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Contributing Factors to Run-Off-Road Crashes and Near-Crashes

Final Report

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| 16. Abstract <p>The purpose of this investigation is to identify factors associated with run-off-road (ROR) crashes. Events from the 100-Car Naturalistic Driving Study that constituted ROR crash or near-crash events were investigated to identify conditions in which the events occurred and contributing factors. ROR events occur more frequently per mile in low-visibility (including darkness) and low-friction conditions than in clear and dry conditions. Approximately half of the events (56%) occurred on straight roadways, with the remainder occurring in curves (30%) and intersection turns (14%). The most frequently identified contributing factor among the ROR events was distraction. Changes in roadway boundaries (e.g., discontinuities) also appear to be a common factor. Short following distances appear to be more commonly a factor than lead-vehicle braking. Other factors include fatigue/impairment, low friction, vehicle encroaching on the subject vehicle, low-speed maneuvering errors, and late route selection.</p> | | | | | |
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EXECUTIVE SUMMARY

The run-off-road (ROR) crash type was investigated by identifying ROR-related events from the 100-Car Naturalistic Driving Study (Dingus et al., 2006). For this investigation, in addition to the events classified in the ROR category, other event types were included that demonstrated a driver avoidance response other than braking and where the vehicle contacted or crossed a road edge or where severe maneuvers were necessary to avoid crossing the road edge. With these criteria, 122 ROR-related events were identified for investigation — 28 ROR crashes (including minor crashes) and 94 ROR near-crashes. These events (crashes and near-crashes) were reviewed together with baseline data to estimate the rate of occurrence of ROR events in different driving conditions and roadway geometries, to characterize driver inputs during the ROR maneuver, and to determine contributing factors.

Through a review of the 100-Car dataset, the vehicle-miles-traveled (VMT) in different driving conditions was estimated for 101 primary drivers in the present study. The types of conditions investigated described levels of precipitation, lighting, and roadway surface conditions. The number of events occurring for the primary drivers in the different conditions was divided by estimated VMT to determine a per-mile ROR event rate in each condition. When adjusted in this way for exposure to different driving conditions, ROR events were found to occur most frequently, on a per-mile basis, in low-friction conditions and poor-visibility conditions (including darkness). Precipitation (fog, mist, or rain) increased the likelihood of an ROR event 2.5 times that of clear conditions. In darkness on unlighted roads, the likelihood of an ROR event increased 2.5 times that of clear or daylight conditions. Wet roads increased the likelihood of an ROR event approximately 1.8 times that of dry conditions, and snow or ice increased the likelihood by seven times that of dry conditions. Driving time did not appear to be related to the occurrence of ROR events. Fifty-six percent of the ROR events occurred on straight roadways. Thirty percent occurred in curved roadways and 14 percent occurred while making turns at intersections.

The ROR maneuver was defined to capture driver inputs (such as steering or braking) that created the ROR event, and driver inputs while attempting to regain control. Speed prior to the maneuver was higher in the straight-roadway and curved-roadway events as compared to the events occurring at intersections. Drivers applied the brakes during the ROR maneuver in approximately half of the events.

The 122 ROR events were also analyzed with the intention of identifying a contributing factor, rather than solely recording the presence of factors that have been associated with crashes. This analysis represents an approach in which an attempt is made to determine if the elimination or removal of one or more factors, which occurred in temporal proximity to the crash, may have prevented the event. Multiple factors were recorded for an event where more than one factor appeared to contribute, or where the various factors could not be isolated from each other. No ordering or hierarchy was assigned when multiple factors were identified.

The most common contributing factor was distraction/inattention (40% of ROR events), with 36 percent of the events involving secondary task distraction and 4 percent involving driving-related

inattention to the forward roadway. 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 a contributing factor in 22 percent of the events. Short following distance (14%), fatigue/impairment (11%), low friction (11%), and another vehicle encroaching on the subject vehicle (10%) were the next most commonly identified contributing factors. Less frequently identified contributing factors include low-speed maneuvering errors, lead-vehicle braking, and late route selection. Figure 1 illustrates the distribution of the contributing factors identified within the ROR events.

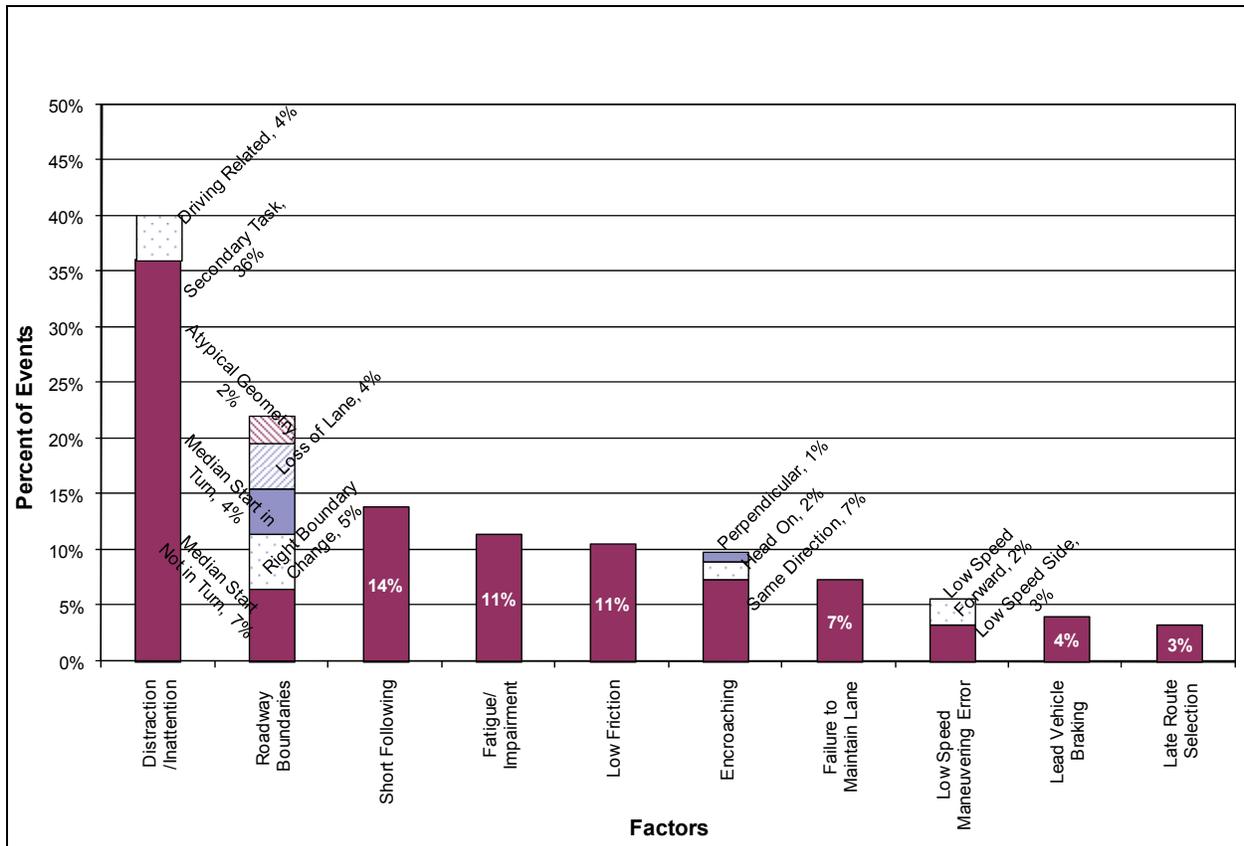


Figure 1. Percentage of ROR Events by Contributing Factors

Within the secondary task distraction category, the most common distraction tasks involved cellular phone talking and dialing cellular phones (8% combined; 5% and 3% respectively), talking to or looking at passengers (6% combined), and Original Equipment Manufacturer (OEM) devices (5%). Figure 2 provides a distribution of the percentage of ROR events and the percentage of distraction-related events including each type of contributing factor.

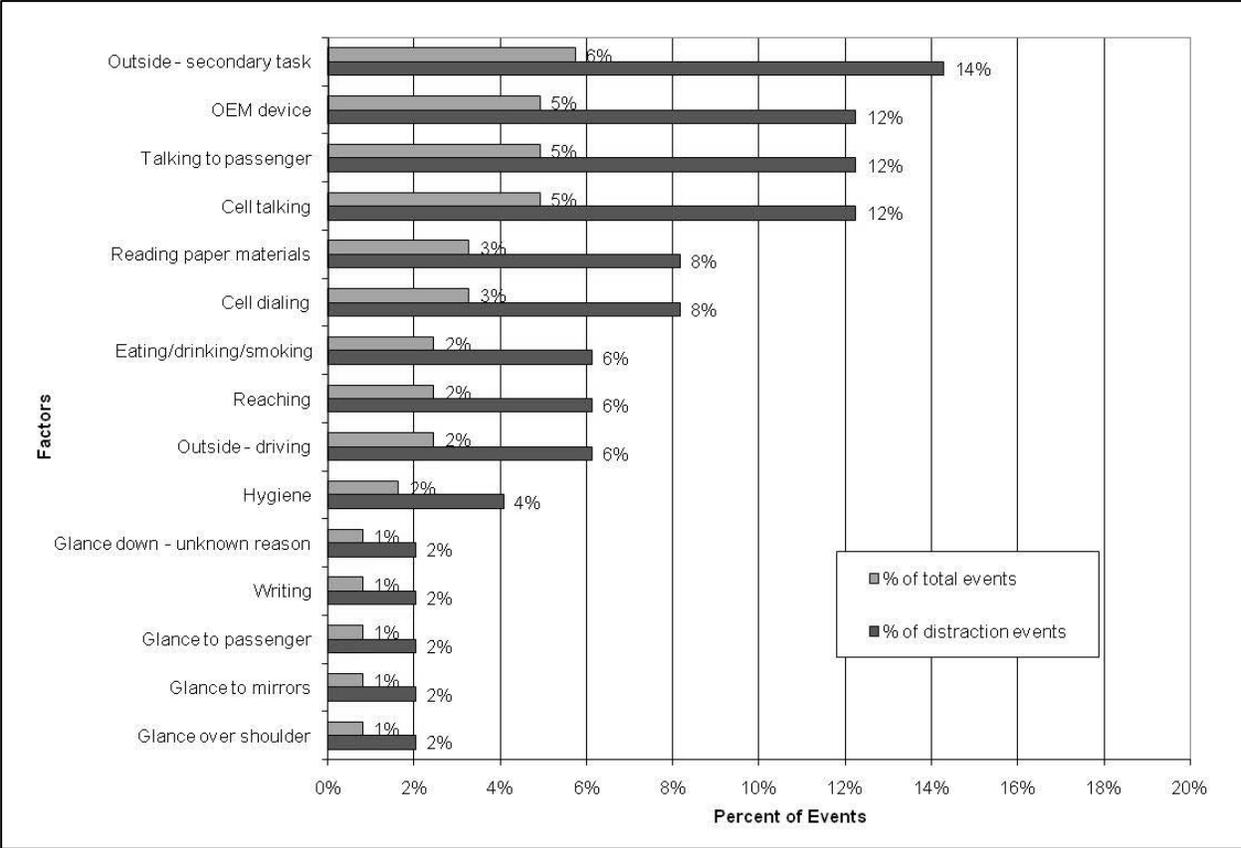


Figure 2. Percentage of ROR Events With Indicated Distraction

The results of this research confirm distraction, and fatigue/impairment as contributing factors in ROR events. In addition, for the first time, these findings allow an assessment of the relative frequencies of ROR events associated with specific driver behaviors. The work also provides insight into the relative frequency of other commonly cited factors such as short following, lead-vehicle braking, low-friction conditions, and excessive speed. Finally, due to the comprehensiveness of the 100-Car data, the findings introduce consideration of factors such as changes in roadway boundaries, encroaching vehicles, and late route selection.

GLOSSARY OF TERMS AND ACRONYMS

Contributing Factors – Any circumstance that leads up to or affects the outcome of the event. This term encompasses driver proficiency, willful behavior, roadway infrastructure, distraction, vehicle contributing factors, and visual obstructions.

Crash – Any contact with an object, either moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated. Includes other vehicles, roadside barriers, miscellaneous objects on or off of the roadway, pedestrians, cyclists or animals.

DAS – Data acquisition system

Driver-Related Inattention to the Forward Roadway – Inattention due to a necessary and acceptable driving task where the subject is required to shift attention away from the forward roadway (e.g., checking blind spots, center mirror, or instrument panel)

Driver Reaction – The evasive maneuver performed in response to the precipitating event

Event – A term referring to all crashes, near-crashes, and incidents. The “event” begins at the onset of the precipitating factor and ends after the evasive maneuver.

FARS – Fatality Analysis Reporting System

GES – General Estimates System

GPS – Global positioning system

Lead Vehicle – Vehicle preceding the participant vehicle in the same lane

Loss of Control – Situation where the vehicle appears to be skidding or sliding

Low-Speed Maneuvering Error – Situation where vehicle is traveling at low speed (~10 mph or less) and contacts an object when no other factors appear to be present

MVMT – Million vehicle miles traveled

NTSB – National Transportation Safety Board

NHTSA – National Highway Traffic Safety Administration

Naturalistic – Unobtrusive observation; observation of behavior taking place in its natural setting

Near-crash – Any circumstance that requires a rapid, evasive maneuver by the subject vehicle, or any other vehicle, pedestrian, cyclist, or animal in order to avoid a crash. A rapid, evasive

maneuver is defined as a steering, braking, accelerating, or any combination of control inputs that approaches the limits of the vehicle capabilities.

OEM – Original equipment manufacturer

Primary Driver – The recruited participant designated as the main the driver of his/her own vehicle or the leased vehicle

Prior to Maneuver – Situation observed on video and in numeric data one video frame prior to the beginning of the run-off-road maneuver

Secondary Task – Task, unrelated to driving, which requires subjects to divert attention from the driving task, e.g., talking on the cell phone, talking to passenger(s), eating, etc.

