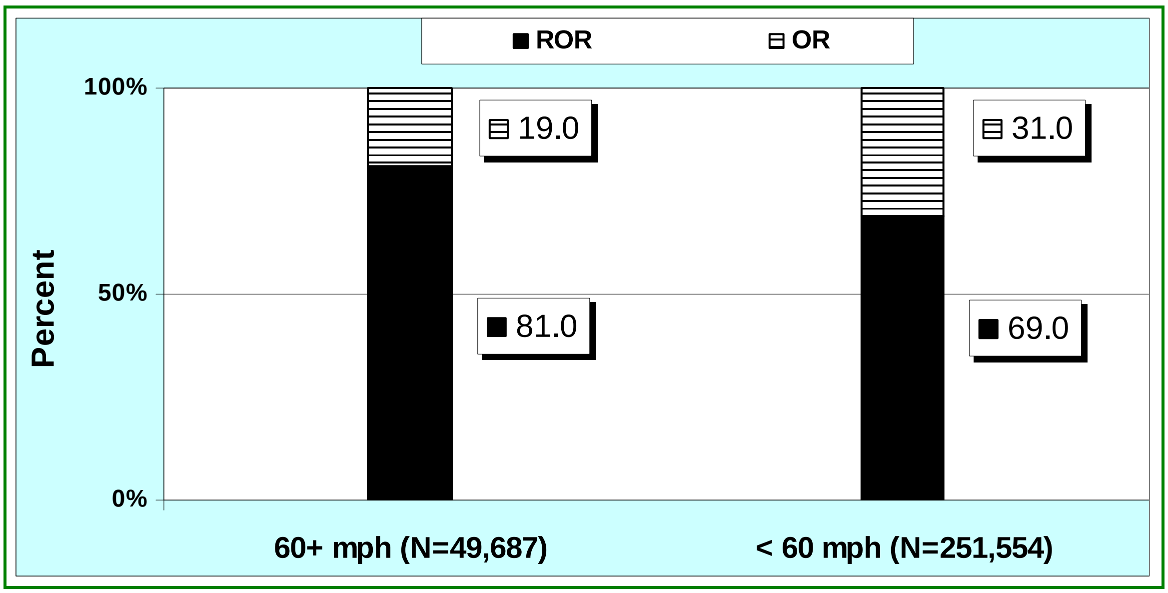

Figure 4. Percentage Frequency Distributions of Fatal Single-Vehicle ROR and OR Crashes by Road Posted Speed Limits (FARS 1991-2007).

Roadway Number of Lanes

Another factor that is worth investigating is the roadway number of lanes. Figure 5 shows the percentage frequency distributions of passenger vehicles involved in fatal single-vehicle ROR and OR crashes by roadway number of lanes. Four categories of roadways were considered with reference to the number of lanes: one or two lanes (divided or undivided) and three or more lanes (divided or undivided). The number of lanes refers to the number of lanes of a continuous cross-section of roadway. For example, a local roadway with one lane going north and one lane going south would be coded as two lanes. However, if a trafficway is a divided highway, with two lanes going north, a median, and two lanes going south, then the number of lanes is coded as two. If a trafficway has two lanes going north immediately adjacent to two lanes going south, one continuous cross-section of roadway, then the number of lanes is coded as four.

The results in Figure 5 show that among the fatal single-vehicle crashes that occurred on roadways with fewer lanes (one or two lanes), 67.8 percent (divided) and 76.6 percent (undivided) were ROR crashes, while among the crashes that occurred on roads with three and more lanes, 62 percent (divided) and 40 percent (undivided) were ROR crashes. In contrast, the occurrence of OR crashes were more frequent on roadways with three and more lanes as compared to one or more lanes both in the case of divided and undivided roadways.

Statistically significant (p <0.0001) difference shows that the roadways with fewer lanes (one or two lanes) are more likely to be the scene of ROR crashes as compared to the roadway with three and more lanes (divided or undivided). The roadway design or rehabilitation strategy such as building more lanes is likely to reduce ROR crashes. [8]

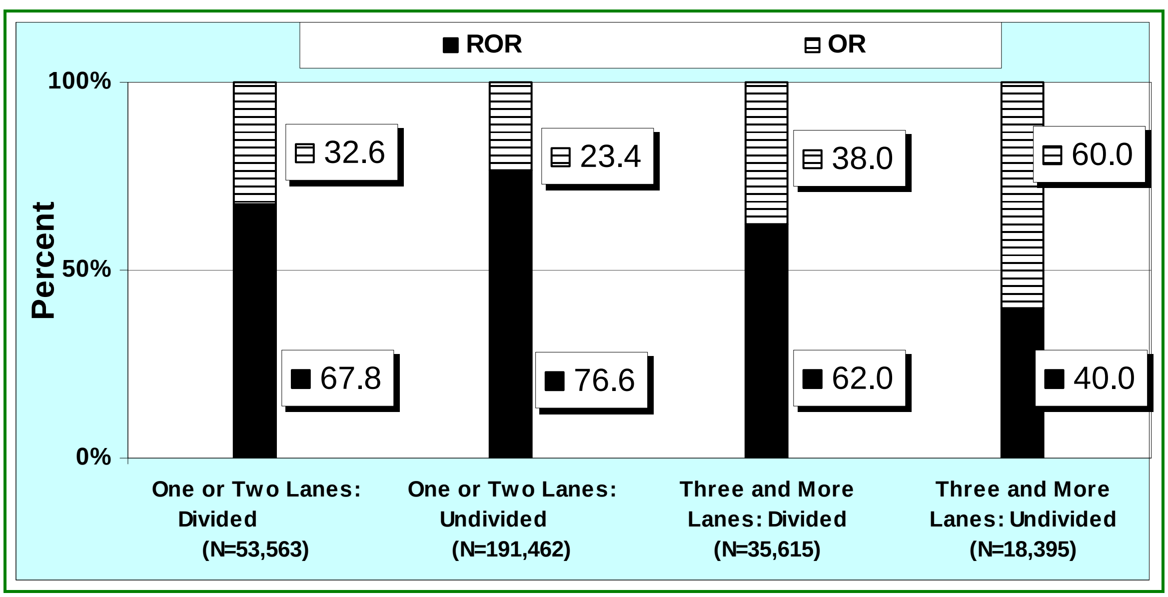

Figure 5. Percentage Frequency Distributions of Fatal Single-Vehicle ROR and OR Crashes by Roadway Number of Lanes (FARS 1991-2007).

