Comparison of Factors Associated with Run-Off-Road and Non-Run-Off Road Crashes in Kansas

by Uttara Roy and Sunanda Dissanayake

This study examines the trends, characteristics, as well as contributory causes associated with run-off-road (ROR) and non-run-off-road (NROR) crashes. Likelihood ratios of these causes for ROR crashes with respect to NROR crashes are assessed using the Bayesian Statistical Approach. Nighttime, weekends, adverse weather, rural area, gravel and curved roads, higher speed limits, wet and icy road surface, and utility vehicles are found to be the common characteristics of ROR crashes. Fell asleep, ill or medical condition, driving under the influence, too fast for conditions, tires and wheels, strong winds, freezing rain, shoulders, ruts, holes, and bumps are found to have the greatest likelihood ratios and as such have a greater role in contributing to ROR crashes than NROR crashes.

INTRODUCTION

Run-off-road (ROR)[1] crashes in recent times have become a major cause of serious injuries and fatalities in the United States. Statistics from the *Fatality Analysis Reporting System (FARS)* illustrates that traffic fatalities in the United States due to ROR crashes represent about one-third of the total traffic fatalities (USDOT 2010a). The Kansas Strategic Highway Safety Plan (KSHSP) shows that ROR crashes accounted for 55% of all crashes involving fatal and serious injuries in Kansas. Almost 31% of all fatal and serious injury crashes in ROR crashes in Kansas occur on rural state highways compared with 26% that occur on county roads (USDOT 2010b). As a result, ROR crashes have become a major concern in the United States as well as in Kansas.

Dedicated efforts have been made to reduce these types of crashes and their severity. Installing shoulder rumble strips, providing enhanced shoulder or in-lane delineation and marking for sharp curves, providing improved highway geometry for horizontal curves, providing enhanced pavement markings, and applying shoulder treatments (to enhance safety by widening, paving, and reducing edge drops of shoulder) are some of the measures that have been taken in order to keep vehicles from encroaching on the roadside (Neuman et al. 2003). To minimize the severity of ROR crashes, some of the measures that have been taken are improving design of roadside hardware (for example, bridge rails), and improving design and application of barrier and attenuation systems. The countermeasures developed to minimize the likelihood of crashing into an object or overturning if the vehicle travels beyond the edge of the shoulder are designing safer slopes and ditches to prevent rollovers, removing objects in hazardous locations, and delineating trees or utility poles with retro-reflective tapes (Neuman et al. 2003). But it has become a difficult task to reduce these types of crashes due to ever-changing characteristics of the vehicle-fleet, driver population, traffic conditions, and highway environment.

In contrast to ROR crashes, there are crashes in which vehicles remain on the road after the crashes and those are considered as non-ROR crashes (NROR). An estimated cost of $110 billion has been imposed upon society each year due to roadside crashes,[2] the majority of which are single vehicle ROR crashes (McGinnis et al. 2001). The importance of the roadside safety problem has been recognized by different organizations, and efforts have been made to reduce the types of errors most likely to cause roadside crashes. The societal costs associated with roadside crashes must be recognized before cost-effective strategies can be developed to improve roadside safety. Investigating the factors as well as contributing causes associated with ROR crashes is necessary so that effective strategies can be developed to reduce their number and severity. With that intention, this study discusses characteristics as well as contributory causes associated with ROR and NROR crashes.

OBJECTIVES

The objectives of the study are;

- To examine the trends in ROR and NROR crashes
- To identify the characteristics associated with ROR and NROR crashes and to compare the findings between ROR and NROR crashes
- To identify the contributory causes and likelihood of occurrence of these causes in ROR crashes with respect to NROR crashes

LITERATURE REVIEW

Numerous studies have been conducted in recent years on roadside safety crashes. A 2001 study examined longitudinal trends (1975-1997) in fatal roadside crashes in the USA (McGinnis et al. 2001). To investigate how different driver characteristics such as age, gender, and alcohol usage relate to ROR crashes, the study used data from the Fatality Analysis Reporting System and the National Personal Transportation Studies. The study found out that ROR crash rates peaked in 1980 and had decreased 40% for oth male and female drivers. Even after adjusting for driving exposure, it was found that male crash rates were higher than female crash rates. ROR crash rates were found to be higher for young inexperienced drivers and older drivers aged 70 years or older. Teenage female drivers had a 3.75 times higher crash rate than average females. While examining alcohol usage, the study found large reductions in alcohol involvement for very young drivers, aged 17 or younger, but male drivers aged 20 to 40 continued to be the group with the highest occurrence of alcohol involvement for ROR crashes. While examining vehicle body type, the study found an increase in utility vehicles involved in ROR crashes of about 600% from 1975 to 1997.

McLaughlin et al. (2009) investigated the effects of levels of precipitation, lighting, and roadway surface conditions in occurrence of ROR crashes through a 100-car naturalistic driving study, which was undertaken in order to obtain data on driver performance and behavior in the moments leading up to a crash. Data in the 100-car study was collected from drivers in the Northern Virginia/Washington D.C. area for a year. The study adjusted vehicle-miles-traveled (VMT) in different conditions and found that ROR crashes were more frequent on a per-mile basis in low friction and poor visibility conditions. Precipitation (fog, mist, and rain) increased the occurrence of ROR crashes 2.5 times compared with clear conditions. Snow or ice increased the likelihood of ROR crashes relative to dry conditions. While investigating driver-related factors, it was found that multiple factors were responsible for an event but distraction/inattention (40% of ROR events) was the most common contributing factor. Changes in roadway boundaries such as the start of a median, narrowing of the lane from the right, loss of a lane, or atypical roadway geometry were considered as a contributing factor in 22% of the events.

Spainhour and Mishra (2008) in Florida examined human, roadway, vehicle, and environmental factors associated with overcorrection as opposed to traditional ROR crashes using binary logistic regression analysis. Overcorrection occurs when a vehicle begins drifting off the road one way and the driver oversteers in the opposite direction, leading the vehicle to cross over into oncoming lanes of traffic, sideswipe an adjacent vehicle, or travel off the road into a hazard. The study used data from Florida Traffic Crash Report (FTCR) and Florida Department of Transportation (FDOT) Crash Analysis Reporting System (CAR) database for ROR crashes in 2000 in Florida. The analysis of the data revealed the fact that approximately 36% of the vehicles crossed the entire roadway and departed on the opposite side from the initial roadway departure. Among different contributory factors, alcohol was the major one, followed by speed, inattention, and fatigue/sleep. It was also found that overcorrection had a strong positive association with the presence of rumble strips, inclement weather, rural locations, incapacitated drivers, and running off the road to the left or straight. The authors found strong negative association with male drivers, speeding, paved or curbed shoulders, wet or slippery roads, and larger vehicles. Fewer than 20% of fatal ROR crashes occurred where rumble strips were present; drivers were more than 50% more likely to overcorrect than when they were not present.