Rear-end Striking – Refers to the subject vehicle striking a lead-vehicle

Roadway Boundaries – Edges of the roadway such as curbs, medians or the edge of the pavement

Roadway Geometry – Classification of a road segment as intersection, straight, or left, or right curve

Run-Off-Road (ROR) – Describes a situation when the subject vehicle departs the roadway

Run-Off-Road Crash – Describes a situation when the subject vehicle departs the roadway and contacts some object

Run-Off-Road Maneuver – Period of time between the start of an input that led to a roadway departure, or near roadway departure, to the time when control is established and control inputs begin that will lead to normal lane position, or when the vehicle comes to a stop

Run-Off-Road Near-Crash – Describes a situation in which the subject vehicle almost departs the roadway or executes a rapid evasive maneuver in order to avoid departing the roadway

Steering Wheel Input – Rotation of the steering wheel by the driver

SUV – Sport utility vehicle

SV – Subject vehicle

TTC – Time-to-collision

VMT – Vehicle miles traveled

VTTI – Virginia Tech Transportation Institute

Yaw – Angular position measured on a plane perpendicular to the vertical axis

Yaw Rate – The data collected by the data acquisition system gyro indicating rate of rotation around the vertical axis

Yaw Rate of Change – The rate of change in yaw rate computed by finding the change in yaw rate from the maximum in one direction to the maximum in the opposite direction, and dividing this difference by the time elapsed between these two maximums

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CHAPTER 1: INTRODUCTION

The run-off-road or roadway-departure crash is one of the most lethal types of crashes. Two categories of data related to roadway departure are crashes with fixed objects and rollover crashes. In 2003, crashes with poles, culverts, curbs, trees, guardrails, and other objects surrounding roadways made up 15.5 percent of all crashes, but 31.1 percent of fatal crashes. Rollover crashes make up 2.1 percent of crashes, but 11.1 percent of fatal crashes. In 2003, over 16,000 people were killed in these types of crashes and approximately 414,000 people were injured (NHTSA, 2003).

Wang and Knipling (1994) investigated single-vehicle roadway departure crashes cataloged in the General Estimates System (GES) and the Fatality Analysis Reporting System (FARS). They found that collision with fixed objects (61.2%), collision with parked vehicles (26.2%), and rollover-overturn (11.6%) were the most common first harmful events in these crashes. Vehicles were found to depart the right side of the road in approximately 40 percent of the crashes, and departed the left side in 27 percent of the crashes. Approximately 12 percent occurred near intersections. In a database review conducted later, Pomerleau et al. (1999) found that 76 percent of ROR crashes occur on straight roads. The review also found that 62 percent of these crashes occur on dry roads and 73 percent occur in good weather. The six primary causal factors identified were: excessive speed (32.0%), drowsiness/intoxication (20.1%), loss of control due to low coefficient of friction (16%), avoidance maneuvers (15.7%), inattention (12.7%), and vehicle failures (3.6%). The databases collect crash information from across the country, but are limited to police-reported events.

Davis and Swenson (2003) provide a thorough explanation of the concept of crash causation as is applied in various specialty areas including the National Transportation Safety Board (NTSB), the U.S. Air Force, traffic crash reconstruction, and legal interpretations. Across the specialty areas, a possible cause is considered a cause in situations where if the possible cause had been eliminated, the accident would not have happened. Davis and Swenson summarize by saying that what occurred with the possible cause present should be compared to what would have happened with the possible cause absent. If the accident would not have occurred with the possible cause absent, it is a cause. They also indicate that because a number of alternatives can be imagined that might change an outcome, the change (elimination of the possible cause) should be “minimal.” That is, one should consider whether or not the accident would have occurred if everything else had remained the same minus the one possible cause.

The approach described by Davis and Swenson could limit appropriate consideration of alternate causes or inappropriately deemphasize the (often) multiple-event nature of accidents (Benner, 1980). However, highlighting a reduced set of causes or contributing factors also has some benefits. In using real-time crash data, the approach has the potential of exposing new information. Due to the nature of previous crash data (i.e., primarily databases created from post-accident reports), past analyses have been unable to differentiate factors that were merely present in a crash from factors that were causal. Dingus et al. (2006) collected continuous vehicle and video data during actual crashes as well as near-crashes and baseline driving during the 100-Car Naturalistic Driving Study. The breadth of the data collected provides information that has not previously been available. The 100-Car data, which include video views of outside

and inside the vehicle as well as continuous vehicle kinematics data, permit detailed review of the environment, actions, and timing of different events associated with crashes and near-crashes; in many cases permitting identification of contributing factors. By identifying a small number of contributing factors that are proximate to an event, determination of potential corrective measures becomes more feasible. The objective of the present project is to use 100-Car data to investigate contributing factors of these types within the ROR crash problem and provide comparison of crashes and near-crashes.

CHAPTER 2: METHODS

In this section, following a description of the 100-Car Study data collection methods, the specific methods used in the present analysis are provided. Vehicle instrumentation, driver demographics, event review, and event category definitions are provided.

100-CAR STUDY DATA COLLECTION

Data in the 100-Car Study was collected from drivers primarily in the Northern Virginia/Washington, DC, area, but also included all mileage these participants drove outside that area over the course of a year. The data include baseline driving as well as events ranging from mild to more severe. A number of ROR-related events are included in the data. For the investigation conducted here, the primary data source is the driving performance data obtained in the seconds preceding ROR-related crashes and near-crashes. In the 100-Car data, crashes and near-crashes were defined as follows:

- Crashes: Any contact between the subject vehicle and another vehicle, fixed object, pedestrian, pedalcyclist, animal, etc.
- Near-crashes: Defined as a conflict situation requiring a rapid, severe evasive maneuver to avoid a crash.

Certain crashes and near-crashes from the 100-Car Study were reviewed for inclusion in the present study. Crashes and near-crashes coded in the 100-Car Study to indicate a driver response other than only braking (i.e., steering, braking and steering, other), or coded as roadway departure, were further reviewed to identify events where the vehicle contacted or crossed a boundary that defined the road edge or separated the direction of travel (e.g., edge markings, parked cars, construction barrels, curbs, pavement edge), or where a rapid, severe, evasive maneuver was required to avoid departing the roadway or entering an oncoming lane. The roadway edge is defined either as edge markings, where present, or the pavement edge. Based on these conditions, an ROR crash was defined as a crash from the 100-Car Study in which the vehicle contacted a road edge. An ROR near-crash was defined as a near-crash in the 100-Car Study in which a rapid evasive maneuver was necessary to avoid contacting the road edge or departing the roadway. Twenty-eight events were classified as ROR crashes and 94 events were classified as ROR near-crashes for the present analysis. Examples of the events identified are provided in the ROR Event Selection section included later in this report.

Table 1 describes the ages and estimated annual mileage of the drivers included in the dataset used for this investigation. Drivers in 55 of the events were female, with male drivers accounting for the remaining 67. The frequencies for these groups are presented as rates per vehicle mile traveled (VMT) in the Results section of this document.

Table 1. Biographical Data for Drivers in Selected Events

| Biographical Data for Drivers in Selected Crashes and Near-crashes | Age (yrs) | Estimated Annual Miles |
|--|-----------|------------------------|
| Average | 31 | 22,000 |
| Maximum | 68 | 75,000 |
| Minimum | 18 | 10,000 |

For a complete description of 100-Car Study methods, instrumentation, and data collection procedures, refer to the Dingus, Klauer, and Neale, et al. (2006) report. The following brief description is adapted from Neale et al. (2005).

100-Car Study Instrumentation

The 100-Car Study instrumentation package was engineered by researchers at the Virginia Tech Transportation Institute to be rugged, durable, expandable, and unobtrusive. It constituted the seventh generation of hardware and software, developed over a 15-year period, which has been deployed for a variety of purposes. This data acquisition system consisted of a Pentium-based computer that received and stored data from a network of sensors distributed around the vehicle. Data storage was achieved via the system's hard drive, which was large enough to store data for several weeks of driving before requiring data downloading.

Each of the sensing subsystems in the car was independent, so that any failures that occurred were constrained to a single sensor type. Sensors included a vehicle network box that interacted with the vehicle network, an accelerometer box that obtained longitudinal and lateral kinematic information, a headway detection system to provide information on leading or following vehicles, side obstacle detection to detect lateral conflicts, an incident box to allow drivers to flag incidents for the research team, a video-based lane-tracking system to measure lane-keeping behavior, and video to validate any sensor-based findings. The video subsystem was particularly important as it provided a continuous window into the happenings in and around the vehicle. This subsystem included five camera views monitoring the driver's face and driver side of the vehicle, the forward view, the rear view, the passenger side of the vehicle, and an over-the-shoulder view for the driver's hands and surrounding areas. An important feature of the video system is that it was digital, with software-controllable video compression capability. This facilitated the simultaneous review of 100-Car Study video and numeric data, as well as efficient archiving and retrieval. A frame of compressed 100-Car Study video data is shown in Figure 3. The driver's face is shown in the upper left quadrant, distorted to protect the driver's identity. The lower right quadrant is split to show the right-side view (top) and the rear view (bottom).

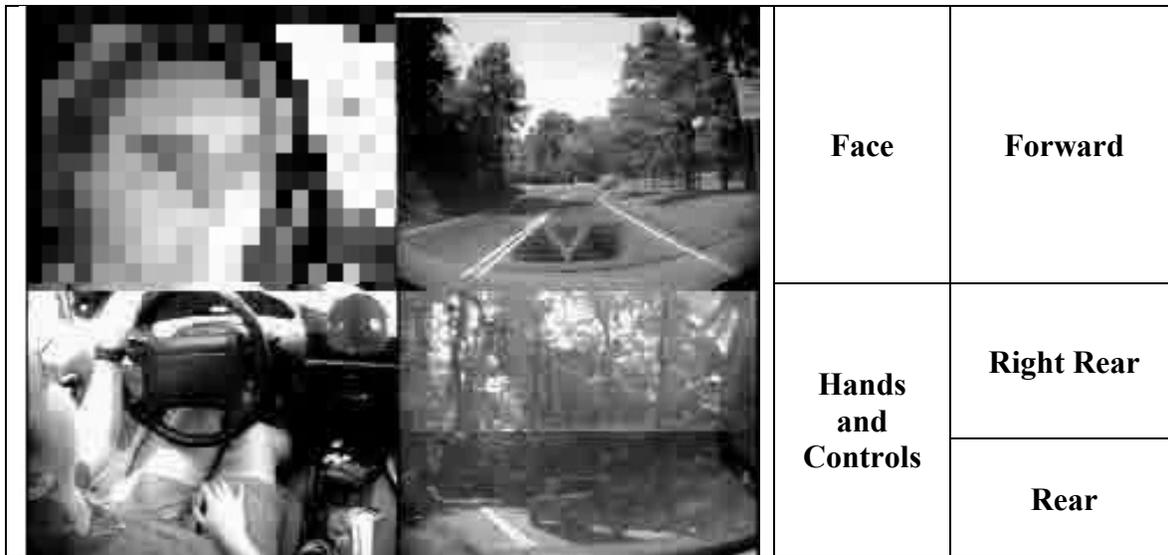


Figure 3. A Video Image From the 100-Car Study Data

The modular aspect of the data collection system allowed for integration of instrumentation that was not essential for data collection, but that provided the research team with additional and important information. These subsystems included automatic crash notification that informed the research team of a possible crash; cellular communications that were used by the research team to communicate with vehicles on the road to determine system status and position; system initialization equipment that automatically controlled system status; and a GPS subsystem that collected information on vehicle position. The GPS subsystem and the cellular communications were often used in concert to allow for vehicle localization and tracking.

The system included several major components and subsystems that were installed on each vehicle. These included the main DAS unit that was mounted under the package shelf for the sedans (Figure 4) and behind the rear seat in the sport utility vehicles.

Doppler radar antennas were mounted behind special plastic license plates on the front and rear of the vehicle (Figure 5). The location behind the plates allowed the vehicle instrumentation to remain inconspicuous to other drivers.



Figure 4. The Main DAS Unit Mounted Under the “Package Shelf” of the Trunk



Figure 5. Doppler Radar Antenna Mounted on the Front of a Vehicle

The final major components in the 100-Car Study hardware installation were mounted above and in front of the center rear-view mirror. These components included an “incident” pushbutton box that housed a momentary contact pushbutton that the subject could press whenever an unusual event happened in the driving environment. Also contained in the housing was an

unobtrusive miniature camera that provided the driver's face view. The camera was invisible to the driver since it was mounted behind a smoked plexiglas cover.

Mounted behind the center mirror were the forward-view camera and the glare sensor (Figure 6). This location was selected to be as unobtrusive as possible and did not occlude any of the driver's normal field of view.



Figure 6. The Incident Pushbutton and Camera Box Mounted Above the Rearview Mirror

100-Car Study Participants

One hundred drivers who commuted into or out of the Northern Virginia/Washington, DC, metropolitan area were initially recruited as primary drivers, i.e., to have their vehicles instrumented or to receive a leased vehicle for this study. Drivers were recruited by placing flyers on vehicles as well as by placing newspaper announcements in the classified section of the newspaper. Drivers who had their private vehicles instrumented (78) received \$125.00 per month and a bonus at the end of the study for completing necessary paperwork. Drivers who received a leased vehicle (22) received free use of the vehicle, including standard maintenance, and the same bonus at the end of the study for completing necessary paperwork. Drivers of leased vehicles were insured under the Commonwealth of Virginia policy.

As some drivers had to be replaced for various reasons (for example, a move from the study area or repeated crashes in leased vehicles), 109 primary drivers were included in the 100-Car Study (this number was reduced to 101 drivers for the present study based on criteria described in the Drivers section of this report). Since other family members and friends would occasionally drive the instrumented vehicles, data was collected on 132 additional drivers.