3.1.2 Weather Conditions

To investigate if certain weather conditions contribute to the occurrence of ROR crashes, the percentage frequency distributions of passenger vehicles involved in fatal single-vehicle ROR and OR crashes by weather conditions were obtained. Two weather conditions were considered for this purpose: adverse (rain, sleet, snow, fog, fog, and others - smog, smoke, blowing sand, or dust) and good weather conditions (normal, or clear). The results are presented in Figure 6.

Among fatal single-vehicle crashes that occurred during adverse weather conditions, 75.5 percent were ROR crashes, while among crashes that occurred during good weather conditions, 70 percent were ROR crashes. On the other hand, OR crashes were more frequent in good weather conditions.

The significant difference between the two percentages (p <0.0001) shows that ROR crashes are more likely to occur in adverse weather conditions as compared to good weather conditions. Improving roadway design (*e.g.*, providing skid-resistant pavement surfaces) could reduce the likelihood of ROR crashes.

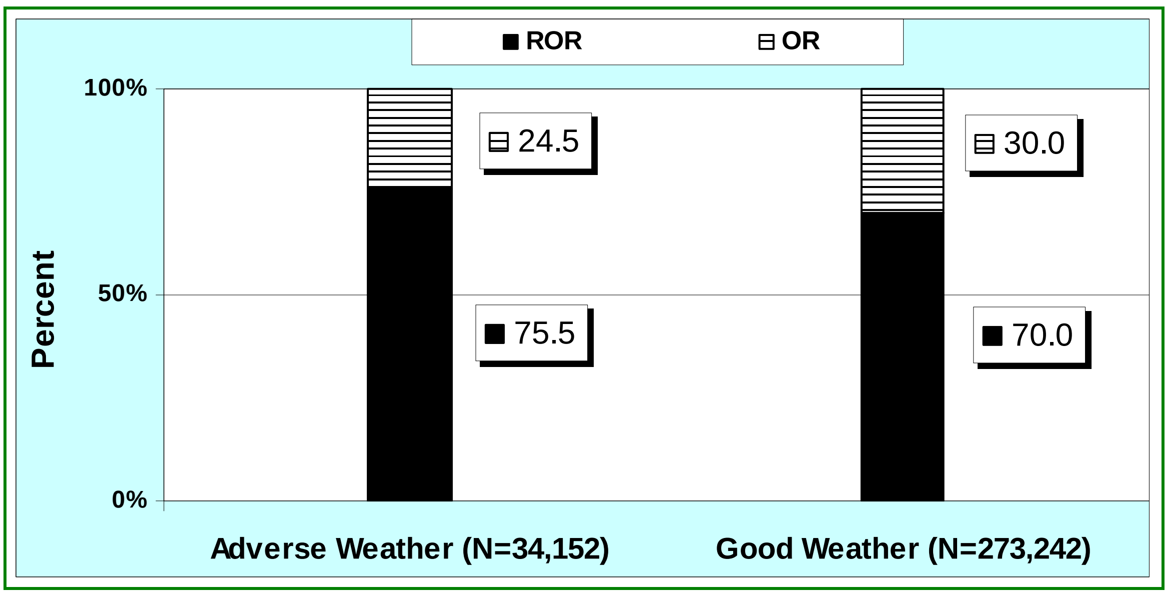

Figure 6. Percentage Frequency Distributions of Fatal Single-Vehicle ROR and OR Crashes by Weather Conditions (FARS 1991-2007).

3.1.3 Natural Lighting Conditions

Could visibility due to natural lighting be an issue in the occurrence of ROR crashes? To answer this question, frequency analysis was conducted for two lighting conditions: nighttime and daytime. Figure 7 shows the percentage frequency distributions of passenger vehicles involved in fatal single-vehicle ROR and OR crashes by lighting conditions.

Among fatal single-vehicle crashes that occurred during nighttime (8 p.m. – 5:59 a.m.), 74.2 percent were ROR crashes, while among the crashes that occurred during daytime (6 a.m. – 7:59 p.m.), 66.5 percent were ROR crashes. In contrast, the occurrence of OR crashes are more frequent during day time.

A χ^2 test confirms that the difference between two percentages is statistically significant (p <0.0001). This shows that the night time driving is more likely to result into ROR crashes as compared to the day time period. Reduced lighting like adverse weather is associated with a significant increase in the likelihood of single-vehicle ROR crashes.

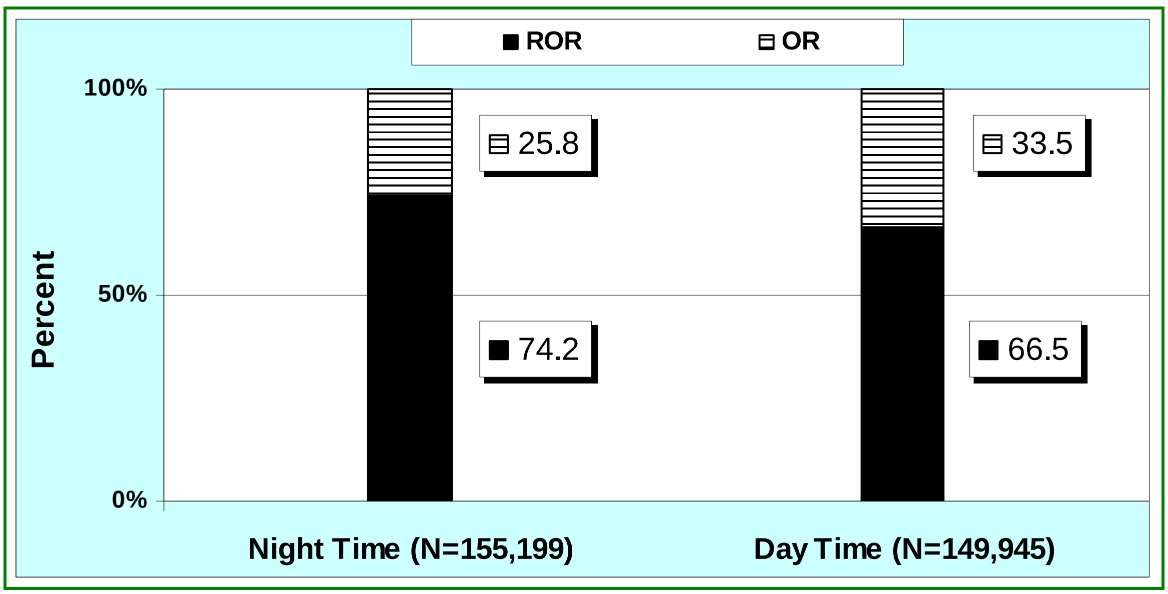

Figure 7. Percentage Frequency Distributions of Fatal Single-Vehicle ROR and OR Crashes by Lighting Conditions (FARS 1991-2007).