Liu and Subramanian (2009) used the Fatality Analysis Reporting System database for fatal ROR crashes occurring during the period 1991 to 2007. Logistic regression analysis was used in the study and the results revealed that ROR crashes were more likely to take place on curved roads, rural roads, and roadways with fewer lanes. Speeding vehicles, vehicles with high occupancy, adverse weather conditions, dark conditions, vehicles driven by male and young drivers, and passenger cars posed special challenges for roadside safety improvement efforts.

In another study conducted by Dissanayake (2003), a sequential binary logistic regression model was used to identify the most important causes of ROR crashes and to estimate the severity of young driver ROR crashes, which are extracted from the Florida Traffic Crash Database for 1997-1998. The study found that use of alcohol or drugs, ejection in the crash, gender, impact point of the vehicle, restraint device usage, urban/rural location, grade/curve existence of the crash location, lighting condition, and speed were the most important factors affecting the severity of young driver single-vehicle ROR crashes.

Zhu et al. (2010) used logit models for analyzing fatal single-vehicle ROR crashes on rural two-lane highways in the southeastern United States. The researchers used two-lane rural highway fatal crashes from the Fatality Analysis Reporting System database (FARS) for the year 1997 for the states of Alabama, Georgia, and Mississippi and for 1998 for South Carolina. There were a wide variety of variables that influence a single-vehicle fatal crash in the three states: Alabama, Georgia, and South Carolina. These included location, lane width, shoulder width and type, horizontal curve direction, crest vertical curves present, horizontal and vertical geometric interactions, roadside hazard rating, traffic volume, driveway type, lighting conditions, and crash time.

This study uses drivers' license data in determining ROR and NROR crash rates. Important driver, vehicle, roadway, and environment characteristics associated with ROR crashes are identified in this study, which will help to identify countermeasures to reduce ROR crashes. In comparing ROR and NROR crashes, the Bayesian statistical approach was used for the first time in this study.

METHODOLOGY

Crash Data

Ten-year crash data from 1999 to 2008 was obtained from the Kansas Accident Reporting System (KARS) database for this study (Kansas Department of Transportation 2010). The Microsoft Access database KARS consists of all police-reported crashes in Kansas. It includes descriptive data on environmental conditions, time, roadway, driver, and vehicle-related factors. The total number of ROR and NROR crashes for the 10-year period was found to be 167,977 and 565,896 respectively. The number of licensed drivers for 10-year periods was taken from Federal Highway Administration's *Highway Statistics Series* (2010a).

ROR crashes in this study are defined as those where the vehicles leaving the roadway encroach upon the median, shoulders, or beyond and either overturns, collides with fixed objects, or leads to head-on crashes with other vehicles; sideswipe with opposing vehicles; or crashes where the first harmful events occur off the roadway or median-off roadway in the case of divided highway sections.

Types of crashes that are considered as ROR crashes can be categorized as follows:

- Head-on
- Sideswipe: opposite direction
- Overturned

- Fixed-objects
- Roadside including shoulder-off roadway
- Median-off roadway

The rest of the crashes in the database are considered as NROR crashes and are obtained by deducting the ROR crashes from the total number of crashes.

Based on the definition stated above, KARS data were categorized into ROR and NROR crashes. Once the data for ROR and NROR crashes were extracted, various crash characteristics corresponding to each type of crash were recorded using queries in Microsoft Access and filtering techniques in Microsoft Access and Microsoft Excel. Filtering is a simple and easy way that allows handling a large data set in an efficient way by assigning certain criteria in order to get a subset of data. The trend analysis was done for 10 years, from 1999 to 2008. This long span enabled a detailed analysis of trends for different age groups and gender of involved drivers. For analyzing different factors that are associated with ROR and NROR crashes, and to compare the role of driver, vehicle, environment, and roadway-related contributory causes in ROR and NROR crashes, it was decided to use five-year crash data (2004 to 2008) instead of 10-year as different aspects of the transportation system such as drivers, roadways, and vehicles could have changed over a long period of time. The numbers of ROR and NROR crashes for the five-year time period are 82,660 and 262,099, respectively.

Bayesian Statistical Approach

The approach of Bayesian statistics is an effective measure in recognizing the predominance of crash-related factors while comparing ROR and NROR crashes. Previously, the approach has been used by Bezwada et al. (2010) in comparing fatal truck and non-truck crashes.

The conditional probability of the occurrence of a driver, vehicle, environment, and road-related contributory cause for an ROR crash can be obtained by using the following equation (Bezwada and Dissanayake 2010):

$$(1)\quad P\ (CC/\ ROR) = \frac{P(ROR\ /\ CC) * P(CC)}{P(ROR)}$$

Where,

P (CC/ROR) = Probability of the specific driver, vehicle, environment, and road-related cause being reported as a contributory cause for a particular ROR crash.

P (ROR/CC) = Probability that the crash is an ROR crash, given that a specific contributory cause is also reported. As shown in Equation (2), this value is estimated from the data by considering the total number of crashes with the contributory cause and those in which an ROR crash and the contributory cause are coded together.

P (CC) = Overall probability of the specific driver, vehicle, environment, and road-related cause being reported as a contributory cause, and is estimated from the number of cases in which the CC is reported.

P (ROR) = Overall probability of a ROR crash and is estimated via equation (3).

$$(2)\quad P(ROR\ /\ CC) = \frac{\text{Number of ROR crashes with that contributory cause}}{\text{Number of all ROR and NROR crashes with that contributory cause}}$$

$$(3)\quad P(ROR) = \frac{\text{Number of ROR crashes}}{\text{Number of all ROR and NROR crashes}}$$

(4) $$P(CC) = \frac{\text{Number of crashes with that contributory cause}}{\text{Number of all ROR and NROR crashes}}$$

Similarly, the conditional probability of a contributory cause for a given NROR crash is calculated. The likelihood ratio is then estimated with the following equation:

(5) $$\text{Likelihood Ratio} = \frac{P(CC/ROR\ Crash)}{P(CC/NROR\ Crash)}$$

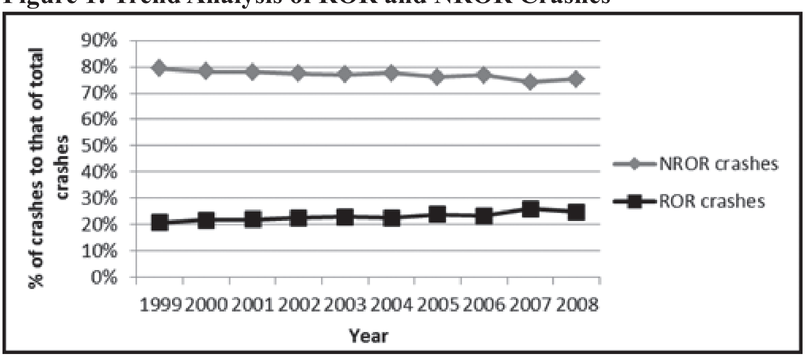
The likelihood ratio is the probability of a crash being an ROR crash when the contributory factor is recorded, as compared with the probability of a crash being a NROR crash when the same contributory factor is identified.