A goal of the 100-Car Study was to maximize the potential to record crash and near-crash events through the recruitment of subjects from a population expected to have higher than average crash or near-crash risk exposure. Exposure was manipulated through the selection of a larger sample of drivers below the age of 25, and by the selection of a sample that drove more than the average number of miles. The age by gender distribution of the primary drivers is shown in Table 2. The distribution of miles driven by the subjects during the study appears as Table 3.

One demographic feature with the 100-Car Study data sample is that the data was collected in only one area, Northern Virginia/Metro Washington, DC. This area represents primarily urban and suburban driving conditions, often in moderate to heavy traffic. Thus, rural driving and differing demographics within the United States are not well represented.

Table 2. Driver Age and Gender Distributions for 100-Car Study Dataset

| Age | Gender N % of total | | Grand Total |
|--------------------------------|---------------------------|-------------|----------------|
| | Female | Male | |
| 18-20 | 9 8.3% | 7 6.4% | 16 14.7% |
| 21-24 | 11 10.1% | 10 9.2% | 21 19.3% |
| 25-34 | 7 6.4% | 12 11.0% | 19 17.4% |
| 35-44 | 4 3.7% | 16 14.7% | 20 18.3% |
| 45-54 | 7 6.4% | 13 11.9% | 20 18.3% |
| 55+ | 5 4.6% | 8 7.3% | 13 11.9% |
| Total N Total Percentage | 43 39.4% | 66 60.6% | 109 100.0% |

Table 3. Actual Miles Driven During the 100-Car Study

| Actual Miles Driven | Number of Drivers | Percentage of Drivers |
|----------------------------|--------------------------|------------------------------|
| 0-9,000 | 29 | 26.6% |
| 9,001-12,000 | 22 | 20.2% |
| 12,001-15,000 | 26 | 23.9% |
| 15,001-18,000 | 11 | 10.1% |
| 18,001-21,000 | 8 | 7.3% |
| More than 21,000 | 13 | 11.9% |

Vehicles

Since 100 vehicles had to be instrumented with a number of sensors and data collection hardware, and since the complexity of the hardware required a number of custom mounting brackets to be manufactured, the number of vehicle types had to be limited for this study. Six different vehicle models were selected based upon their prevalence in the Northern Virginia area. These included five sedan models (Chevrolet Malibu and Cavalier, Toyota Camry and Corolla, and Ford Taurus) and one SUV model (Ford Explorer). The model years were limited to those with common body types and accessible vehicle networks (generally 1995 to 2003). The distribution of these vehicle types was:

- Toyota Camry – 17 percent;
- Toyota Corolla – 18 percent;
- Chevy Cavalier – 17 percent;
- Chevy Malibu – 21 percent;
- Ford Taurus – 12 percent; and
- Ford Explorer – 15 percent.

BASELINE EPOCHS

In addition to crash and near-crash events, the dataset was used to develop a description of baseline driving. A stratified random review of the entire 6.4-terabyte dataset was conducted to develop a baseline database that quantified the frequency with which different conditions and behaviors are present while driving. This method guides analysts to random epochs in the data for each of the drivers. The weather conditions, lighting, and surface conditions observed in the epoch are then classified by analysts. Using the proportion of driving in different conditions, multiplied by the estimate of miles traveled by the participant in the study, provides an estimate of the miles traveled in different conditions. The sampling was stratified according to the involvement of each driver in crashes, near-crashes, and incidents of all types (rear-end-striking, ROR, lane-change/merge, etc). If a driver was involved in 3 percent of the total number of events (i.e., crashes, near-crashes, and incidents), then 3 percent of the baseline epochs would be drawn from this driver's data. These baseline epochs were used to quantify exposure to various conditions (e.g., rain, darkness) that will be discussed in subsequent sections.

ROR EVENT SELECTION IN PRESENT STUDY

Crashes and near-crashes from the 100-Car dataset that were marked with road departures or driver reactions other than just braking (e.g., steering, steering and braking) were considered for inclusion in the ROR analysis. These events were reviewed and included in the present analysis if the subject vehicle contacted or crossed a roadway boundary or a boundary defining direction of travel (e.g., edge markings, parked cars, construction barrels, curbs, pavement edge), or if a rapid, severe evasive maneuver was required to avoid departing the roadway or entering an oncoming traffic lane. Lane-change events, which involve a vehicle moving from one lane to another, but not departing the roadway, are not considered here. The 100-Car analysis designation of the selected events as crashes or near-crashes was maintained for this analysis. Events identified in this manner include situations where:

- one or two tires contacted a curb or left the roadway before returning to the roadway,
- vehicles departed the road and came to a stop,
- vehicles collided with physical objects delineating lanes (e.g., curbs, toll booths, construction barrels), and
- drivers braked hard and swerved to the road edge to avoid a crash.

Based on these criteria, ROR events in which some object was contacted (including curbs, parked vehicles, sand barrels) were classified as crashes. On the other hand, almost colliding with those objects or driving onto a shoulder were classified as near-crashes. Illustrations of some of the events are provided in Figure 7. Figures 7a and 7b were classified as crashes. Figure 7c was classified as a near-crash.

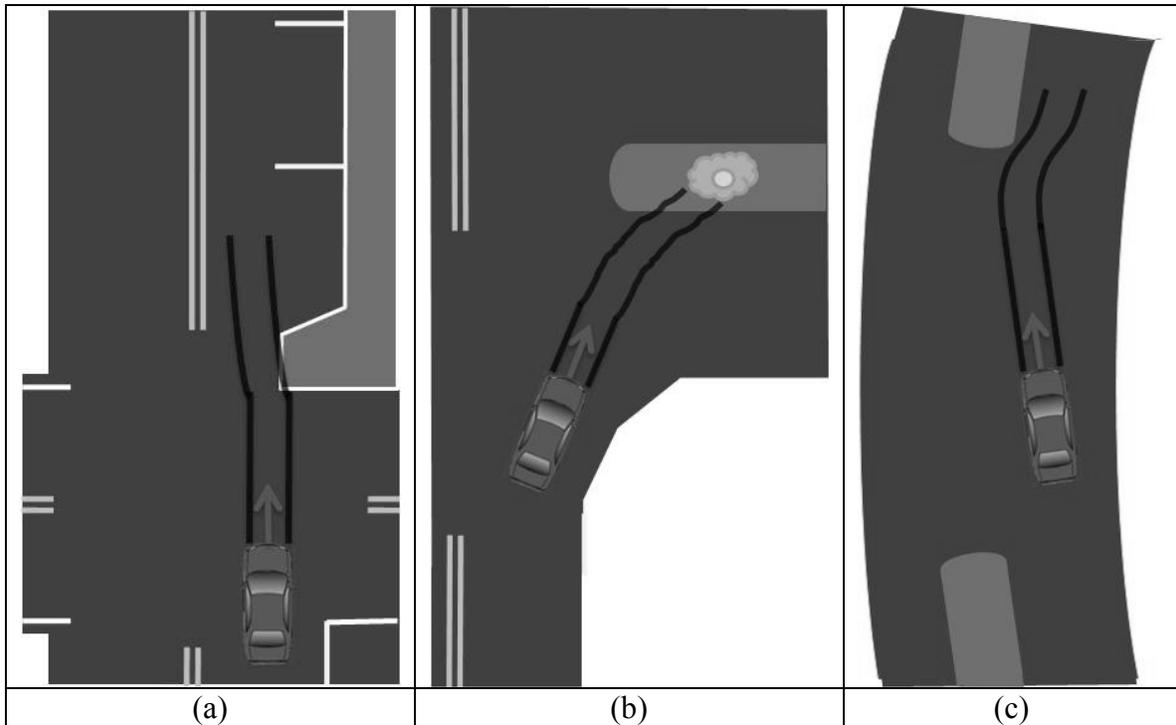


Figure 7. Examples of Roadway Departures

DRIVERS

The drivers in the event frequency estimation met two criteria. They were primary drivers in the data collection effort, which means complete demographic data were collected for them, and their estimated vehicle miles traveled in the study were greater than 1,000. Based on these criteria, 101 drivers remained for inclusion in estimating event rates.

ROR EVENT RATES

To estimate the frequency of ROR events, and the relative frequencies of events under different precipitation levels, lighting conditions, and road surface conditions, the events as well as baseline epochs were classified according to the following non-independent categories:

Precipitation

- Clear
- Fog, mist, or rain
- Snowing, sleet, other

Lighting

- Daylight
- Darkness but lighted
- Dark
- Dawn/dusk

Road surface conditions

- Dry
- Wet
- Snowy

These categories represent factors that were present at the time of the crash or near-crash. Frequency of event occurrence is reported for each of these conditions.

VEHICLE MILES TRAVELED (VMT) ESTIMATION

VMT was computed for each of the primary drivers. Because each vehicle may have been driven by the primary driver as well as other drivers, estimation of VMT required a combination of video review (to estimate how frequently the primary driver drove the vehicle) and numerical review of data (to estimate how many miles the vehicle was driven during the study). The video review used 100 trip files from each of the vehicles and determined the proportion of the files in which the primary driver was driving. The numerical review used time and speed values to estimate distance traveled. The proportion of time the primary driver was driving multiplied by the estimate of miles the car was driven provided the estimate of VMT for each of the primary drivers.

FREQUENCY OF EVENTS

ROR crashes and near-crashes were counted for each of the following groups or factors: overall, by driver, by weather conditions, by roadway surface conditions, and by lighting conditions.

RATE OF ROR EVENTS

Rate of occurrence of ROR events was determined using the estimates of VMT in combination with the event categories described so far. Rate of occurrence was quantified in the following groups or factors: overall, by driver, by weather conditions, by roadway surface conditions, and by lighting conditions. Event rates are reported per million VMT.

To estimate the number of ROR crashes and near-crashes that occur under similar driving conditions, the numbers of VMT in the lighting condition and surface condition categories (described previously) were used to estimate the number of miles each participant drives in the different driving condition categories. For example, if fog, mist or rain conditions were found in 9 percent of the baseline epochs, this was multiplied by the total VMT to estimate the amount of miles driven in these conditions. The number of events found in these conditions was then divided by the estimate of miles driven in the conditions, and multiplied by one million to estimate the frequency of events in the same conditions per MVMT.

ROR MANEUVER CHARACTERIZATION

Maneuver Definition

It is helpful to consider two general types of ROR events. In one situation, the vehicle path is altered in some way that sends the vehicle off the road. This might occur, for example, during an avoidance maneuver. In another type of event, a selected path of the vehicle is maintained for too long, and a change in the roadway geometry leads to the vehicle departing the road. This occurs, for example, when a driver is looking left holding a set path and runs off the road when a merge lane narrows from the right. The start of the maneuver is defined as the start of input (i.e., steering, braking, gas pedal) that led to an ROR situation (see Figure 8). In cases where the path of the vehicle is altered, which leads to roadway departure, the start of the input creating that path change was selected as the start of the ROR maneuver. Initiation of braking or gas pedal inputs alone does not define the start of the ROR maneuver unless it initiates a loss of control (e.g., skidding, sliding, etc). In cases where a control input was maintained for too long, the start of the maneuver was identified by locating where the roadway departure occurred, and backing up to where the beginning of that input started. The investigated period ends when control is present and the driver begins inputs to return to normal lane position and/or speed, or if the vehicle comes to a stop. Note that loss of control is not a requirement for defining the start of all ROR maneuvers, but does suffice to define the start in some situations.

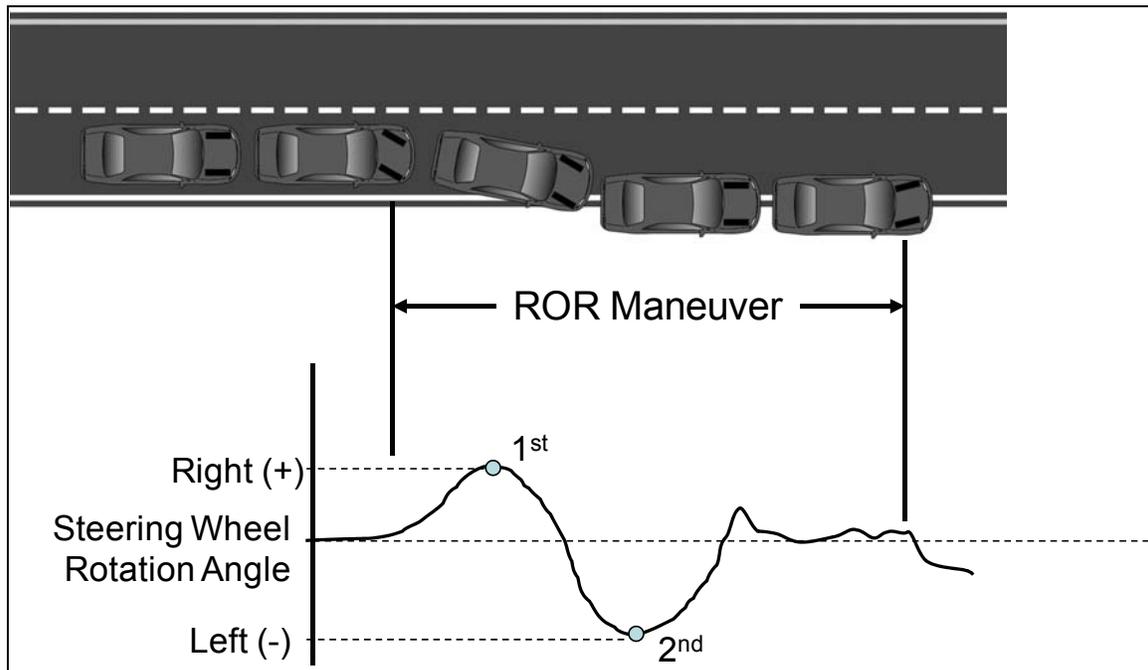


Figure 8. Illustration of ROR Maneuver Beginning and End Points (Note: Time-Series Steering Position Not Collected)

Steering Wheel Position Prior to Maneuver

Steering wheel position was not part of the 100-Car vehicle instrumentation. For this investigation, the steering wheel position is estimated using the video. Steering wheel position was estimated in 45-degree increments. Rotation to the left is recorded as negative. The closest multiple of 45 degrees is used for the estimate. Therefore, values less than approximately +/- 22.5 degrees from center are recorded as zero position. For the prior-to-maneuver position, the steering position in the video frame immediately prior to driver input for the maneuver is recorded.