3.2 Occupant-Related Factors

The occupant-related factors examined in the study include vehicle occupancy, driver's gender, age, alcohol use, and driver performance-related factors, such as sleep, inattention, over-correction of the vehicle, etc.

3.2.1 Occupancy

It is of interest to see if the occupancy of a vehicle makes a difference in the occurrence of ROR crashes. Figure 8 shows the percentage frequency distributions of passenger vehicles involved in fatal single-vehicle ROR and OR crashes by vehicle occupancy.

Among fatal single-vehicle crashes involving a vehicle with only one occupant (driver alone), 68.0 percent were ROR crashes, while among crashes involving a vehicle with two or more occupants, 74.8 percent were ROR crashes. A χ^2 test confirms the difference between these two percentages to be statistically significant (p <0.0001).

This shows that vehicles with high occupancy (two or more occupants) are more likely to be involved in ROR crashes as compared to a vehicle with the driver alone. The reason for this is not immediately clear. However, a possible explanation could be the fact that the presence of other occupants in the vehicle is a likely source of distraction to the driver due to conversation and other activities. [12]

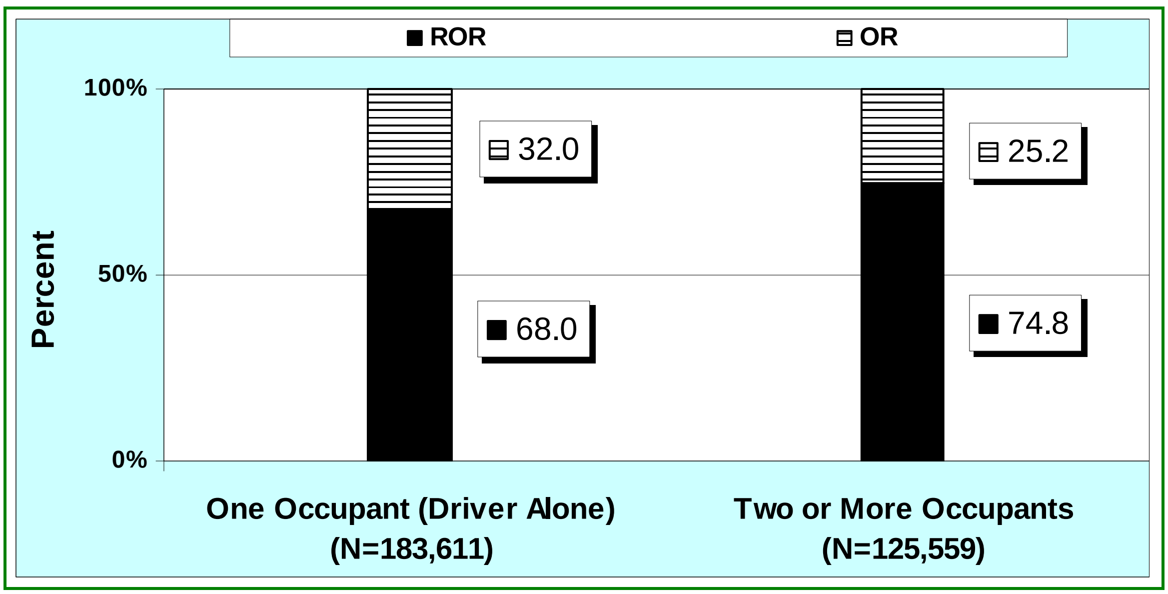

Figure 8. Percentage Frequency Distributions of Fatal Single-Vehicle ROR and OR Crashes by Vehicle Occupancy (FARS 1991-2007).

3.2.2 Driver's Gender

Among many driver-related factors, driver gender that could possibly contribute to the occurrence of ROR crashes was studied. Figure 9 shows the percentage frequency distributions of passenger vehicles involved in fatal single-vehicle ROR and OR crashes by driver's gender.

Among fatal single-vehicle crashes involving male drivers, 72.2 percent were ROR crashes, while 66.5 percent crashes involving female drivers were ROR crashes. In contrast, the occurrence of OR crashes are more frequent for female drivers. A χ^2 test shows that the difference between the two percentages is statistically significant (p <0.0001).

Thus, one could infer that vehicles with the male drivers are more likely to be involved in ROR crashes as compared to the vehicles with the female drivers.

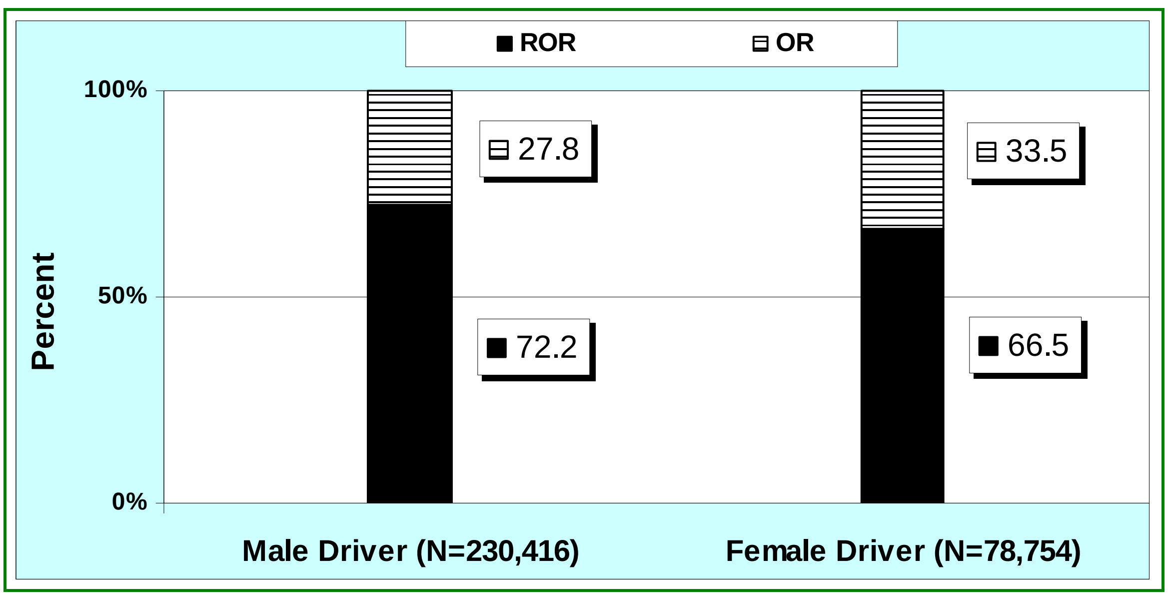

Figure 9. Percentage Frequency Distributions of Fatal Single-Vehicle ROR and OR Crashes by Driver's Gender (FARS 1991-2007).