ANALYSIS AND RESULTS

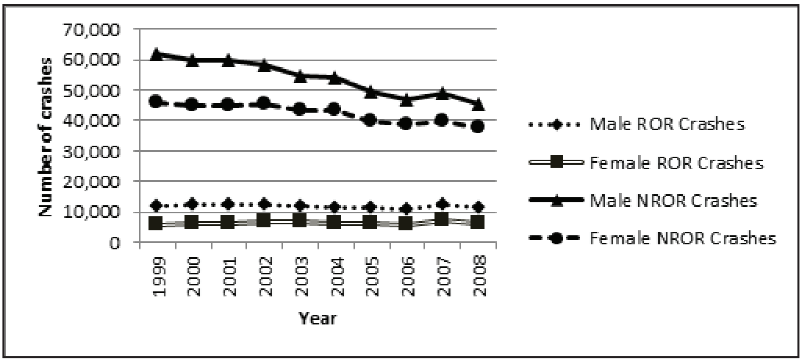
Trends of ROR and NROR Crashes, 1999 to 2008

Figure 1(a) illustrates the percentages of ROR and NROR crashes to that of total crashes. The figure shows that the percentage of ROR crashes has increased during the 10 years with the lowest being observed in 1999 (20.6%) and with the highest being observed in 2007 (25.8%). The percentage of NROR crashes, on the other hand, has decreased slightly over the 10 years. Figure 1(b) and 1(c) demonstrate ROR and NROR crashes and crash rates per 1,000 licensed drivers for 10 years. ROR and NROR crashes and crash rates by driver gender are shown in Figures 1(b) and 1(c), respectively. As more than one driver can be involved in an ROR or NROR crash, the total number of drivers involved in ROR and NROR crashes is higher than the total number of ROR and NROR crashes respectively. From Figure 1(b) and 1(c), it is observed that the difference between male and female crashes as well as crash rates is much higher for ROR crashes than that for NROR crashes. This suggests that the proportion of male driver involvement is greater in ROR crashes than in NROR crashes.

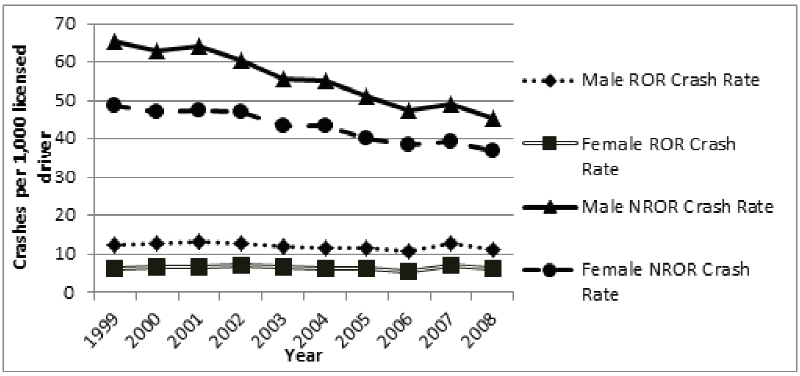
Figure 1: Trend Analysis of ROR and NROR Crashes



a) Percentage of ROR and NROR Crashes to That of Total Crashes



b) ROR and NROR Crashes by Gender



c) ROR and NROR Crash Rates by Gender

Characteristics and Comparison of ROR and NROR Crashes

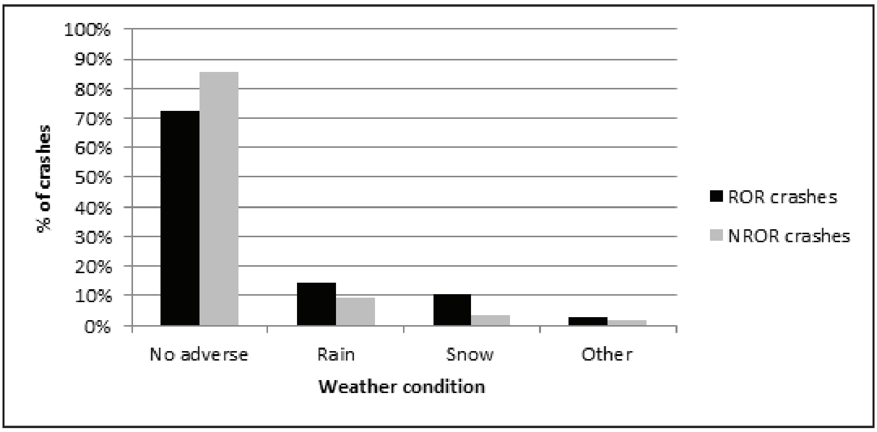
In this section, several variables are discussed such as environment, time of occurrence of crashes, roadway, and vehicle-related factors, which have strong association with ROR and NROR crashes. Based on studies mentioned in the literature review section, different variables are considered are weather and light conditions as environment-related factors; days of week and time of the day to find the critical time of occurrences of crashes; road alignment, roadway functional class, lane class, road surface condition, road surface character, road surface type, and speed limit as roadway-related factors; and vehicle body type as vehicle-related factors. All the factors that are considered in this study are compared between ROR and NROR crashes. For the ease of comparison, percentages in each sub-category are calculated by taking the total number of ROR or NROR crashes as the base value.