Steering Wheel Maximum Input During Maneuver

The first steering wheel maximum input is the extent of steering wheel position in the first input direction during the ROR-maneuver period (see Figure 8). The second is the extent of steering wheel input in the opposite direction to cancel or reverse the first input. For further discussion of steering inputs see Jagacinski and Flach (2003).

Yaw Rate During Maneuver

Yaw rate is the rate of rotation of the vehicle around a vertical axis measured in degrees. In this analysis, during a normal turn to the left, yaw rate is recorded as negative. Rotation to the right is recorded as positive. The rate of change of the yaw rate is also considered. The rate of change in yaw rate was computed by finding the change in yaw rate from the maximum in one direction to the maximum in the opposite direction, and dividing this difference by the time elapsed between these two maximums.

Braking Prior to Maneuver

This measure indicates whether the brakes were being applied immediately prior to the ROR input being entered or prior to loss of control. This measure differentiates, for example, if the participant had already been braking for a stopped lead vehicle at the time he or she began departing the roadway.

Braking During Maneuver

This measure indicates if brakes were being applied during the ROR maneuver. For example, did the participant continue braking, or did the participant start braking after the vehicle path was heading off the roadway? Or, were the brakes never applied?

INVESTIGATION OF CONTRIBUTING FACTORS

Identification of contributing factors entailed review of each of the events using data visualization software that permitted frame-by-frame video review along with graphical presentation of vehicle and kinematics measures such as speed, yaw rate, brake-pedal actuation, gas-pedal input, and lateral and longitudinal acceleration – all synched to the video. This review was conducted entirely by a senior researcher. The researcher reviewed each of the crashes and near-crashes to identify the sequence of events, what potentially contributing factors were present in the set of events, and the methods of differentiating factors from each other. While considering that accidents are frequently a result of the convergence of multiple factors that contribute in differing degrees to the occurrence of an event, the approach used here was to identify a small number of contributing factors. The crashes and near-crashes were analyzed in detail to identify factors that could have been altered close to the occurrence of the event

(generally, close in time) and that, if altered, would likely have eliminated the event. In this effort, for example, darkness would only be included as a factor if there are indications that the event occurred due to darkness and, had it not been dark, the event would likely not have occurred. In an effort to keep changes minimal when considering alternatives (Davis and Swenson, 2003), consideration of changes was restricted to the sequence of events and conditions apparent immediately prior to the event. Though changes were limited to immediately before an event, review of data could include well before an event, including other trips, to assist in interpreting what is observed in an event. All video views and numerical data were considered to the extent necessary to evaluate the contribution of factors. Based on this review, a set of definitions of factors was developed. Using these definitions (shown below), the events were reviewed in further detail and coded according to the definitions. Through this process, four groups of factors were identified: distraction, roadway boundaries, encroaching, and low-speed maneuvering errors. Five other unique factors not fitting into any of these groups were also identified: short following, fatigue or impairment, low friction, failure to maintain lane, late route selection, and lead-vehicle braking.

In identifying contributing factors, a caveat is appropriate. This approach tends to emphasize a small set of factors. In many accidents, factors work together, and focusing on a minimal set of factors may de-emphasize the multiple-event nature of accidents. An example of this is a situation where a driver following closely (defined here as headway of less than 1.5 s) is exposed to a braking lead vehicle. An ROR event associated with short following only occurs in the presence of lead-vehicle braking. However, in the approach used here, due to the short headway, short following is counted as the contributing factor and lead-vehicle braking is not. The occurrence of the lead-vehicle braking should still be recognized as part of the scenario. The following definitions describe each group and its factors.

Distraction—Driving-Related Inattention to Forward Roadway

Driving-related inattention is considered a factor if a glance is made to exterior locations or mirrors for driving-related reasons (e.g., checking for traffic, reading signage). The Distraction—Driving-related group is composed of:

- Glance to mirrors;
- Glance over shoulder; and
- Outside glances that appear to be for the purpose of checking other traffic (but are not over the shoulder).

Distraction—Secondary Task

The Distraction—Secondary Task-related group is composed of:

- Outside – Any glances to exterior locations that do not appear to be for driving-related reasons (e.g., locations where no scan for a threat would be expected and landmark or signage navigation does not appear to be needed, such as to pedestrians that pose no threat or objects distant from the roadway).
- Cell dialing – Dialing or possibly text messaging using a hand held cellular phone.
- Cell talking – Any time a cellular phone is being held to the ear or mouth when an ROR event occurs (note: hands-free cell use is not considered here).
- Glance to passenger – Driver glances to a passenger.

- Talking to passenger – Driver is talking to the passenger immediately before or during the event, but not looking at him or her, and when other factors do not appear to be present during the event.
- Hygiene – Tasks such as looking at self in mirrors or applying makeup.
- Original equipment manufacturer – Any task occurring in the vehicle that utilizes a device installed by the original vehicle manufacturer, such as radio or climate control, when an ROR event occurs. Includes looking at and handling CDs or CD cases.
- Reading paper material – Driver is looking at papers or a book.
- Writing – Driver is making notes.
- Reaching – Driver is reaching for some non-fixed object.
- Eating/drinking/smoking.
- Glance down for unknown reason.

Roadway Boundaries

The Roadway Boundaries group captures cases where some characteristic of the roadway boundaries (e.g., curbs, medians) appears to contribute to the ROR event. Examples of these cases include changes in a boundary, such as where a median starts, or where the lateral position of a right edge boundary narrows a lane.

The Roadway Boundaries group is composed of:

- Median start while SV not in intersection turn – Driver comes in contact with the start of a median (curb or other barrier where present or end of pavement) or executes an avoidance maneuver to avoid the start of a median when no intersection turn is being made. Note: Includes cases on straight and curved roads (see Figure 7 c).
- Median start in intersection turn – While turning at an intersection, driver comes in contact with the start of a median or executes an avoidance maneuver to avoid the start of a median.
- Right boundary change – Driver travels off the pavement or exceeds the lane boundary where a right lane boundary discontinuity encroaches on the driver's previous path. Transitions from a straight to a curve, or changes in curve radii, are not included in this category. Examples of a right boundary change include loss of a lane from the right or a curb present after a break for an intersection (see Figure 7 a).

Low-Speed Maneuvering Error

The Low-Speed Maneuvering Error group is composed of:

- Low-Speed Side Separation Error – This factor is assigned for events in which no specific contributing factors can be identified, and that occur at low speeds (~10 mph or less), where a driver departs the roadway to the side or comes in contact with a stationary object (e.g., parked car or curb) located on the side of the road. Separation refers to maintaining separation between the vehicle and other objects.
- Low-Speed Forward Distance or Speed Error – This factor is assigned for events in which no specific contributing factors can be identified, and that occur at low speeds (~10 mph or less), where a vehicle rolls forward into an object (e.g., curb or barrier) at low speed.

Note: these low-speed events generally arise in parking type situations or where a driver is negotiating a narrow space between objects defining the edge of the roadway.

Fatigue/Impairment

Fatigue/Impairment is assigned as a factor if one of the following conditions is met:

- Driver's eyes closed or nearly closed and the driver does not appear to track the lane continuously.
- A driver wandering in the lane with abrupt corrections when no other distractions are apparent.

Encroaching

The Encroaching group is composed of:

- Same direction – Assigned as a factor when a vehicle initially traveling in the same direction as the SV encroaches on the SV's path of travel from the side, causing the SV driver to divert off the roadway.
- Perpendicular – Assigned as a factor when a vehicle encroaches on the initial SV path of travel from a perpendicular path, causing the SV driver to divert off the roadway.
- Head on – Assigned as a factor when a vehicle traveling in the opposite direction, encroaches on the SV's path of travel, causing the SV driver to divert off the roadway.

Low Friction

Low friction is assigned as a contributing factor if both of the following conditions are met:

- If at any time during the event the vehicle appears not to be responding directly to steering inputs as judged by viewing the steering wheel inputs and the exterior views.
- Evidence of water, snow, or ice on the roadway is present in the video view.

Failure to Maintain Lane

Failure to Maintain Lane is assigned as a contributing factor when no specific contributing factors can be identified and the following conditions are met:

- speed is greater than ~10 mph;
- driver departs the lane.

Note: this category describes cases where other factor categories do not appear to explain the roadway departure. In many cases this factor may be considered to be due to excessive speed, but may also include intentional roadway tracking beyond lane boundaries.

Late Route Selection

Late Route Selection is assigned as a factor if the driver crosses or nearly departs the roadway at an intersection, when changing course quickly from his or her initial path to a different route.

Lead-Vehicle Braking

Lead-Vehicle Braking is assigned as a factor if the driver departs the road while attempting to avoid colliding with a braking lead vehicle, if headway prior to lead-vehicle braking was greater than or equal to 1.5 s.

Short Following

Short Following is assigned as a factor when headway prior to lead-vehicle braking was less than 1.5 s.

CHAPTER 3: RESULTS

Events were counted according to level of precipitation, lighting, and roadway surface condition present at the time of the crash or near-crash (Table 4 through Table 6). To support the computation of exposure based on VMT, these tables describe the number of ROR events for the 101 primary drivers for which VMT could be estimated during the study. For this reason, the total number of events in this portion of the analysis is reduced from 122 to 103. ROR events most frequently occur in clear, dry conditions, in daylight. Note that these results are adjusted for exposure later in this section (Table 7 through Table 9).

Table 4. Number of ROR Crash and Near-Crash Events by Precipitation Type

| Number of Events | Precipitation | | |
|------------------|---------------|--------------------|--------------------------|
| | Clear | Fog, mist, or rain | Snowing, sleet, or other |
| Crashes | 23 | 3 | 0 |
| Near-Crashes | 55 | 21 | 1 |
| Total | 78 | 24 | 1 |

Table 5. Number of ROR Crash and Near-Crash Events by Lighting Condition

| Number of Events | Lighting | | | |
|------------------|-----------|------------------|----------------------|------------|
| | Daylight | Darkness–lighted | Darkness–non-lighted | Dawn /Dusk |
| Crashes | 13 | 9 | 2 | 2 |
| Near-Crashes | 42 | 11 | 17 | 7 |
| Total | 55 | 20 | 19 | 9 |

Table 6. Number of ROR Crash and Near-Crash Events by Roadway Surface Condition

| Number of Events | Roadway Surface | | |
|------------------|-----------------|-----------|----------|
| | Dry | Wet | Snowy |
| Crashes | 19 | 3 | 4 |
| Near-Crashes | 62 | 12 | 3 |
| Total | 81 | 15 | 7 |

These frequency counts are converted to event rates (per mile) in the next section of this report.

EVENT RATES

Based on the 101 primary drivers for which VMT could be estimated, the number of ROR events ranged from 0 to 10 per driver, with 49 drivers having one or more ROR events. Figure 9 provides a distribution of the number of ROR events occurring for each participant. Twenty-one drivers had two or more events and six had five or more events.

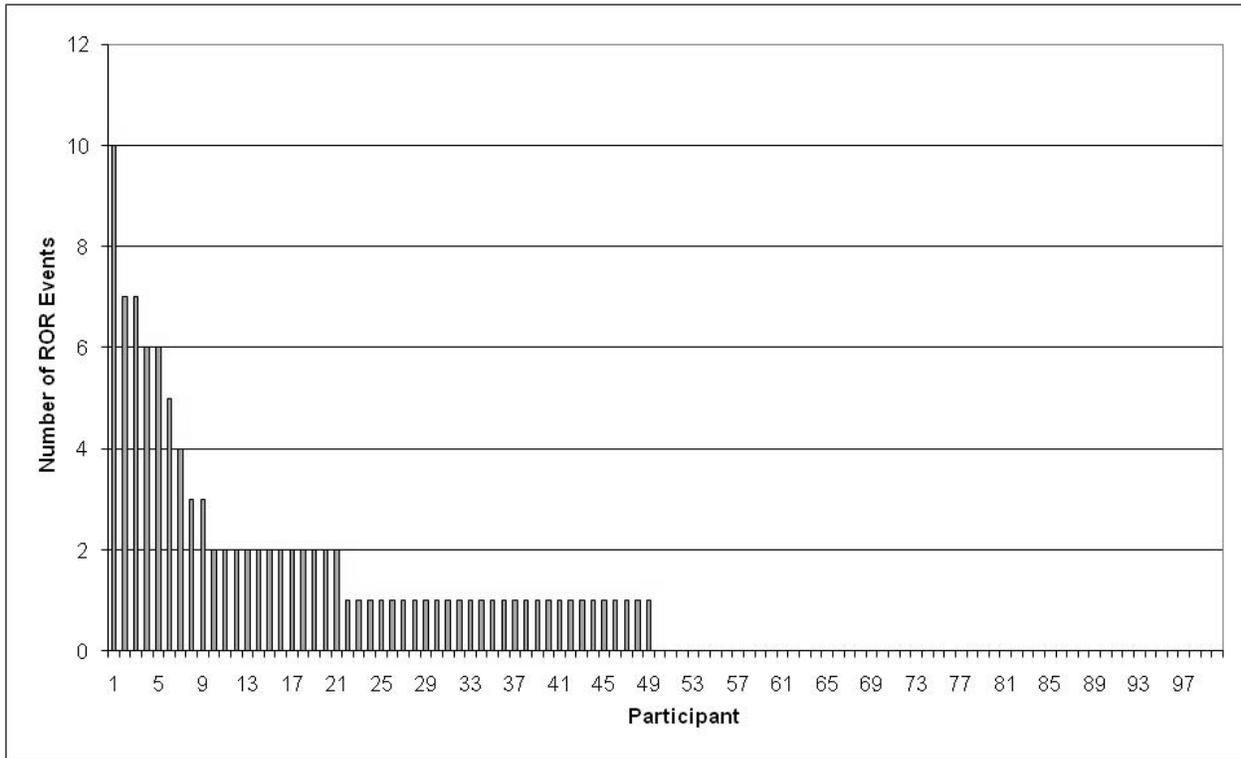


Figure 9. Number of ROR Events by Participant

The total VMT for these drivers (1.178 MVMT) results in an estimate of 87 ROR events occurring per MVMT (22 crashes and 65 near-crashes). When analyzed by driver, it becomes clear that there is considerable variability between drivers. Figure 10 (participant number differs from Figure 9) provides the estimation in terms of ROR events per MVMT for the 101 primary drivers. Approximately half of the drivers had ROR event rate estimates of zero per MVMT. The remaining half of the drivers had ROR event rate estimates that ranged from 42 per MVMT to 1238 per MVMT.