3.2.3 Driver's Age

To look into driver age as a contributing factor in ROR crashes, four age groups were considered: 15 to 24, 25 to 44, 45 to 64, and 65 and older. Figure 10 shows the percentage frequency distributions of passenger vehicles involved in fatal single-vehicle ROR and OR crashes by these age groups.

Among fatal single-vehicle crashes involving young drivers 15 to 24, a higher percentage (75.2 percent) were of ROR crashes as compared to other age groups. This shows that vehicles with young drivers 15 to 24 are more likely to be involved in ROR crashes as compared to other three age groups.

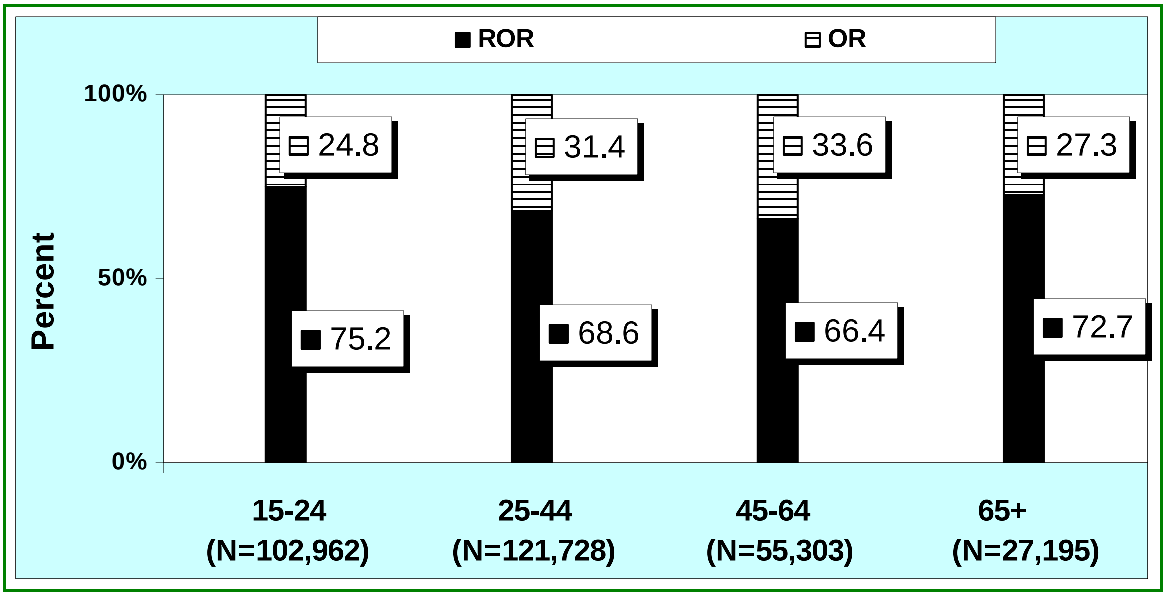

Figure 10. Percentage Frequency Distributions of Fatal Single-Vehicle ROR and OR Crashes by Driver's Age (FARS 1991-2007).

3.2.4 Alcohol-Related Driving

Alcohol involvement of a driver often leads to safety issues such as loss of vehicle control that may result into a ROR crash. Two categories of drivers: sober (BAC=0) and alcohol involved (BAC=.01+) were considered in the analysis to see if alcohol use contributes to ROR crashes. Figure 11 shows the percentage frequency distributions of passenger vehicles involved in fatal single-vehicle ROR and OR crashes by driver's alcohol use.

Among fatal single-vehicle crashes involving drivers with alcohol use (BAC=.01+), 86.5 percent were ROR crashes, while among those drivers with no alcohol (BAC=0), 58.3 percent were ROR crashes. The difference between these two percentages is statistically significant (p <0.0001). This indicates that the drivers with alcohol use are more likely to be involved in ROR crashes as compared to sober drivers.

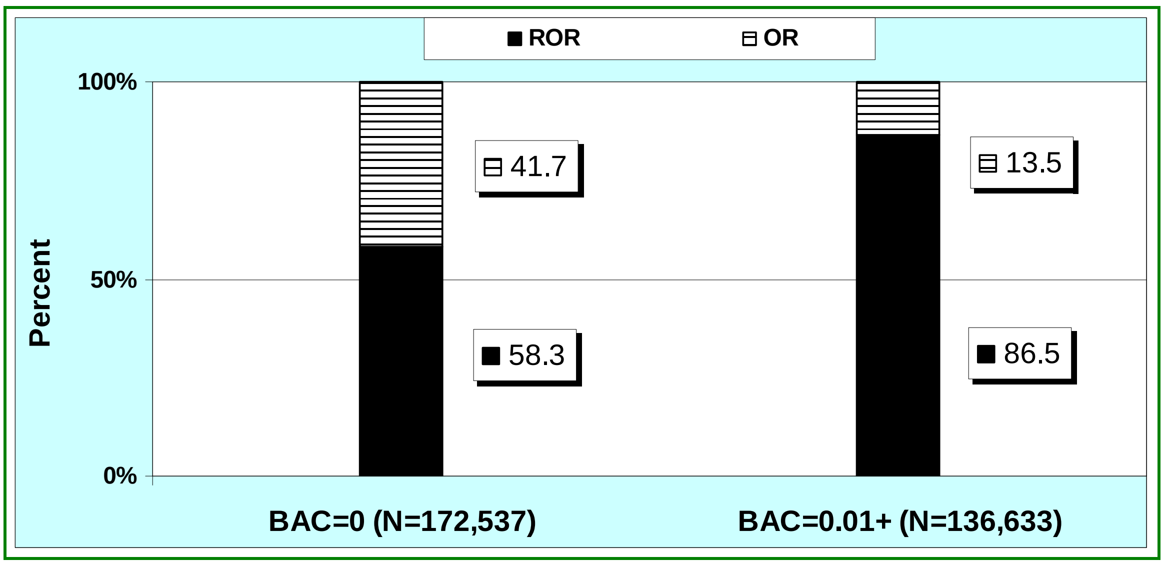

Figure 11. Percentage Frequency Distributions of Fatal Single-Vehicle ROR and OR Crashes by Driver's Alcohol Use (FARS 1991-2007).