Environment Related Factors

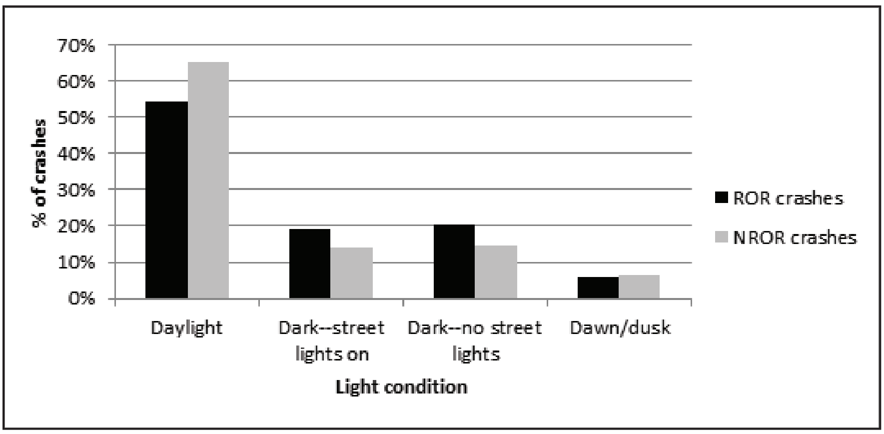
The environment-related factors considered in this study are weather condition and light condition, and Figure 2 illustrates the relative occurrence of environmental factors in ROR and NROR crashes.

Weather Condition. To investigate if a certain weather condition has any consequence on the occurrence of ROR and NROR crashes, the bar chart of ROR crashes and NROR crashes is obtained and is shown in Figure 2 (a). Among different weather conditions being observed, it is found that, although maximum number of crashes for both ROR and NROR crashes occur under no adverse conditions, the percentage of crashes in good weather conditions is much higher for NROR crashes than for ROR crashes. This suggests that adverse weather conditions have more effect on ROR crashes. The percentages of ROR crashes are higher than that of NROR crashes under rain and snow condition. This clearly demonstrates that ROR crashes are more likely to occur in adverse weather conditions.

Figure 2: Bar Charts of Environmental Factors in ROR and NROR Crashes



a) Bar Chart Based on Weather Condition



b) Bar Chart Based on Light Condition

Light Condition. It is observed from Figure 2 (b) that the percentages of both ROR and NROR crashes occurring during daylight are much higher than those of nighttime hours. But when light condition is considered in ROR/NROR crash scenarios, it has been found that ROR crashes are more likely than NROR crashes to occur during nighttime. Dark conditions, even if the streets lights are present, relate to a larger number of ROR crashes in comparison with NROR crashes.

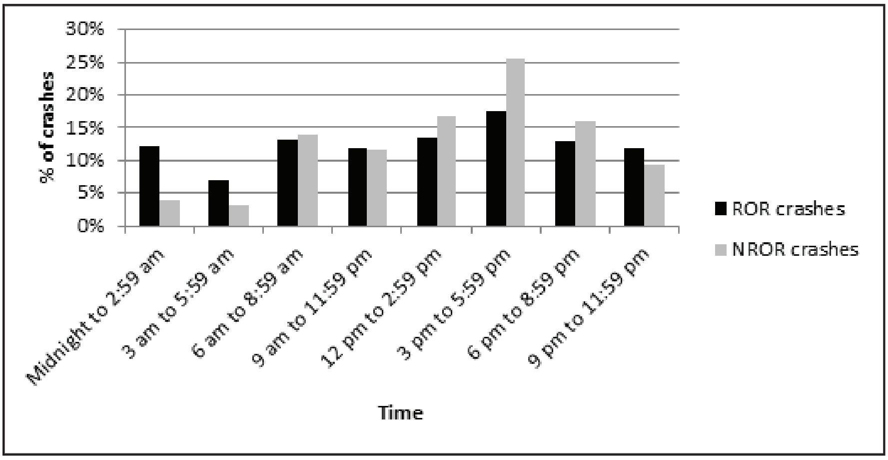
Time of Occurrence of Crashes

To find out the time of occurrence of ROR crashes, two factors are considered: time of day and days of week, and these are shown in Figure 3.

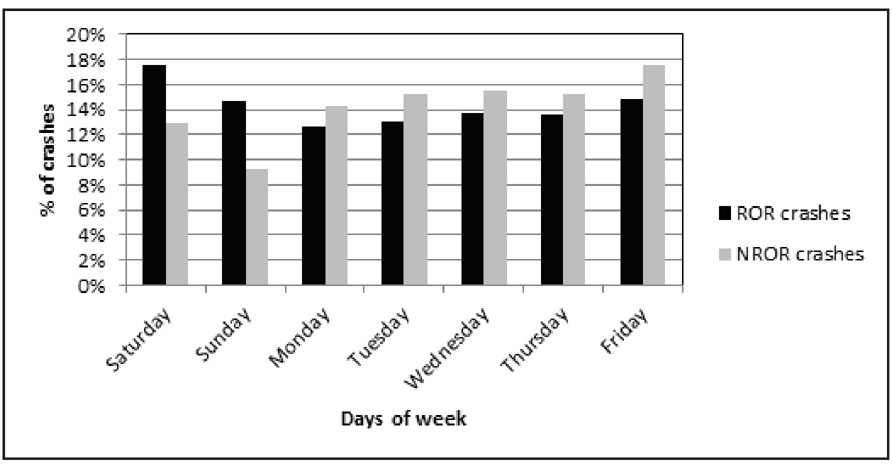
Time of Day. Bar chart of ROR crashes and NROR crashes based on time of day show that the percentages of both ROR and NROR crashes are higher during daytime than at night. But the percentage of ROR crashes is higher than the percentage of NROR crashes at night. The difference between two types of crashes is the highest between midnight and 3:00 am. This finding reveals that nighttime driving apparently results in more ROR crashes relative to NROR crashes.

Day of Week. Among various days of a week, the percentage of ROR crashes is greater during weekends. On the contrary, NROR crashes are higher in number during weekdays. From Figure 3 (b), it is seen that the percentage of ROR crashes is higher during Saturday and Sunday than any other days of the week. For NROR crashes, weekdays constitute the larger percentage of crashes with Friday being the highest.

Figure 3: Bar Charts for Time and Days of Week in ROR and NROR Crashes



a) Bar Chart Based on Time of Day



b) Bar Chart Based on Days of Week

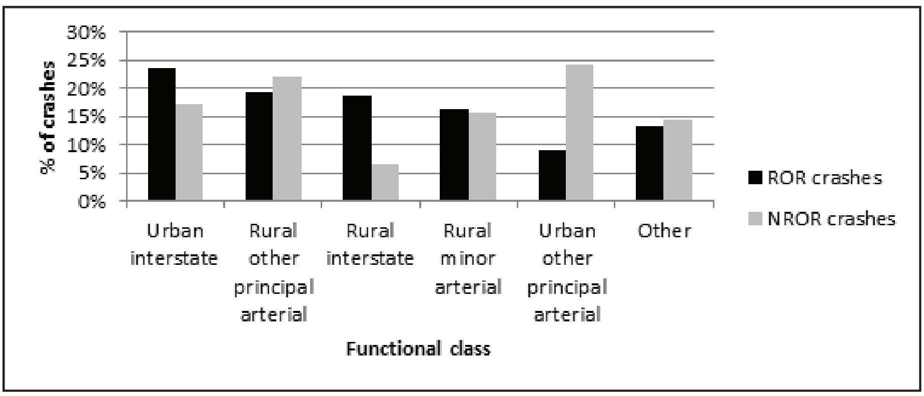
Roadway Environment

Roadway-related factors being examined in this study are roadway functional class, lane class, road surface character, road surface condition, road surface type, and speed limit, and these are shown in Figure 4 and Figure 5.