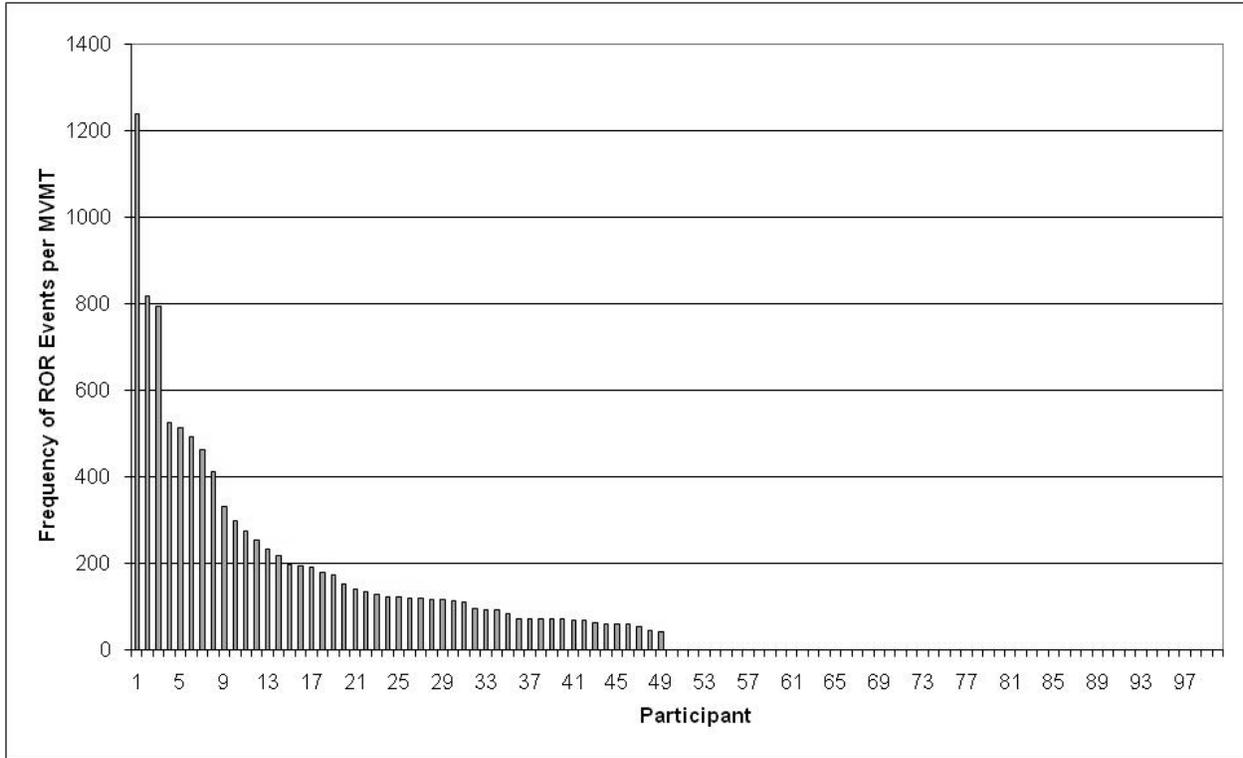


Figure 10. Frequency of ROR Events per MVMT by Participant

Figure 11 provides the distribution of the average number of ROR events by participant by age group.

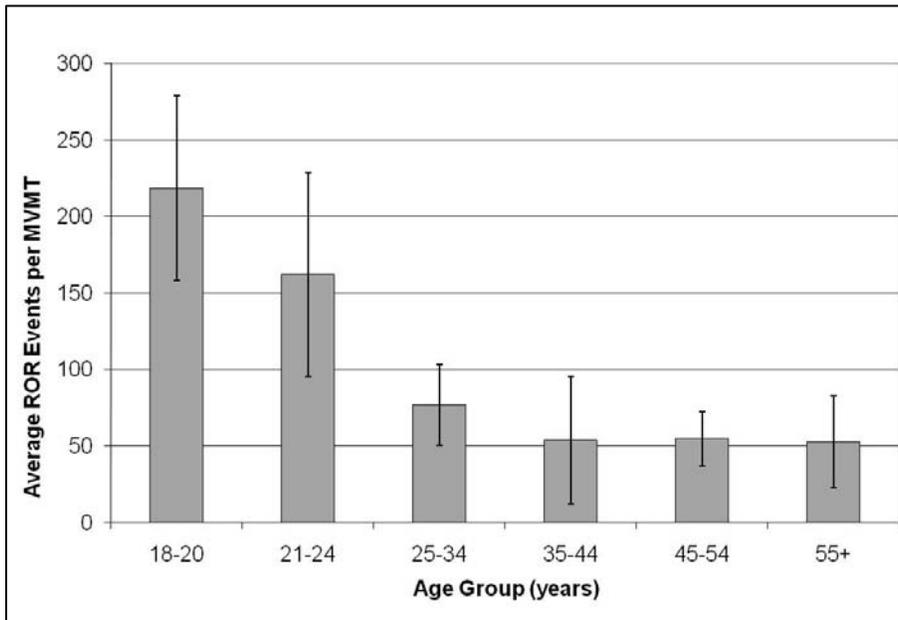


Figure 11. Average ROR Events per MVMT by Age Group (Error Bars Indicate Standard Error)

When considered according to age group, the frequency of events declines with age until approximately 35 years old. Participants in the 18–to 20-year-old age group averaged four times the number of ROR events of the participants 35 and older. The 21– to 24-year-old age group also appeared to have more frequent ROR events than the participants 35 and older. Though the average events per MVMT for females was 134 and for males was 87 (Figure 12), based on the overlapping error bars, the frequency of ROR events was not significantly different between genders.

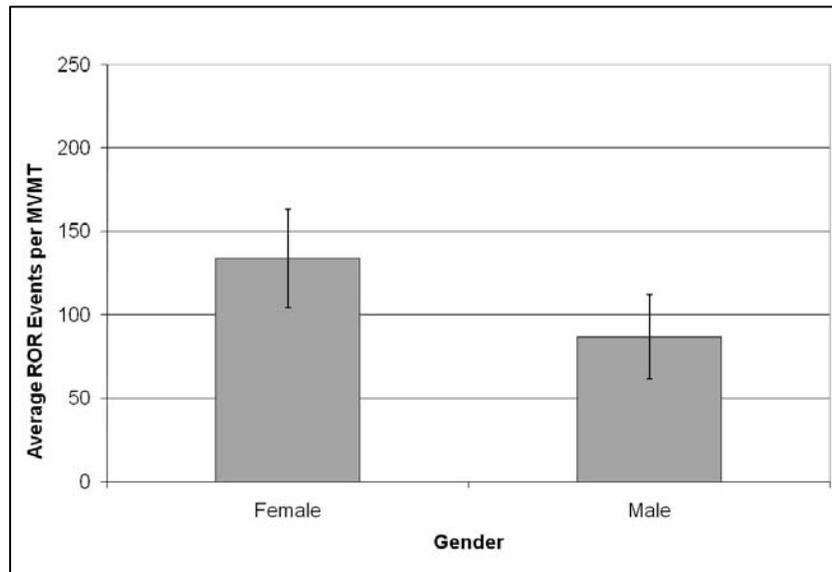


Figure 12. Frequency of ROR Events per MVMT by Gender (Error Bars Indicate Standard Error)

Using the miles driven by each of the drivers during the study, in combination with the estimates of the amount of driving in various conditions developed using the review of baseline epochs, estimates of frequency of ROR crashes and near-crashes were developed per MVMT, and are presented in Table 7 through Table 9. These rates align with what might be expected of the different condition categories. In terms of miles traveled in the different conditions (i.e., adjusted for exposure), ROR events occur more frequently in low-friction conditions and poor-visibility conditions, including darkness.

Table 7. Frequency of ROR Events per MVMT by Precipitation Type

| | Precipitation | | |
|--------------|---------------|--------------------|-----------------------|
| | Clear | Fog, Mist, or Rain | Snowing, sleet, other |
| Crashes | 22 | 24 | 0 |
| Near-Crashes | 53 | 165 | 207 |
| Total | 75 | 189 | 207 |

Table 8. Frequency of ROR Events per MVMT by Lighting Condition

| | Lighting | | | |
|--------------|-----------|------------------|------------|------------|
| | Daylight | Dark but Lighted | Dark | Dawn /Dusk |
| Crashes | 16 | 45 | 18 | 30 |
| Near-Crashes | 52 | 55 | 153 | 105 |
| Total | 68 | 100 | 171 | 135 |

Table 9. Frequency of ROR Event per MVMT by Roadway Surface Condition

| | Roadway Surface | | |
|--------------|-----------------|------------|------------|
| | Dry | Wet | Snowy |
| Crashes | 18 | 27 | 313 |
| Near-Crashes | 59 | 109 | 235 |
| Total | 77 | 136 | 548 |

TIME IN VEHICLE BEFORE ROR EVENT

The time in the vehicle before an ROR crash occurred ranged from approximately 2 min to 100 min with a mean time of 20 min. Figure 13 shows the distribution of the mean time in vehicle before an ROR crash for each driver (some drivers had more than one crash). If the 100-minute case is eliminated, the mean time becomes 14 min.

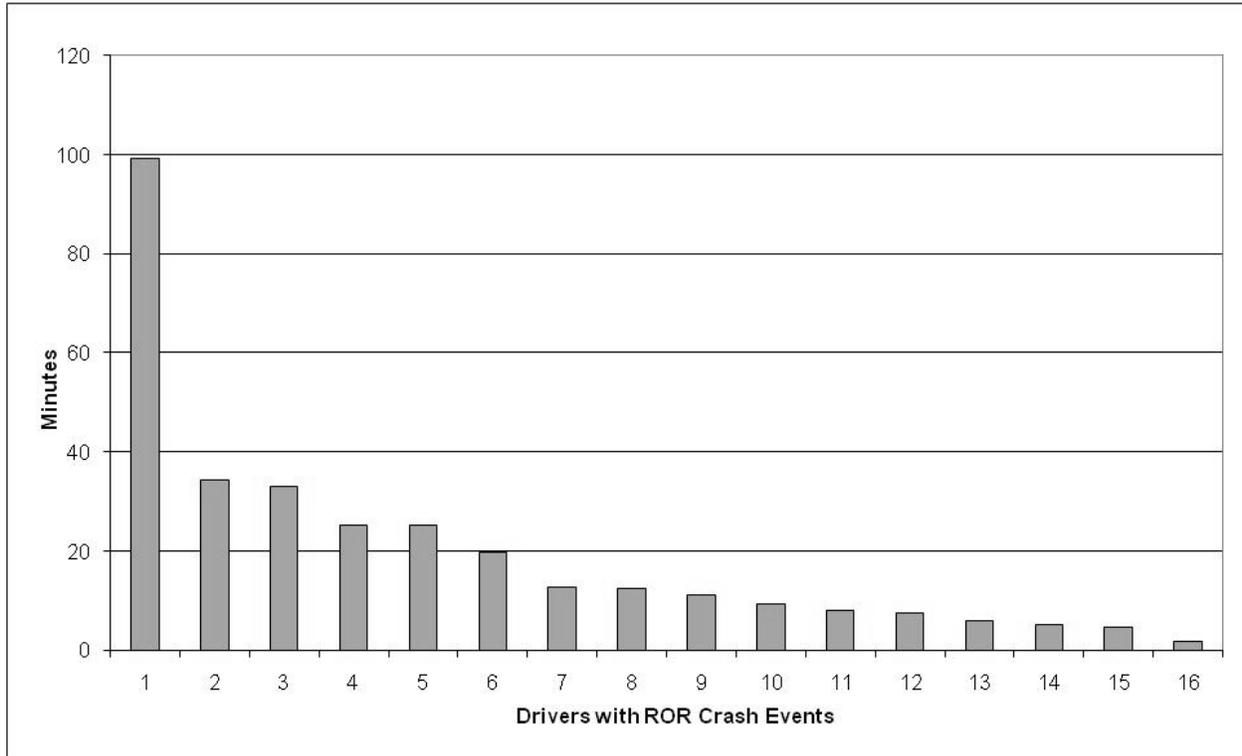


Figure 13. Mean Number of Minutes in Vehicle Before an ROR Crash

The distribution of the number of minutes in the vehicle before an ROR near-crash occurs is presented in Figure 14. The time in the vehicle before an ROR event ranged from 167 min to less than 1 min. The mean value was 21 min. If the two longest times are removed from the distribution, the average becomes 14 min. Based on the short pre-event driving time represented in these distributions (in most cases, less than 40 min), while overall fatigue could be present, it appears that driving time alone is not likely related to the occurrence of an ROR event.