3.2.5 Driver-Performance-Related Factors

Some of the driver performance-related factors that are likely to contribute to the occurrence of ROR crashes were also examined.

These include: (1) sleepy (drowsy, asleep, fatigued, and sleepy); (2) inattentive (talking, eating, etc.); (3) over-correcting of the vehicle; (4) avoiding (avoiding, swerving, or sliding due to severe crosswind, tire blow-out or flat, live animals in road, vehicle in road, etc.); (5) distractions inside vehicles (cellular telephone, computer, fax machine, etc.); and (6) other driver-performance-related factors, such as mentally challenged, following improperly, failure to signal intensions, etc.

Figure 12 shows the percentage frequency distributions of passenger vehicles involved in fatal single-vehicle ROR and OR crashes based on the driver performance-related factors. The statistics show that the percentages of sleepy (91.2%), inattentive (75.4%), over correction of the vehicle (85.6%), and crash avoiding (79.8%) drivers involved in fatal single-vehicle ROR crashes are significantly greater (p <0.0001) than the drivers with 'Other driver performance-related factors' that account for 67 percent of ROR crashes.

This means that drivers with these performance-related factors (sleepy, inattentive, over correction, avoiding, etc.) are more likely to be involved in ROR crashes as compared to drivers with other performance-related factors. These results are consistent with those obtained from other studies using different approaches and other crash databases. [2-11]

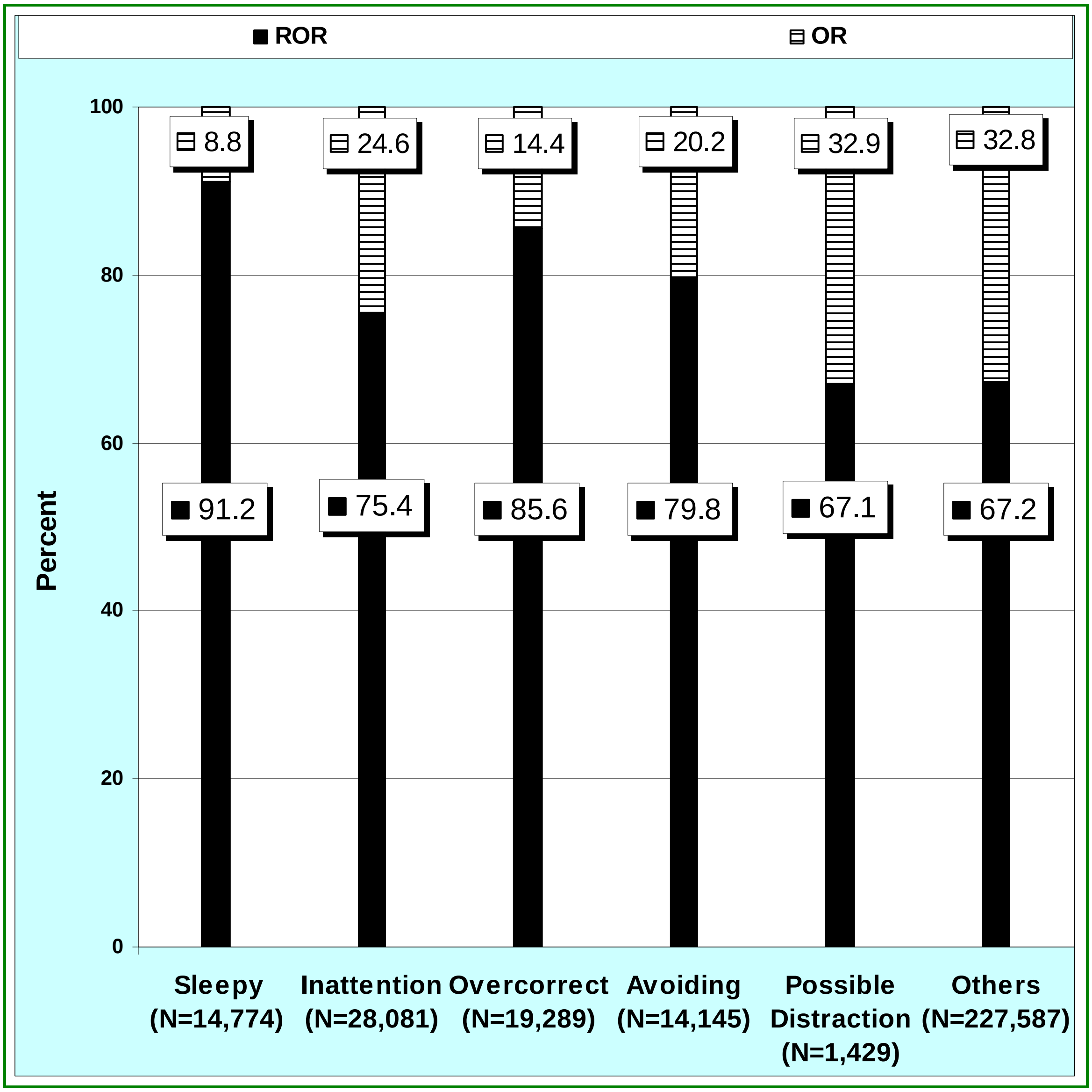

Figure 12. Percentage Frequency Distributions of Fatal Single-Vehicle ROR and OR Crashes by Driver Performance-Related Factors (FARS 1991-2007).

3.3 Vehicle-Related Factors

It is generally believed that ROR crashes are likely to occur due to some vehicle-related factors, such as vehicle speeding or vehicle type.

3.3.1 Vehicle Speeding Status

A crash is considered speeding-related if any driver involved in the crash is charged with a speeding-related offense or if a police officer indicates that racing, driving too fast for the conditions, or exceeding the posted speed limit was a related factor in the crash. [13]

Figure 13 shows the percentage frequency distributions of passenger vehicles involved in fatal single-vehicle ROR and OR crashes by vehicle speeding status.

Among fatal single-vehicle crashes that involved a speeding vehicle, 90 percent were ROR crashes, while among crashes that did not involve a speeding vehicle 59.5 percent were ROR crashes. A χ^2 test shows that the difference between two percentages is statistically significant (p <0.0001) thereby showing that speeding vehicles are more likely to be involved in ROR crashes as compared to non-speeding vehicles.