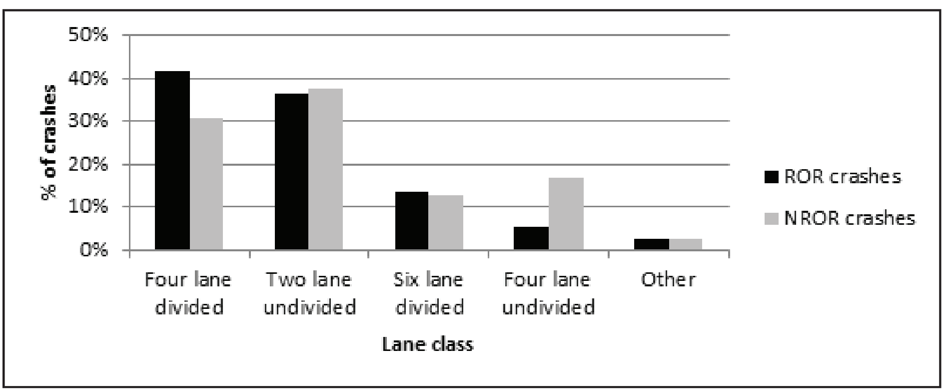
Functional Classes of Roadway. Six major functional classes of roadways are categorized in this study: urban and rural interstate, urban and rural other principal arterial, rural minor arterial. Rural major collector, rural minor collector, urban freeway/expressway, urban collector, rural local road, and urban minor arterial are included in the category of others. There are major differences between ROR and NROR crashes based on functional classes of roadway. From Figure 4 (a), it is found that the percentage of ROR crashes is much higher on interstates, both in rural and urban areas; whereas the percentage of NROR crashes is higher in rural and urban other principal arterials.

Lane Class. Four categories of lanes are considered in this study: two-lane undivided, four-lane divided and undivided, and six-lane divided. Eight-lane divided and two-lane divided are considered as others. The bar chart for ROR and NROR crashes shows that the highest percentage of ROR crashes occurs on four-lane divided highways followed by two-lane undivided highways. If comparison between ROR and NROR crashes is done, it is found that NROR crashes are more likely to occur on undivided highways relative to ROR crashes, while ROR crashes are more common on divided highways compared with NROR crashes.

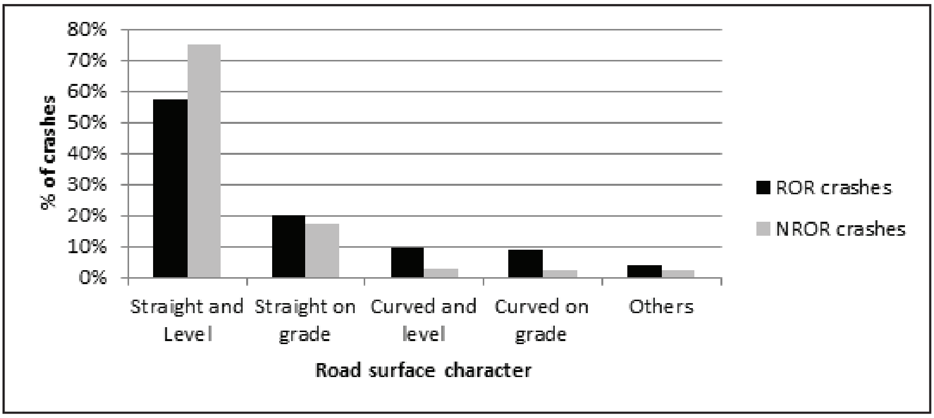
Figure 4: Bar Charts of Roadway-Related Factors for ROR and NROR Crashes



a) Functional Classes of Roadway



b) Lane Classes of Roadway

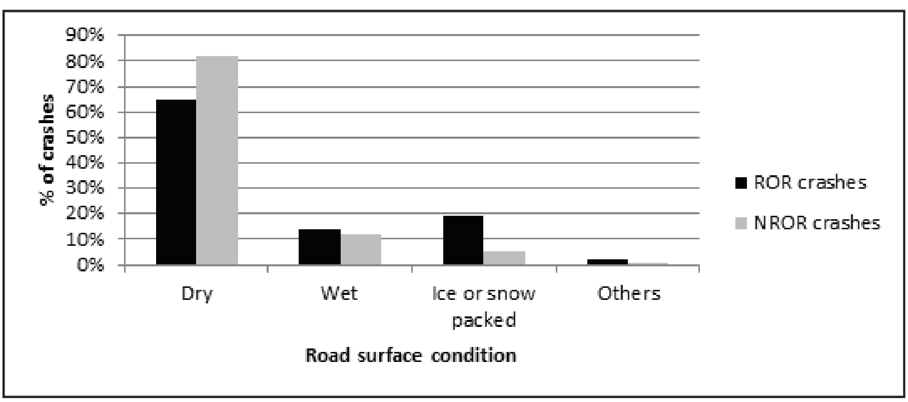


c) Road Surface Character

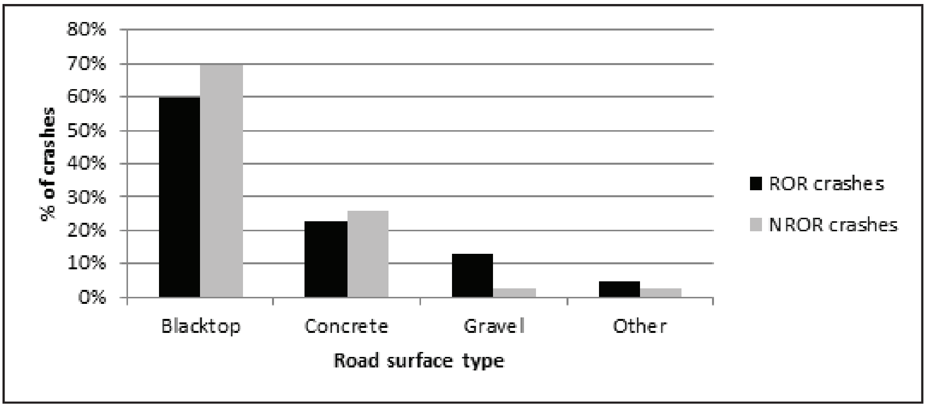
Road Surface Character. It is also of interest to see if the roadway surface character makes any difference in the occurrence of ROR and NROR crashes. Although the majority of ROR and NROR crashes occur on straight and level road surfaces, the bar chart shows significant differences between ROR and NROR crashes based on road surface character. It is found that the percentage of ROR crashes is less than the percentage of NROR crashes on straight and level roads. On the other hand, the percentage of ROR crashes are higher than the percentage of NROR crashes on straight on grade, curved, and level, as well as curved on grade roads.