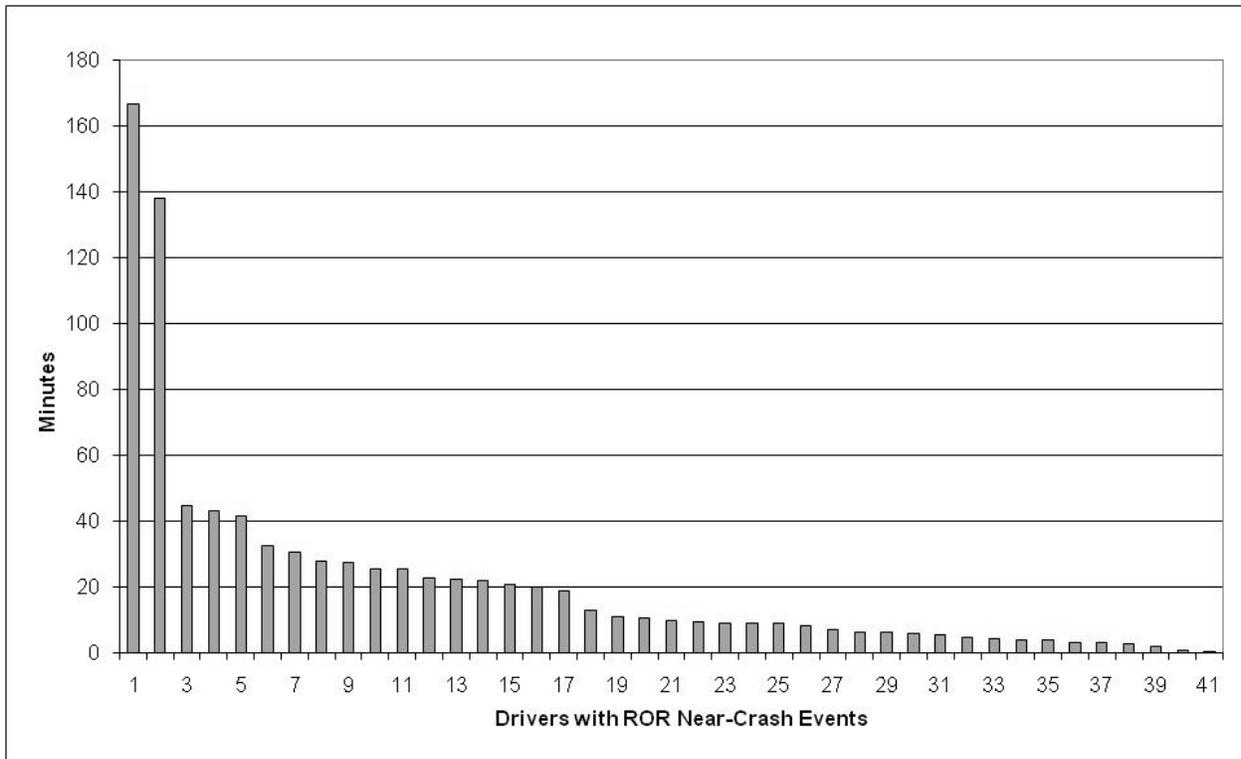


Figure 14. Mean Number of Minutes in Vehicle Before an ROR Near-Crash

ROADWAY GEOMETRY

Figure 15 provides the distribution of events according to roadway geometry and turn direction. Over half of the ROR events occurred on straight roadways (56%). ROR events occurring in curves, either to the right or left, are the next most common type of event. Approximately 14 percent of ROR events occur in situations where the driver was turning at an intersection. Further separation of the events according to the side of the roadway that was exited is presented in Figure 16.

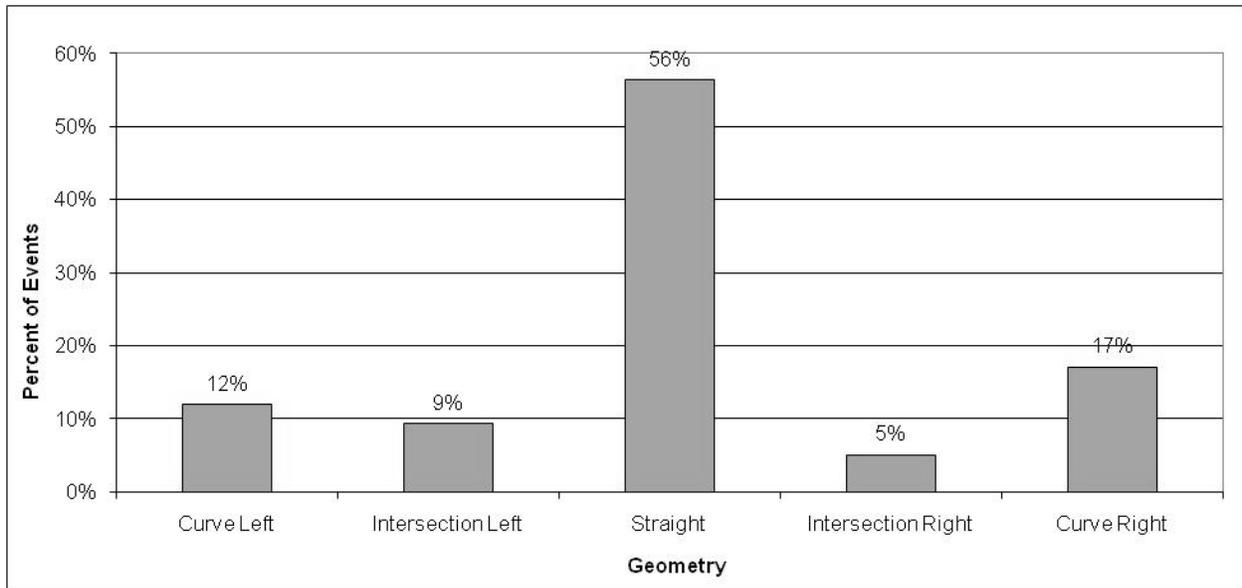


Figure 15. Percentage of ROR Events by Roadway Geometry

The right side of the road appears to be the most common side for ROR events. Where “both” is indicated, the event involved a driver crossing or almost crossing both side boundaries. A total of 70 percent of the events involved crossing the right boundary. A total of 34 percent of the events involved crossing the left boundary. Crossing a left boundary on a straight roadway is most often a situation of contacting the start of a median or diverting to the left to avoid colliding with a lead vehicle.

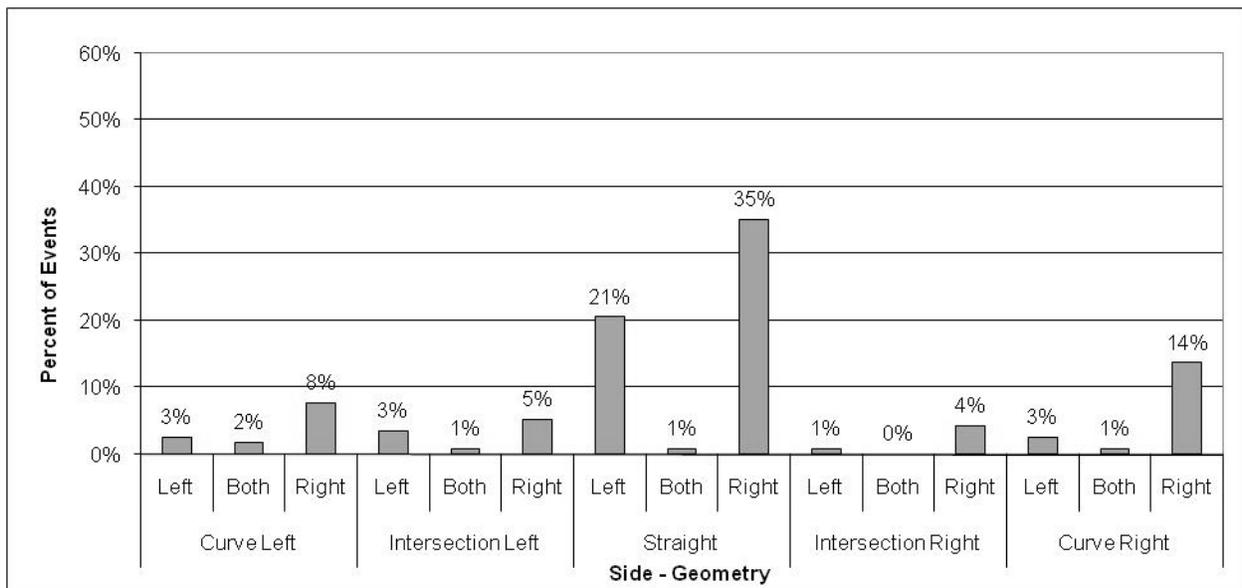


Figure 16. Percentage of ROR Events by Roadway Geometry and Side Where Departure Occurs

The SV speed at the time of the maneuver also varied with roadway geometry. Figure 17 illustrates the mean speed of the SV prior to the ROR maneuver according to the different roadway geometries. The mean speeds in intersection turns were lower than in curves or on straight sections of roadway.

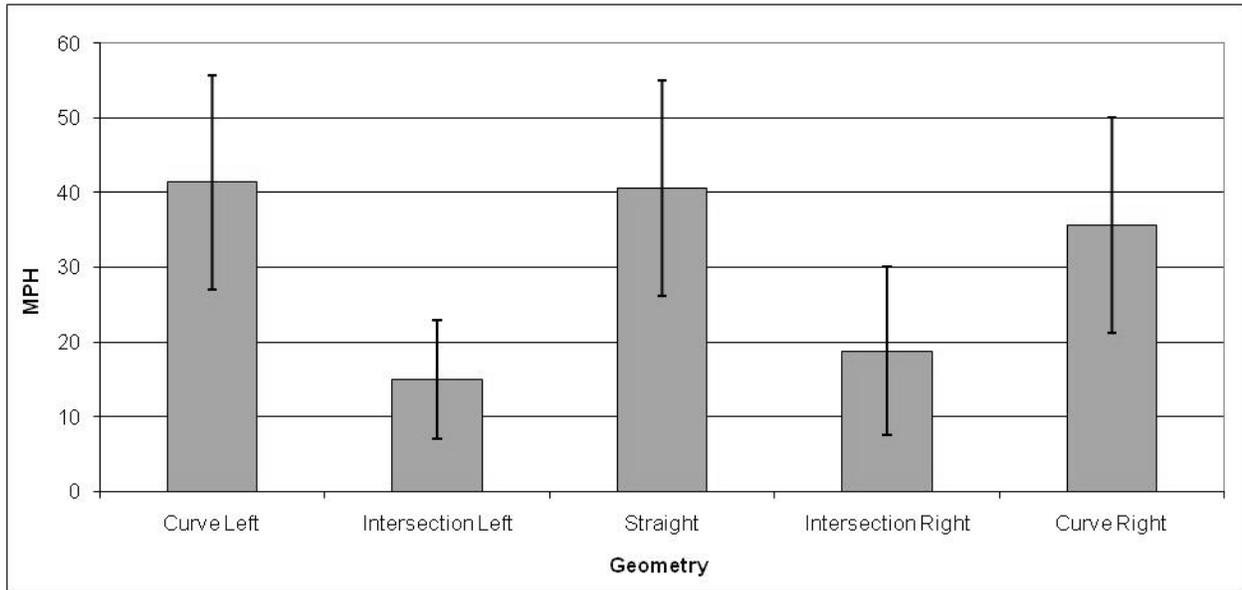


Figure 17. Mean Speed Before ROR Maneuver by Roadway Geometry (Error Bars Indicate One Standard Deviation)

MANEUVER DESCRIPTION

Steering Wheel Inputs

As was shown in Figure 8, the amount of steering input involved in the maneuver can be described by the amount of travel present from the maximum in steering wheel travel in one direction to the maximum travel in the opposite direction. This is first described in terms of distance traveled in degrees. Figure 18 illustrates the mean travel of the steering wheel recorded in one direction to the other (left is recorded as negative, right as positive).

ROR maneuvers in intersection turns to the left involve a much wider range of steering wheel inputs than ROR events in the other geometries. Where insufficient left turn input causes an ROR to the right, a large left-hand recovery input is needed. When too much left turn input is initially used (e.g., when impacting an inside turn median in a left-hand turn), a right correction followed by a greater left correction is needed to return to the normal lane. Cases occurring when turning right at intersections mostly involved the driver cutting the intersection corner too tightly. In this situation, generally holding an constant steering wheel input, or a slight release in input, will return the vehicle to the roadway. ROR events occurring in curves and straightaways are generally at higher speeds, and so only small steering inputs are present in the maneuvers.