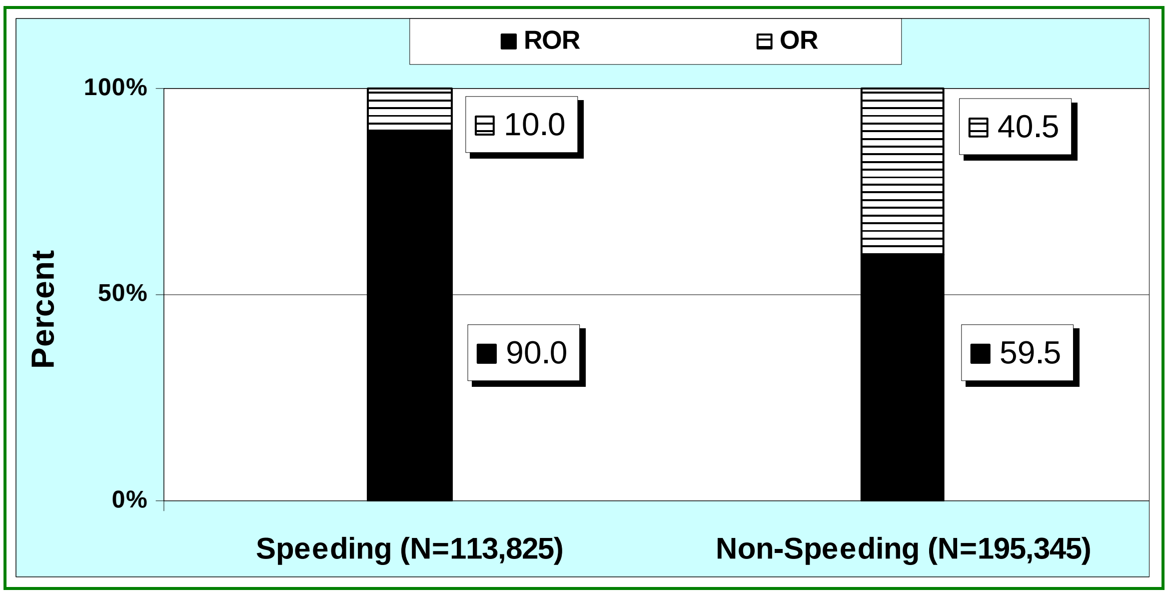

Figure 13. Percentage Frequency Distributions of Fatal Single-Vehicle ROR and OR Crashes by Vehicle Speeding Status (FARS 1991-2007).

3.3.2 Vehicle Type

Figure 14 shows the percentage frequency distributions of passenger vehicles involved in fatal single-vehicle ROR and OR crashes by passenger vehicle type: passenger car, light truck (LT) including pickup, utility, minivan, other van, and other light trucks).

It shows that passenger cars are more likely to be involved in ROR crashes as compared to other passenger vehicle types. Minivans (60%) are more likely to be involved in ROR crashes (p <0.0001) as compared to other vans (52%).

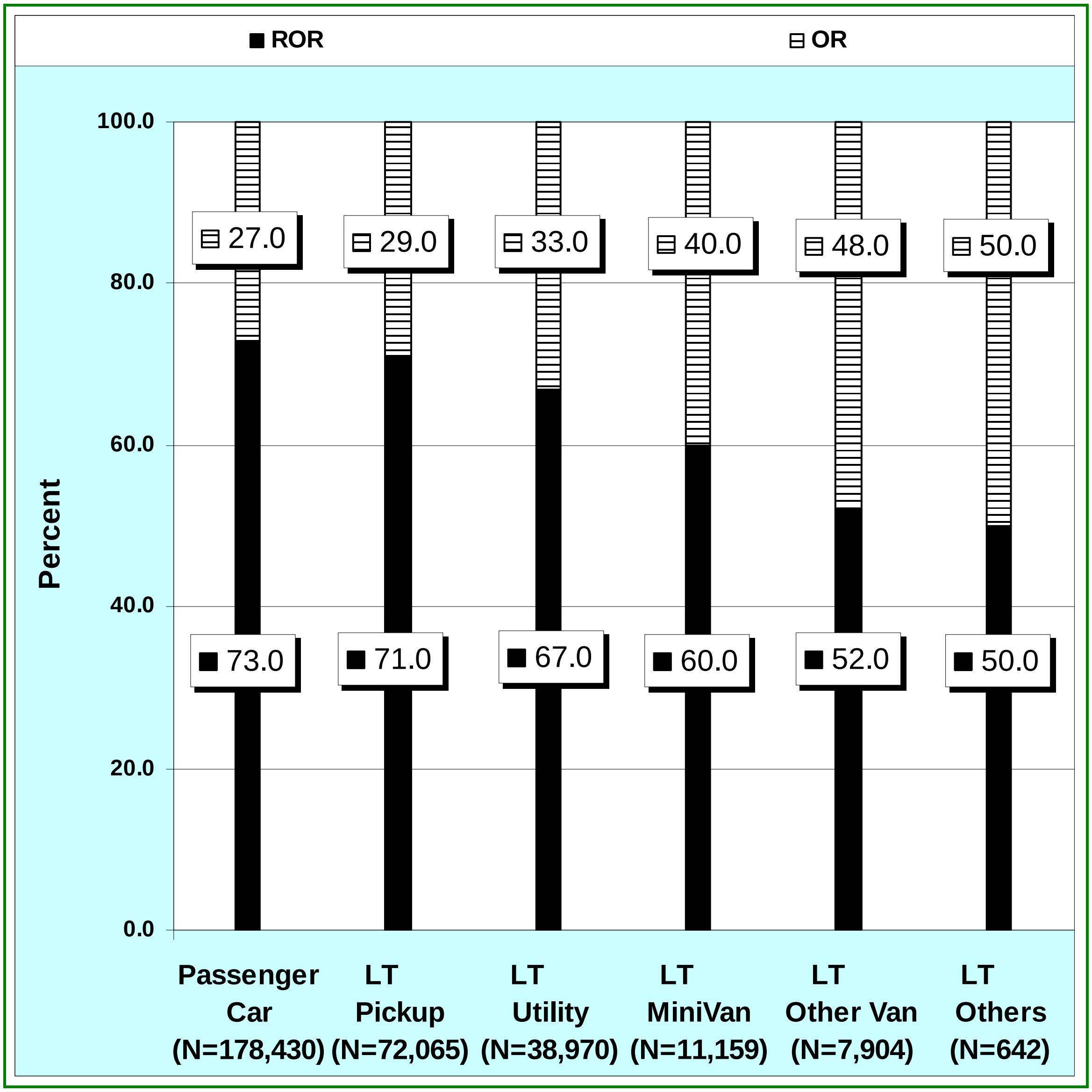

Figure 14. Percentage Frequency Distributions of Fatal Single-Vehicle ROR and OR Crashes by Vehicle Type (FARS 1991-2007).