Road Surface Condition. Another factor worth considering is road surface condition. Three main categories of road surface conditions are considered in this study: dry, wet, and ice or snow packed. Road surface with mud, debris, and unknown categories are classified as others. Among different road surface conditions, it is observed that ice or snow packed roads intensify the occurrence of ROR crashes. Figure 5 (a) also clarifies that if the road surface is wet, a higher percentage of ROR crashes are likely to occur compared with NROR crashes. On the other hand, the percentage of crashes occurring under dry surface conditions is higher for NROR crashes than for ROR crashes. This indicates that ROR crashes are more likely to happen if the road surface is wet, icy, or snow packed relative to NROR crashes.

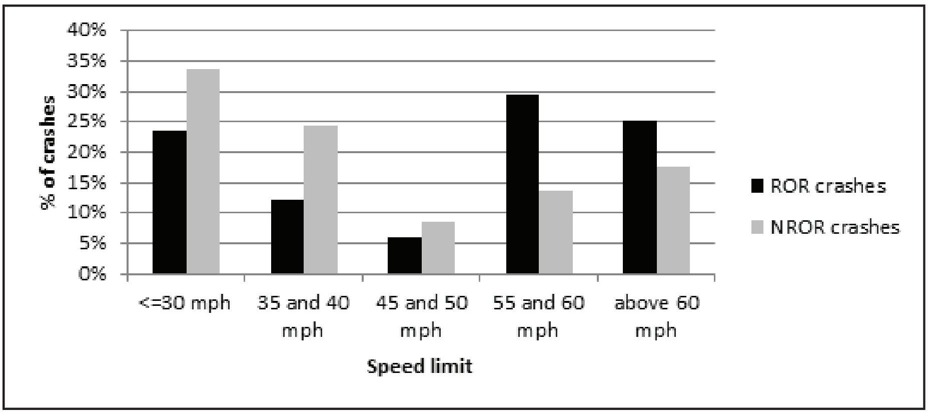
Figure 5: Bar Charts of Roadway-Related Factors for ROR and NROR Crashes



a) Road Surface Condition



b) Road Surface Type



c) Speed Limit

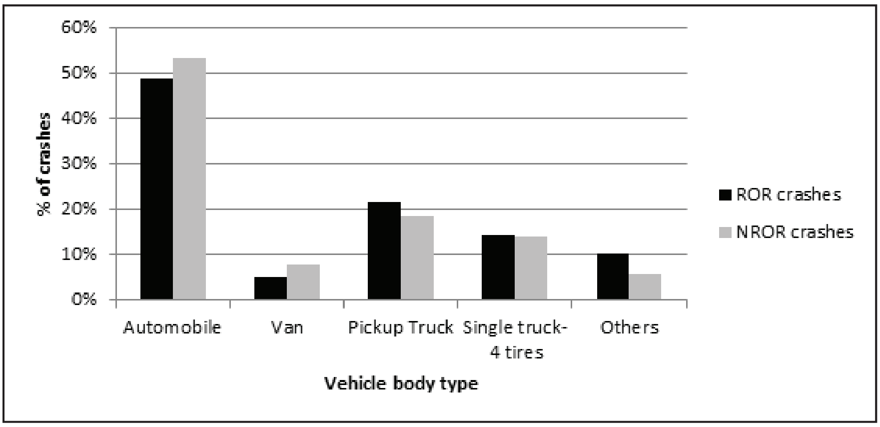
Road Surfacee Type. Major differences are found between ROR and NROR crashes based on road surface type. The bar chart of road surface type for ROR and NROR crashes shows that among three major types of roads that are being considered (blacktop, concrete, and gravel), the percentage of crashes is higher for ROR crashes than for NROR crashes when the road surface type is gravel. A higher percentage of NROR crashes compared with ROR crashes occur on blacktop road surface. Dirt, brick, and unknown types of roads are categorized as others in this study, and it is found that this category also exhibits a larger percentage of ROR crashes than NROR crashes. This suggests that gravel, dirt or brick roads are relatively more common for the occurrence of ROR crashes compared with NROR crashes; whereas blacktop and concrete road surfaces are more common for NROR crashes to occur relative to ROR crashes.

Speed Limit. It is also of interest to see if the speed limit has any consequence in the occurrence of ROR crashes. From the bar chart of ROR and NROR crashes, it is found that the percentage of NROR crashes is relatively more frequent when speed limit is 30 mph or less. But the occurrence of ROR crashes increases with increase in speed. The highest percentage of ROR crashes is obtained when the speed limit is between 55 and 60 mph and also when the speed limit is above 60 mph. This reveals that a higher speed limit is associated with a higher percentage of ROR crashes relative to NROR crashes.

Vehicle Related Factor

Vehicle body type is considered as the only vehicle related factor in this study. Four different vehicle body types are considered to investigate the effects of vehicle body in the occurrence of ROR crashes. These are automobiles, pickup truck, single truck-four tires (SUV), and van. School bus, city bus, single truck over four tires, and unknown categories are classified as others. It is found that automobiles have the largest share both for ROR and NROR crashes, although the percentage of NROR crashes is slightly higher than the percentage of ROR crashes. Pickup trucks and SUVs have a bit of a larger share for ROR crashes than that for NROR crashes. The percentage of ROR crashes for category others is also found to be slightly higher than the percentage of NROR crashes.

Figure 6: Bar Chart of Vehicle Body Type for ROR and NROR Crashes



Contributory Causes and Likelihood Ratios of ROR and NROR Crashes

The likelihood of occurrence of driver, vehicle, environment, and road-related contributory causes in ROR crashes when compared with NROR crashes are discussed with the following tables. The probability of a contributory cause greater than one indicates that contributory cause is more predominant in ROR crashes than in NROR crashes.