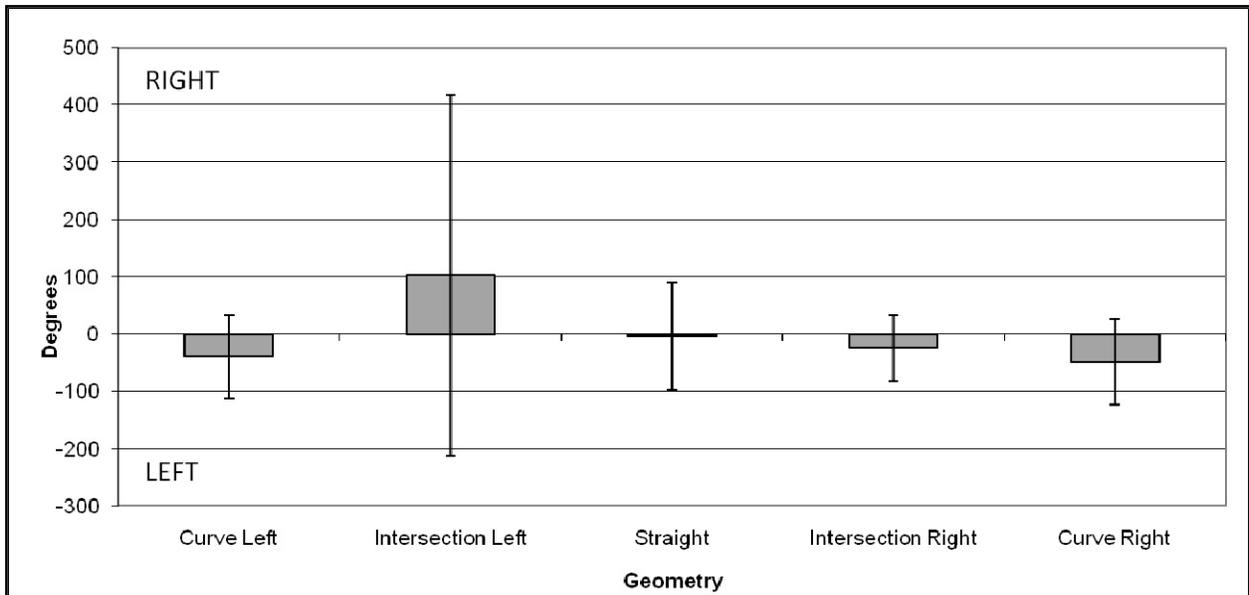


Figure 18. Mean Steering Wheel Travel During ROR Event by Roadway Geometry (Error Bars Indicate One Standard Deviation)

Yaw Rate

Figure 19 illustrates the yaw rate present before the ROR maneuver (shown as solid bars in the figure) as well as the mean maximum left and mean maximum right yaw rates observed during the ROR maneuver (shown as lines in the figure). Rotational rate measures taken before the maneuver in the different events indicate faster mean yaw rate values for intersection turns versus roadway curves. Comparison of the range between maximum left and maximum right yaw rates during the maneuver provides an indication of the severity of the maneuver. Yaw rate measures during the ROR maneuver indicate the greatest range for the intersection turns. In intersection turns to the right, during the ROR event, a mean maximum yaw rate of 4 deg/s to the left was found, although the original (before maneuver) mean yaw rate for these maneuvers was approximately 24 deg/s to the right. As discussed in relation to steering wheel inputs, these right turn events typically indicate that a driver has cut a turn too tight, and the lower, but still right-hand yaw rate, indicates the driver recovering by canceling out an excessive right turn input. In intersection turns to the left, the before-maneuver turn rate is approximately 14 deg/s to the left. During the maneuver, the driver corrects not just by canceling the original input, but by putting in right turn input, as shown by the 14 deg/s mean right hand yaw rate during the maneuvers. Mean right maximum and mean left maximum yaw rates during straight road ROR maneuvers and right curve ROR events appear similar, ranging +/-10 deg/s around zero.

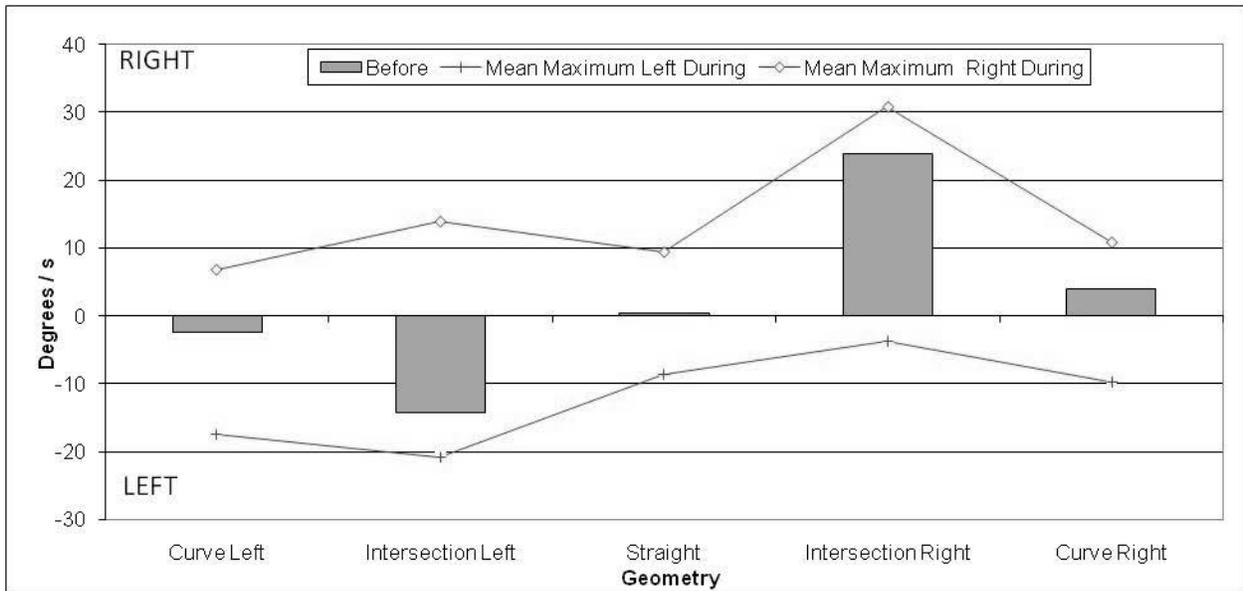


Figure 19. Mean Yaw Rate (deg/s) Before and During ROR Event by Roadway Geometry

Figure 20 illustrates the mean rate of change between these two points for the events according to geometry. The mean rate of change is approximately 30 deg/s². Fast reversals tend to be above 50 deg/s² while slow reversals are around 5 deg/s².

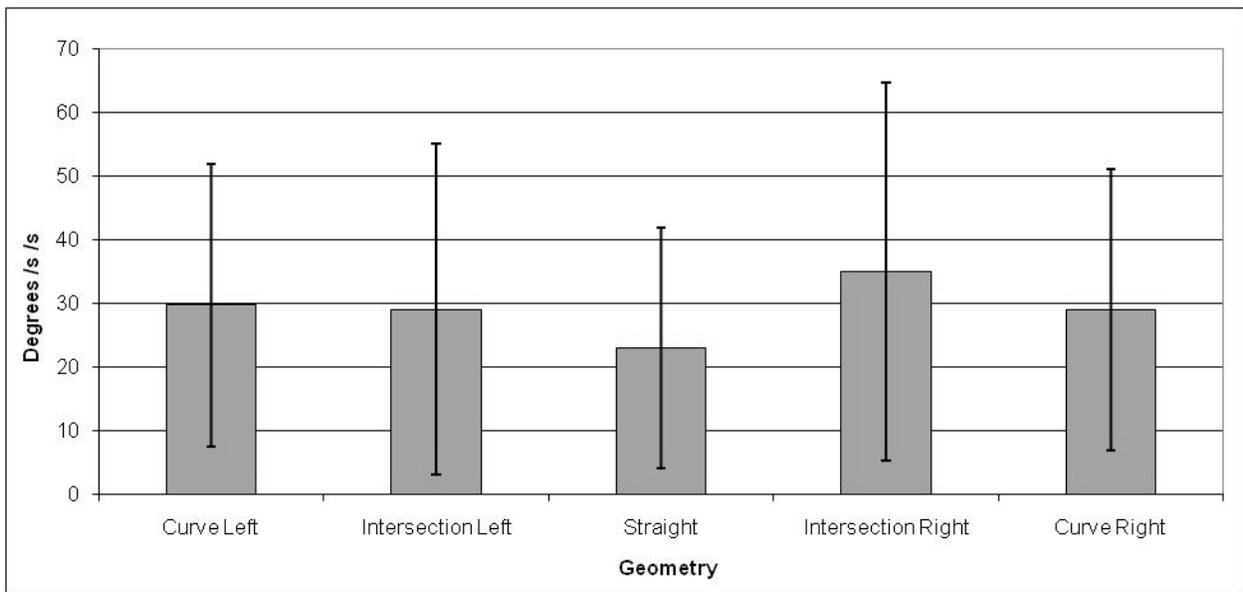


Figure 20. Rate of Change in Yaw Rate between Maximum Value and Minimum Value During ROR Event by Roadway Geometry (Error Bars Indicate One Standard Deviation)

Braking Prior to and During Event

The driver was braking in 38 percent of the events prior to developing a path that would lead to an ROR situation. In 51 percent of the events the driver was applying the brakes during the maneuver itself.

COMPARISON OF CRASH AND NEAR-CRASH EVENTS

Exploration of differences between crashes and near-crashes was performed by separating the events into groups according to geometry of the segment in which the event occurred, and then comparing performance measures collected during the maneuver. Table 10 lists the performance measures and provides the means for any comparisons that were different at the $\alpha < 0.05$ level. As would be expected, differences in measures between the crash and near-crash events tended to indicate more extreme mean values recorded for crashes than near-crashes as well as greater variability for crashes. There are fewer events in the crash category, and the events represent extremes of driving situations. During the maneuver, as drivers attempt to avoid or mitigate a crash, larger inputs are used as compared to the near-crashes. Figure 21 illustrates the differences in the first and second steering wheel input recorded during the maneuvers.

Table 10. Crash versus Near-Crash Comparison – Means for Comparisons Significant at $\alpha < 0.05$ Level

| | Curve to the Left | | Curve to the Right | | Intersection Turn to the Left | | Intersection Turn to the Right | | Straight | |
|--|-------------------|------------|--------------------|------------|-------------------------------|------------|--------------------------------|------------|----------|------------|
| | Crash | Near-Crash | Crash | Near-Crash | Crash | Near-Crash | Crash | Near-Crash | Crash | Near-Crash |
| Observations Available | 1 | 13 | 6 | 14 | 4 | 7 | 4 | 2 | 11 | 55 |
| Yaw Rate Before Maneuver (deg/s) | | | | | | | 34.3 | 3.0 | | |
| Lateral Acceleration Before Maneuver (g) | | | | | | | | | | |
| Longitudinal Acceleration Before Maneuver (g) | | | 0.02 | -0.05 | | | | | | |
| Speed Before Maneuver (mph) | | | | | | | | | | |
| Yaw Rate Maximum Left During Maneuver (deg/s) | | | | | | | | | -15.4 | -7.3 |
| Yaw Rate Maximum Right During Maneuver (deg/s) | 27.7 | 5.2 | | | | | 41.4 | 9.6 | | |
| Separation Between Maximum and Minimum Gyro (s) | | | | | | | | | | |
| Maximum Lateral Acceleration Left During Maneuver (g) | | | | | | | | | 0.65 | 0.28 |
| Maximum Lateral Acceleration Right During Maneuver (g) | -0.60 | -0.24 | | | | | | | -0.60 | -0.24 |
| Maximum Acceleration During Maneuver (g) | | | | | | | | | | |
| Minimum Acceleration During Maneuver (g) | | | -0.48 | -0.15 | | | | | | |
| First Steering Wheel Input During Maneuver (deg) | | | | | -180 | 45 | | | 79 | 6 |
| Second Steering Wheel Input During Maneuver (deg) | | | | | 0 | -219 | | | 113 | -3 |
| Steering Wheel Travel During Maneuver (deg) | | | -98 | -26 | -180 | 264 | | | | |
| Duration of Maneuver (s) | | | | | | | | | 4.9 | 3.6 |
| Yaw rate / s (deg/s/s) | | | | | | | | | | |

In near-crashes, the mean first input is less than 10 deg with a standard error of approximately 10 deg, whereas in crashes it is approximately 80 degrees with standard error of approximately 60 deg. Similar scaling is present for the second input. Charts representing the other comparisons indicating differences may be found in Appendix A.

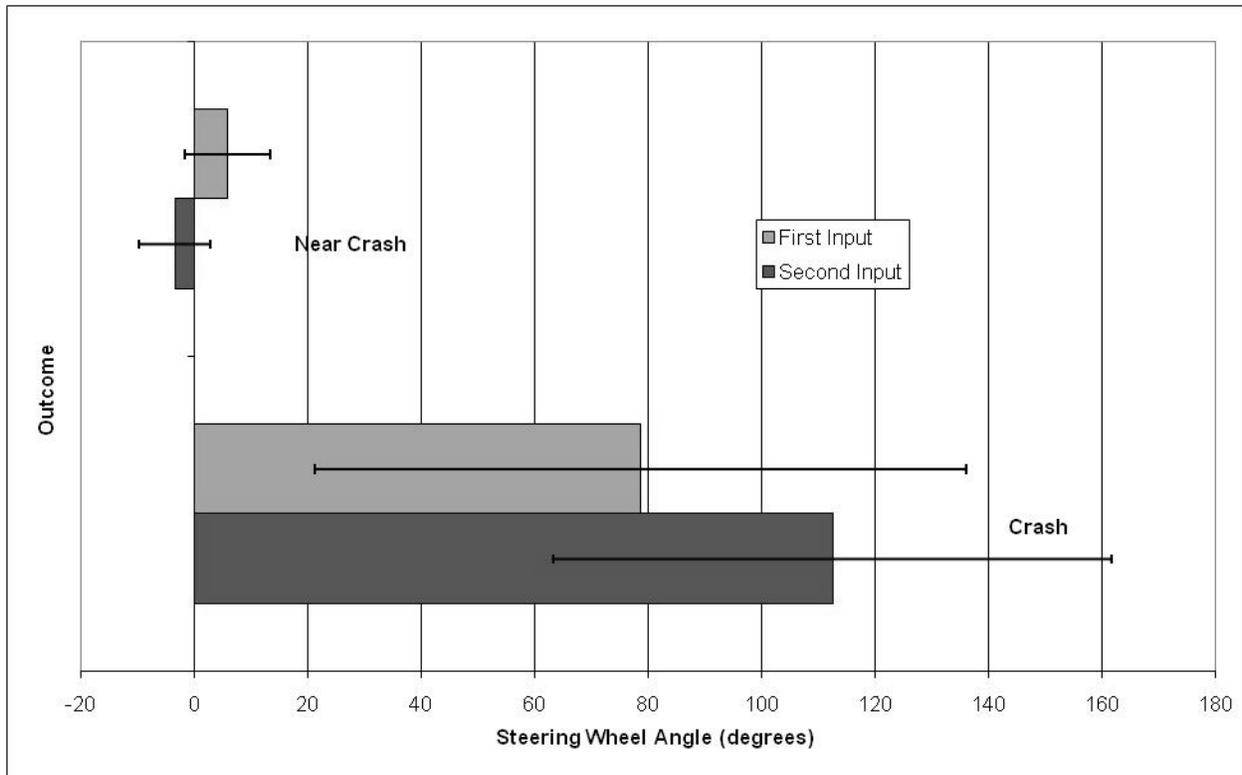


Figure 21. Crash Versus Near-Crash Comparison - First and Second Steering Wheel Maximum Inputs During Maneuver (Error Bars Indicate Standard Error)

CONTRIBUTING FACTORS

As described in the Methods section, the approach used in selection of contributing factors tended to identify a limited number of factors in each event. In 75 percent of the ROR events, a single factor was identified as a contributing factor in the event. In 25 percent of the cases, multiple factors were identified. In 22 percent of the ROR events, two factors are identified, and in the remaining 3 percent of the events, three factors are identified. In the following discussion, a factor is included in the summary values whether it is the only factor or one of two or more.