4. Logistic Regression

The analysis in the previous sections shows that factors such as driver sleepiness, alcohol use, vehicle speeding, curved roadway, rural roads, etc., are significant contributors to the occurrence of fatal single-vehicle ROR crashes. It remains to assess their relative influence as well as estimate the amount of risk each carries in the occurrence of such crashes. Logistic regression was used for this purpose. This is a modeling procedure that predicts the probability (p) of occurrence of an event (fatal single-vehicle ROR crash, in the present case) as a consequence of certain roadway-, driver-, environment- and vehicle-related factors, such as sleepy, alcohol use, weather condition, lighting condition, speeding status, road function, etc. Generally, the logistic regression model provides log of odds as a function of the predictors:

Log (odds)
= a_0 + a_1×driver performance-related factor + a_2×alcohol use + a_3×speeding status + a_4×weather condition + a_5×lighting condition….. + a_k×speeding status×weather condition + a_{k+1}×speeding status×driver's age +……

where a_0 is the intercept and $\{a_1, a_2, a_3, \ldots\ldots, a_k, a_{k+1}, \ldots\ldots\}$ are the regression coefficients.

As in the previous analysis, FARS data was used in the modeling procedure. Since in FARS, driver's alcohol involvement is estimated by Multiple Imputation (MI) [16] [17] procedure, the SAS MIANALYZE procedure was used in this study to perform the analysis of the MI data generated from the logistic regression.[18]

4.1 Logistic Regression: Results and Interpretation

Of all the variables considered in the logistic regression, only 10 showed up as significant predictors (95% confidence level). As regards the interaction effect of these factors, only the interaction of speeding with other variables was considered. However only three of these interactions emerged as significant (95% confidence level). The results in Table 1 present estimates of regression coefficients and the corresponding odds ratio only for significant main effects and interactions. Since the independent variables (predictors) are dichotomous, the influence of the corresponding factors can be compared simply by comparing their regression coefficients.

The ordered (decreasing) estimates of regression coefficients in Table 1 show that the most influential factor in the occurrence of fatal single-vehicle ROR crashes is the driver performance-related factor: sleepy, followed by alcohol use, roadway alignment with curve, speeding, passenger car, rural roadway, number of lanes, high-speed-limit road, adverse weather and avoiding. With regard to the interaction effect of speeding with other factors, speeding with drivers of age groups 15 to 24 and 25 to 44 as well as speeding under adverse weather are significant contributors to the likelihood of ROR crashes.

Table 1: Multiple Imputation Parameter Estimates *‡

Variables	Estimate	Odds Ratio
Driver performance-related factor: sleepy vs. others	1.1675 ‡	3.21
Driver with alcohol : BAC=.01+ g/dL vs. BAC=0	0.6605 ‡	1.94
Road alignment: curve vs. straight	0.5535 ‡	1.74
Vehicle speeding status: speeding vs. non-speeding	0.4966 ‡	1.64
Vehicle type: passenger car vs. other LTs	0.4780 ‡	1.61
Road function: rural vs. urban	0.3637 ‡	1.44
Roadway # of lanes: one or two (undivided) vs. three & more (undivided)	0.3346 ‡	1.41
Road speed limit: ≥ 60 mph vs. <60 mph	0.2659 ‡	1.30
Weather: adverse vs. good	0.2130 ‡	1.24
Driver performance-related factor: avoiding vs. others	0.2007 ‡	1.22
Weather ×Speeding status: adverse & speeding vs. good & non-speeding	0.1056 ‡	1.11
Driver Age × Speeding status: 25-44 & speeding vs. 65+ & non-speeding	0.1003 ‡	1.11
Driver Age × Speeding status: 15-24 & speeding vs. 65+ & non-speeding	0.0578 ‡	1.06

* Statistically significant variables ($\alpha = 0.05$) associated with the high risk (odds ratio >1.00). Other variables with low risk (odds ratio <1.00) or insignificance (p>0.05) after jointly estimating the effect are not shown here.
‡ p-value <0.0001

One of the most important by-product of logistic regression is the estimate of odds ratio that tells a great deal about the risk a certain factor carries in contributing to the occurrence of ROR crashes. Specifically, odds ratio measures the magnitude of increase in odds of happening of an event as a result of a unit increase in a predictor (*e.g.* sober and alcohol-used driver). An odds ratio value of 1 is indicative of no influence.
Table 1 also shows odds ratio estimates of significant factors and interactions.

- The odds ratio 3.21 for the factor "driver performance-related factor" shows that the odds of being involved in an ROR crash for a sleepy driver are three times as large as that for the driver who is not sleepy.

- The odds ratio 1.94 for the factor "driver with alcohol" shows that the odds of being involved in an ROR crash for an alcohol used driver (BAC=.01+ g/dL) are almost two times as large as that for a sober driver (BAC=0).

- The odds ratio 1.74 for the factor "road alignment" shows that the odds of being involved in an ROR crash on curved roadways are 1.74 times as large as that on straight roadways in fatal single-vehicle crashes.

- The odds ratio 1.64 for the factor "vehicle speeding status" shows that the odds of being involved in an ROR crash for speeding vehicles are 1.64 times as large as that for non-speeding vehicles.

- The odds ratio 1.61 for the factor "vehicle type" shows that the odds of being involved in an ROR crash for passenger cars are 1.61 times as large as that for other LTs.

- The odds ratio 1.44 for the factor "road function" shows that the odds of being involved in an ROR crash on rural roadways are 1.44 times as large as that on urban roadways.

- The odds ratio 2.66 for the factor "weather & speeding status" shows that the odds of being involved in an ROR crash under the adverse weather and in speeding vehicle are 2.66 (=1.64×1.24×1.11) times as large as that under the good weather and in non-speeding vehicle (Figure 15).