Driver Related Causes

Table 1 shows contributing driver-related causes as well as their corresponding likelihood ratios in ROR crashes when compared with NROR crashes. The total number of ROR and NROR crashes occurring between 2004 and 2008 due to driver-related contributory causes are 84,718 and 243,099 respectively. However, since some of the categories consist of an insignificant number of crashes, they are not presented in Table 1. Hence the number of ROR and NROR crashes presented in columns 2 and 3 are 79,858 and 155,709, respectively. The contributory cause is identified by the police once the crash occurs. There are some crashes where the contributory cause is not reported by the police as they are not known. Again, there are some crashes which are contributed to by more than one cause. The entries in each column of Table 1 are explained by taking an example of a driver-related cause. The first numbers in columns 2 and 3 represent the number of ROR and NROR crashes, respectively, when falling asleep contributes to the crashes. The detailed calculation to obtain the likelihood ratio for falling asleep is presented.

$$P(ROR/CC) = \frac{\text{Number of ROR crashes due to fell asleep}}{\text{Number of all ROR and NROR crashes due to fell asleep}}$$

$$= \frac{3{,}281}{(3{,}281 + 651)} = 0.834$$

$$P(ROR) = \frac{\text{Number of ROR crashes}}{\text{Number of all ROR and NROR crashes}} = \frac{84{,}718}{84{,}718 + 243{,}099} = 0.25843$$

$$P(CC) = \frac{\text{Number of crashes due to fell asleep}}{\text{Number of all ROR and NROR crashes}} = \frac{(3{,}281 + 651)}{(84{,}718 + 243{,}099)} = 0.01199$$

$$P(\mathrm{CC/ROR}) = \frac{\mathrm{P(ROR/CC)} * \mathrm{P(CC)}}{\mathrm{P(ROR)}} = \frac{0.834 * 0.01199}{0.25843} = 0.0387$$

Similarly, P (CC/NROR) can be calculated. The likelihood ratio due to fell asleep thus is obtained with the following equation.

$$\text{Likelihood Ratio} = \frac{\text{P(CC/ROR Crash)}}{\text{P(CC/NROR Crash)}} = \frac{0.0387}{0.00267} = 14.49$$

Fell asleep, ill or medical condition, driving under influence of alcohol and drugs, exceeded posted speed limit, wrong side or wrong way, avoidance or evasive action, distraction for various electronic devices, distraction in or on vehicle, too fast for conditions, aggressive/antagonistic driving, reckless/careless driving, and not complying with license restrictions are found to have the likelihood ratios greater than one, which indicates that these causes are more predominant in ROR crashes than in NROR crashes.

Table 1: Conditional Probabilities and Likelihood Ratios for Driver-Related Contributory Causes from 2004-2008 (Combined)

Driver Factors (DF)	Number of ROR crashes	Number of NROR crashes	Conditional Probability of this DF given a ROR crash	Conditional Probability of this DF given a NROR crash	Likelihood Ratio
Fell asleep	3,281	651	0.0387	0.00267	14.49
Ill or medical condition	1,538	713	0.01815	0.002933	6.19
Exceeded posted speed limit	3,029	1,817	0.0357	0.0074	4.82
Wrong side or wrong way	2,053	1,388	0.0242	0.0057	4.24
Under influence of alcohol	8,378	5,686	0.0989	0.02339	4.23
Too fast for conditions	21,254	15,486	0.2509	0.0637	3.94
Reckless/Careless driving	4,583	3,341	0.0541	0.0137	3.95
Avoidance or evasive action	5,409	4,145	0.0638	0.0171	3.73
Under influence of drugs	698	651	0.00824	0.0026	3.17
Distraction-other electronic devices	223	310	0.0026	0.0012	2.17
Aggressive/Antagonistic driving	581	820	0.0068	0.0033	2.06
Distraction in or on vehicle	1,807	2,578	0.0213	0.0106	2.01
Did not comply w lic restric	1,146	1,671	0.0135	0.00687	1.97
Distraction-cell phone	573	1,074	0.00676	0.0044	1.54
Made improper turn	2,199	7,288	0.0259	0.0299	0.87
Failed to give time and attention	21,567	92,761	0.2546	0.3816	0.67
Improper parking	59	373	0.00069	0.001534	0.45
Disregard traffic signs, signal	2,053	15,046	0.0242	0.0618	0.39

Vehicle Related Causes

Vehicle-related causes which are responsible for ROR and NROR crashes to occur are subdivided into 11 categories. From Table 2, it is found that tires, trailer coupling, and wheels have the largest likelihood ratios, which suggests that they might contribute to ROR crashes more often than NROR crashes. The likelihood ratios are obtained using the same procedures described previously in the Driver-Related Causes section for “fell asleep.”

Table 2: Conditional Probabilities and Likelihood Ratios for Vehicle-Related Contributory Causes from 2004-2008 (Combined)

Vehicle factors	Number of ROR crashes	Number of NROR crashes	Conditional Probability of this VF given a ROR crash	Conditional Probability of this VF given a NROR crash	Likelihood Ratio
Tires	1,029	487	0.4080	0.1153	3.54
Trailer coupling	190	163	0.0753	0.0386	1.95
Wheels	352	427	0.1395	0.1011	1.38
Unattended (in motion)	135	241	0.0535	0.0571	0.9
Cargo	249	640	0.0987	0.1516	0.7
Brakes	364	1,059	0.1443	0.2509	0.6
Headlights	24	112	0.0095	0.0265	0.4
Windows-windshield	69	295	0.0273	0.0698	0.4
Unattended (not in motion)	50	291	0.0198	0.0689	0.3
Exhaust	15	145	0.0059	0.0343	0.2
Other lights	17	235	0.0067	0.0558	0.1

Environment Related Causes

Environmental and road-related causes responsible for ROR and NROR crashes are summarized in Table 3. Among different environment-related causes, strong winds, sleet, hail, freezing rain, falling snow, rain, and reduced visibility due to cloudy skies are found to have the highest likelihood ratios, which indicates that they significantly contribute to ROR crashes. Besides fog, smoke, or smog, blowing sand, and soil and dirt are also causes that contribute to ROR crashes more often than NROR crashes.