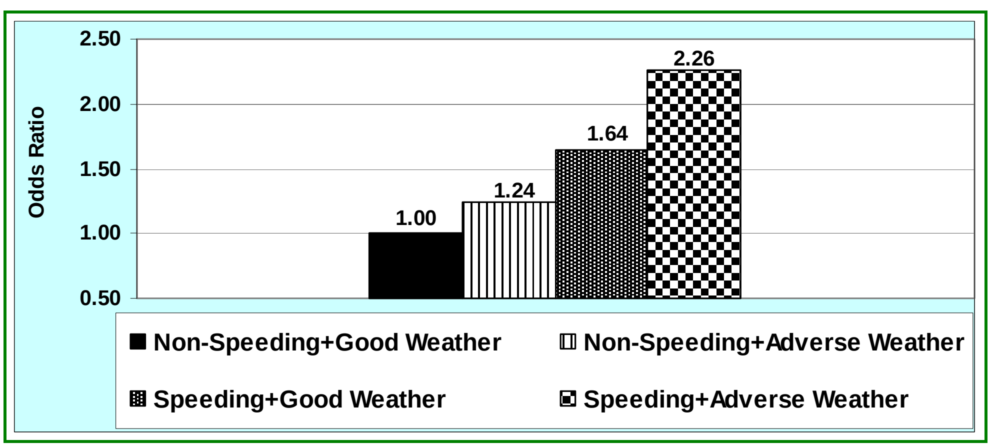

Figure 15. Odds Ratio by Speeding Status and Weather Conditions.

5. Conclusions

Run-off-road crashes account for a significant percentage (around 70%) of all fatal single-vehicle crashes. FARS data (1991 to 2007) that includes detailed information about ROR crashes provided sufficient statistical evidence to conclude that certain roadway-, driver-, environment-, and vehicle-related factors closely associated with the occurrence of these crashes. Appropriate crash countermeasures based on the identified factors can reduce the occurrence of single-vehicle ROR crashes and hence of the fatalities.

Curved road segments, rural roads, high-speed-limit roadways, and roadways with fewer lanes (divided or undivided) are found to be more likely to be the scene of fatal single-vehicle ROR crashes as compared to the fatal single-vehicle OR crashes. Similarly, among environmental factors, adverse weather and night time periods are the factors associated with high risk of fatal single-vehicle ROR crashes.

Vehicles with high occupancy (two and more occupants), male driver, younger driver, and alcohol used by driver, are more likely to be involved in fatal single-vehicle ROR crashes as compared to the fatal single-vehicle OR crashes. Drivers with performance-related factors (sleepy, inattentive, over-correction, avoiding, etc.) are more likely to be involved in the fatal single-vehicle ROR crashes. Speeding vehicles and passenger cars are also associated with high risks of the fatal single-vehicle ROR crashes.

In the adverse weather condition and for the younger drivers (15 to 24 and 25 to 44), the speeding vehicle would increase the risk of fatal single-vehicle ROR crashes by an additional factor.

The above facts based on statistical evidence suggest several crash countermeasures. For example, improving roadway design such as flattening curves and installing shoulder rumble strips, or rehabilitation strategies such as building wide lanes or adding additional unpaved shoulder width on entire system, providing skid-resistant pavement surfaces, could reduce the likelihood of ROR crashes.

6. References

[1] FHWA. (Undated). Reducing Highway Fatalities. Washington, DC: Federal Highway Administration. http://safety.fhwa.dot.gov/roadway%5Fdept/

[2] Neuman, T. R.,Pfefer, R., Slack, K. L., Council, F., McGee, H., Prothe, L., & Eccles, K. (1998). *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan.* Report 500; Volume 6: A Guide for Addressing Run-Off Road Collisions, Washington, DC: Transportation Research Board. Available at http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_500v6.pdf.

[3] Spainhour, L. K., & Mishra, A. (2007). *Analysis of Fatal Run-off-the-Road Crashes Involving Overcorrection*, TRB 87th Annual Meeting, Paper No. 08-0661. Washington, DC: Transportation Research Board.

[4] McGee, H. W. & Hanscom, F. R. *Low-Cost Treatments for Horizontal Curve Safety*. FHWA-SA-07-002, December 2006.

[5] Johnston, I., Corben, B., Triggs,T., Candappa, N., & Lenné, M. *Reducing Serious Injury and Death from Run-off-Road Crashes in Victoria – Turning Knowledge into Action*. (2006, June). RACV Research Report. Victoria, Australia: Royal Automobile Club of Victoria Ltd.

[6] Dissanayake, S. (2003, August). *Young Drivers and Run-Off-the-Road Crashes*, Proceedings of the 2003 Mid-Continent Transportation Research Symposium, Ames, Iowa.

[7] Knapp, K. K., Giese, K. L., & Lee, W. (2003, August). *Urban Four-Lane Undivided to Three-Lane Roadway Conversion Guidelines*, Proceedings of the 2003 Mid-Continent Transportation Research Symposium, Ames, Iowa.

[8] Őrnek, E., & Drakopoulos, A. (2007, August). *Analysis of Run-Off-Road Crashes in Relation to Roadway Features and Driver Behavior*, Proceedings of the 2007 Mid-Continent Transportation Research Symposium, Ames, Iowa.

[9] Ray, M. H. & McGinnis, R. G. (1997). *Guardrail and Median Barrier Crashworthiness: A Synthesis of Highway Practice*, NCHRP Synthesis 244 Washington, DC: Transportation Research Board, National Research Council..

[10] *Roadside Design Guide*. (2006). 3rd Edition. Washington, DC: American Association of State Highway and Transportation Officials.

[11] Elvik, R. (1995). The Safety Value of Guardrails and Crash Cushions: A Meta-Analysis of Evidence from Evaluation Studies, *Accident Analysis and Prevention*, 27 (4).

[12] Stutts, J. C., Reinfurth, D. W., Staplin, L., & Rodgman, E.A. (2001, May). The Role of Driver Distraction in Traffic Crashes. Washington, DC: AAA Foundation for Traffic Safety.

[13] Liu, C., Chen, C.-L., Subramanian, R., & Utter, D. (2005, June). *Analysis of Speeding-Related Fatal Motor Vehicle Traffic Crashes.* NHTSA Technical Report. DOT HS 809 839. Washington, DC: National Highway Traffic Safety Administration.

[14] Hosmer Jr., D. W, and Lemeshow, S. (1989). *Applied Logistic Regression*, New York: John Wiley & Sons, Inc.

[15] SAS Institute Inc. (1995). *Logistic Regression Examples using SAS system*, Cary, NC: SAS Institute Inc.

[16] Rubin, D. B., Schafer, J. L., & Subramanian, R. (1998, October). *Multiple Imputation of Missing Blood Alcohol Concentration (BAC) Values in FARS*. NHTSA Technical Report. DOT HS 808 816. Washington, DC: National Highway Traffic Safety Administration.

[17] Subramanian, R. (2005, March). *Alcohol Involvement in Fatal Motor Vehicle Traffic Crashes*. NHTSA Technical Report. DOT HS 809 822. Washington, DC: National Highway Traffic Safety Administration.

[18] SAS/STAT User's Guide, Version 8, 1999 Cary, NC: SAS Institute Inc.

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