Table 3: Conditional Probabilities and Likelihood Ratios for Environment Contributory Causes from 2004-2008 (Combined)

Environment Factors	Number of ROR crashes	Number of NROR crashes	Conditional Probability of this EF given a ROR crash	Conditional Probability of this EF given a NROR crash	Likelihood Ratio
Sleet, hail, freezing rain	1,961	843	0.1738	0.01908	9.11
Strong winds	902	476	0.0799	0.0107	7.47
Falling snow	2,157	1,407	0.1911	0.0318	6.01
Rain, mist, or dizzle	3,519	3,694	0.3118	0.0836	3.73
Reduced visibility due to cloudy skies	71	105	0.0062	0.0023	2.69
Fog, smoke, or smog	246	488	0.0218	0.0110	1.98
Blowing sand, soil, dirt	58	117	0.0051	0.0026	1.96
Vision-obstruction-vegetation	57	375	0.0050	0.0084	0.60
Vision-obstruction-glare	233	1,755	0.0206	0.0397	0.52

Road Related Causes

It is found from Table 4 that shoulders have the highest likelihood ratios among different road-related causes. Ruts, holes, bumps, and icy or slushy roads also significantly contribute to ROR crashes as they have likelihood ratios greater than one.

Table 4: Conditional Probabilities and Likelihood Ratios for Road-Related Contributory Causes from 2004-2008 (Combined)

Road condition	Number of ROR crashes	Number of NROR crashes	Conditional Probability of this RF given a ROR crash	Conditional Probability of this RF given a NROR crash	Likelihood Ratio
Shoulders: low-soft-high	261	47	0.0213	0.0043	4.94
Ruts, holes, bumps	402	136	0.0329	0.0125	2.63
Ice or slushy	6,513	4,190	0.5331	0.3858	1.38
Wet	2,995	3,625	0.2451	0.3338	0.73
Traffic control device inoperative	43	99	0.0035	0.0091	0.39
Road under construction-maintenance	152	474	0.01244	0.04365	0.29
Debris or obstruction	338	1,140	0.0276	0.1049	0.26

This section identifies driver, vehicle, environment, and road-related causes that directly contribute to crashes. As stated before, the Bayesian Statistical Approach in comparing ROR crashes with NROR crashes has been applied in this study for the first time. Therefore, the causes that are found to be predominant in ROR crashes in comparison with NROR crashes in this study cannot be compared with previous studies.

CONCLUSION

A significant increase in the number of ROR crashes in recent years has been observed. More male drivers are involved in both ROR and NROR crashes than female drivers but the difference is much higher for ROR crashes than for NROR crashes. Among different times of the day and days of the week, the percentage of ROR crashes compared with the percentage of NROR crashes is higher at night and during weekends. This indicates that male drivers under the influence of alcohol while driving during weekends get involved in ROR crashes the most. Shoulder rumble strips in this case can be an effective device to keep drivers on the road. Putting special restrictions on teenage drivers' licenses; especially during nighttime, could also be an effective strategy to reduce ROR crashes experienced by young drivers. Increased usage of seat belts through education, law enforcement, legislation, and training might also be helpful in reducing ROR crashes.

While analyzing different characteristics, it was found that adverse weather and dark conditions increase the percentage of ROR crashes compared with NROR crashes. Among different roadway-related factors, it was observed that rural and urban interstates, curved roads, ice or snow packed road surfaces, gravel roads, and roadways with a posted speed limit of 50 mph or higher are more likely to be the scene of ROR crashes relative to NROR crashes. In contrast, urban roads, straight roads, rural and urban principal arterials, dry road surfaces, asphalt roads, and roadways with a speed limit of 30 mph or less are more common for NROR crashes to occur than ROR crashes. Sport utility vehicles with a high center of gravity cause rollovers and increases in the number of ROR crashes compared with NROR crashes. Various driver, vehicle, road, and environmental-related contributory causes such as fell asleep, ill or medical condition, DUI, too fast for conditions, exceeded posted speed limit, tires and wheels, strong winds, sleet, hail, freezing rain, shoulders, ruts, holes, and bumps are found to have the greatest likelihood ratios and as such have a greater role in contributing to ROR crashes than NROR crashes.

The occurrence and severity of ROR crashes can be reduced if potential countermeasures can be developed based on the identified factors and causes in this study. Designing and testing of roadside barriers, relocating utility poles, removing misplaced highway appurtenances, flattening side slopes, expansion of the roadside recovery spaces (the space that allow drivers to regain the control of the vehicle once they depart from the road) are some of the options to reduce the severity as well as frequency of roadside crashes. Improvements in geometric design standards of the roads could also reduce roadside crashes. Improvements in vehicle headlights and braking systems are useful in order to increase vehicle stability so that vehicles do not roll over. Countermeasures for NROR crashes would be entirely different as the nature of the crashes is different.

Acknowledgements

The authors thank the University Transportation Centre at the Kansas State University for funding this project. The authors would also like to acknowledge the Kansas Department of Transportation for providing necessary data for carrying out this research. The authors thank the editor of JTRF, Dr. Michael Babcock, for his kind help, time, and invaluable comments on the paper that help to improve the quality of the paper to a large extent.

Endnotes

1. Run-off-Road (ROR) crashes in this study are defined as those crashes, where the vehicles leaving the roadway encroach upon the median, shoulders, or beyond and either overturns, collides with fixed objects, or leads to head-on crashes with other vehicles or sideswipes with opposing vehicles; or crashes where the first harmful events occur off the roadway or median-off roadway in the case of divided highway sections. Non-run-off-road (NROR) crashes are defined as those crashes where vehicles remain on the road once the crashes occur. As there is no specific definition of ROR crashes, this study has developed its own definition, and once the ROR crashes are extracted from the database based on the definition stated above, NROR crashes are obtained by subtracting the ROR crashes from the total number of crashes.

2. Roadside crashes are considered as those crashes where vehicles leaving the travel lane collide with any roadside objects such as tree or embankment. A substantial portion of ROR crashes are considered as roadside crashes and they do not include NROR crashes.

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***Sunanda Dissanayake** is an associate professor at the Department of Civil Engineering in Kansas State University. Her primary research interests include various aspects of traffic engineering, highway safety, crash data analysis, and access management. She has published extensively in technical journals in addition to numerous presentations at various transportation conferences. She obtained her B.Sc. (Eng.), M. Eng., and Ph.D. degrees from the University of Moratuwa, Asian Institute of Technology, and University of South Florida respectively.*

***Uttara Roy** is a graduate research assistant in the Department of Civil Engineering at Kansas State University. Before joining KSU, she was a lecturer at the Department of Civil Engineering at a university in Bangladesh. She did her undergrad work at Bangladesh University of Engineering and Technology in civil engineering, and received her master's of science in management of logistics and transportation from Chalmers University of Technology, Sweden. She also worked as a graduate research assistant at two universities in Canada.*