The percentage of the ROR crashes, near-crashes, and events overall are depicted in Figure 22 through Figure 24 with contributing factors. The categories with the largest differences between crashes and near-crashes were short following, encroaching, and low-speed maneuvering errors. Short following and encroaching were found entirely in near-crashes, while low-speed maneuvering instances all were found in crashes. Other smaller differences were also present. In the following sections, crashes and near-crashes will be discussed together as ROR events (Figure 24). Distraction was the most frequently identified contributing factor in the ROR events. Forty percent of the events included distraction as a contributing factor, with 36 percent of the events including distraction due to a secondary (non-driving) task identified as a contributing factor. Within the driving-related inattention-to-the-forward-roadway events and the secondary task distraction events, 15 types of factors were identified that provide further detail on distraction. Figure 25 illustrates the types of distraction found, the percentage of the ROR events that included this factor, and the percentage of the distraction-related events that

involved the factor (similar charts showing crashes and near-crashes separately can be found in Appendix B).

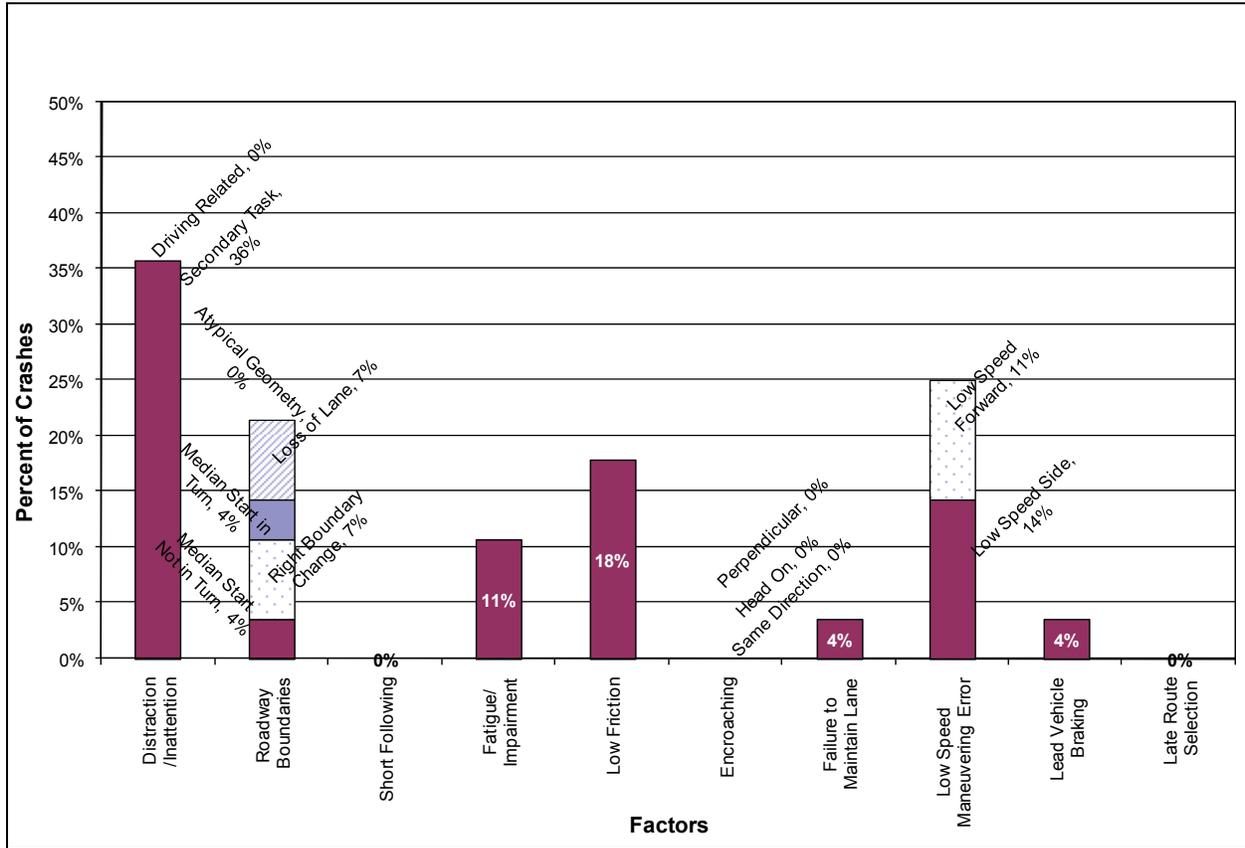


Figure 22. Percentage of ROR Crashes by Contributing Factors

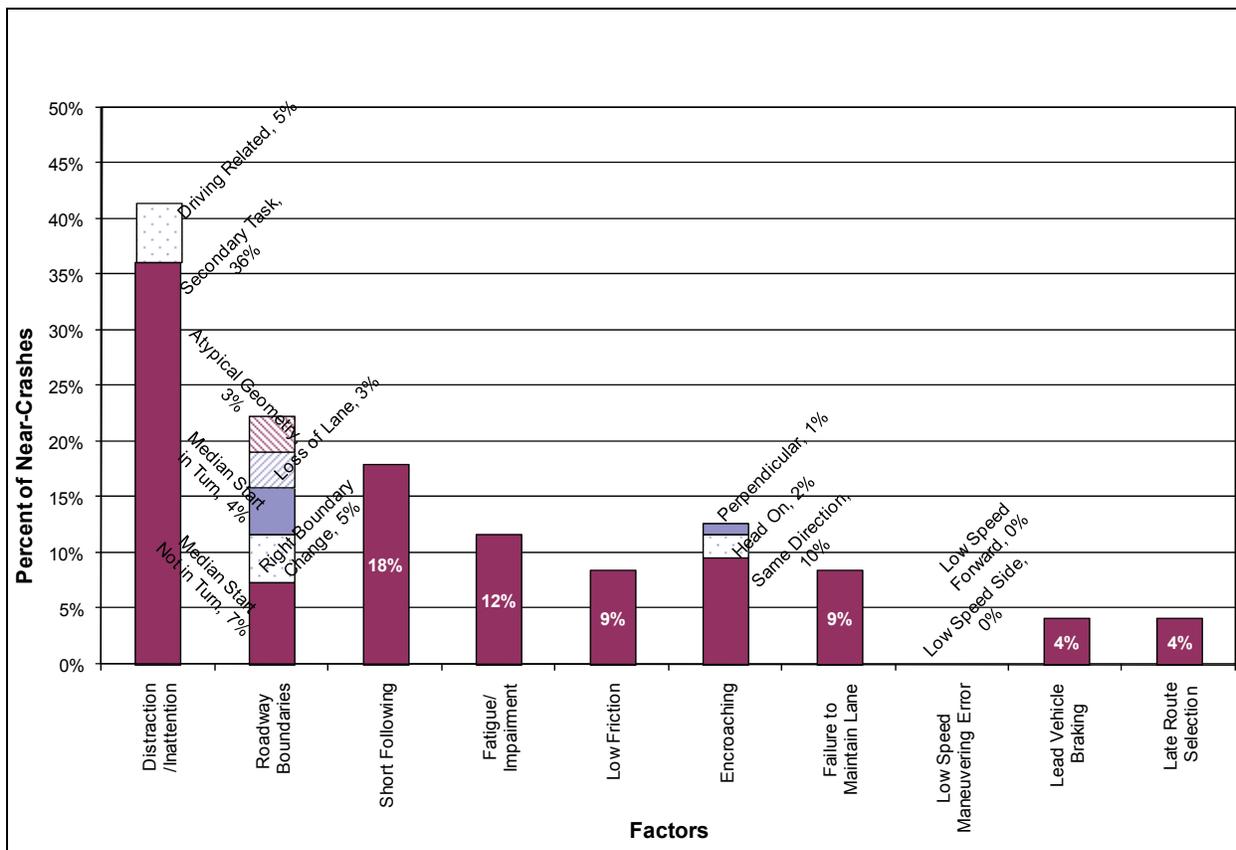


Figure 23. Percentage of ROR Near-Crashes by Contributing Factors

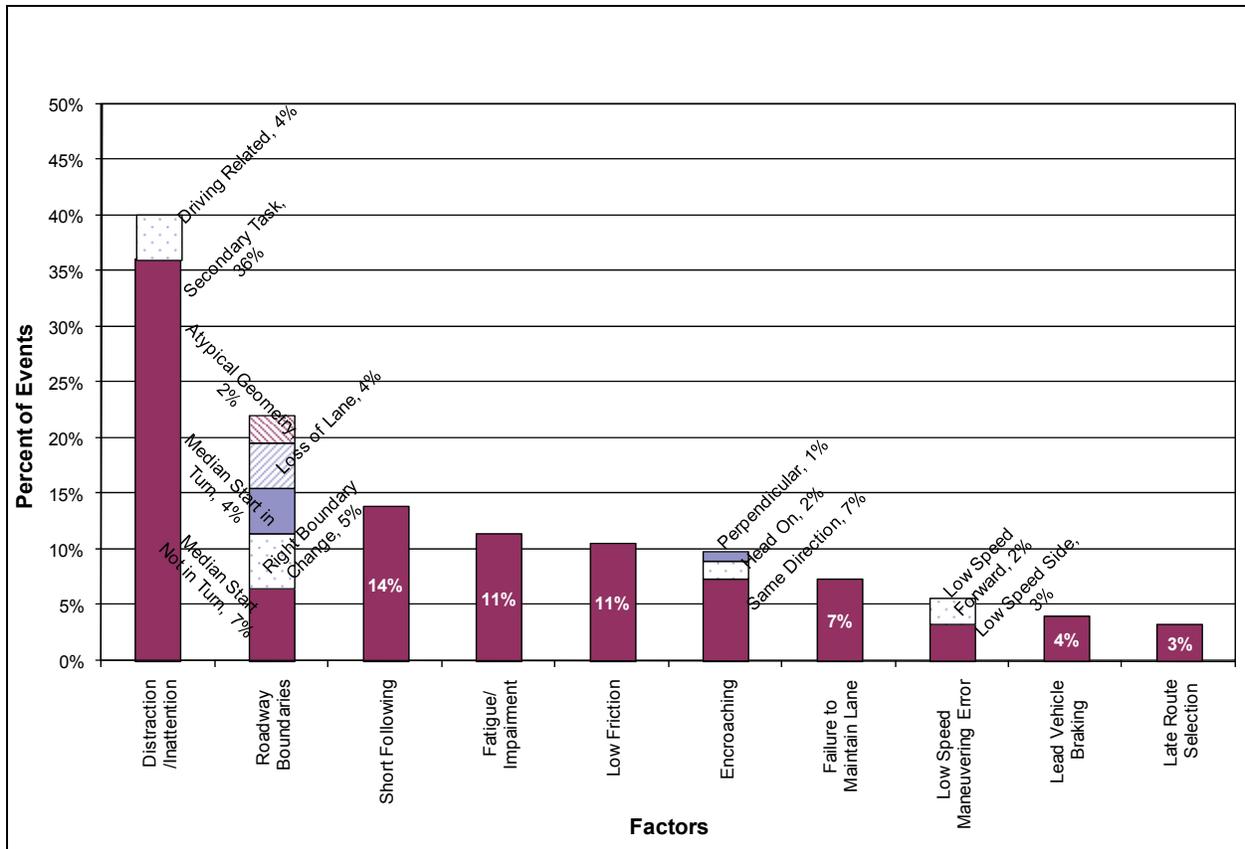


Figure 24. Percentage of ROR Events (Crashes and Near-Crashes) Contributing Factors

The most common forms of distraction related to ROR events included: outside distractions from secondary tasks, distraction while interacting with an OEM device, talking to a passenger, and talking on a cell phone. Five percent of the ROR events appeared to have interaction with an OEM device as a contributing factor. These events make up 12 percent of the distraction events. Talking on a cell phone was considered a contributing factor in 5 percent of the ROR events and dialing a cell phone was a factor in 3 percent of the events, indicating that 8 percent of the ROR events were related to cell phone use. Twenty percent of the ROR distraction events involved a cell phone. Interaction with a passenger, including talking without looking at the passenger, and glance toward the passenger during conversation was considered a contributing factor in 6 percent of the ROR events and 14 percent of the distraction-related ROR events. Other forms of distraction that were considered contributing factors in ROR events included eating, drinking, smoking, reaching for an object, and outside driving-related distraction. The lowest frequency distractions were glances down for unknown reasons, writing, and glances to passengers, mirrors, or over the shoulder.

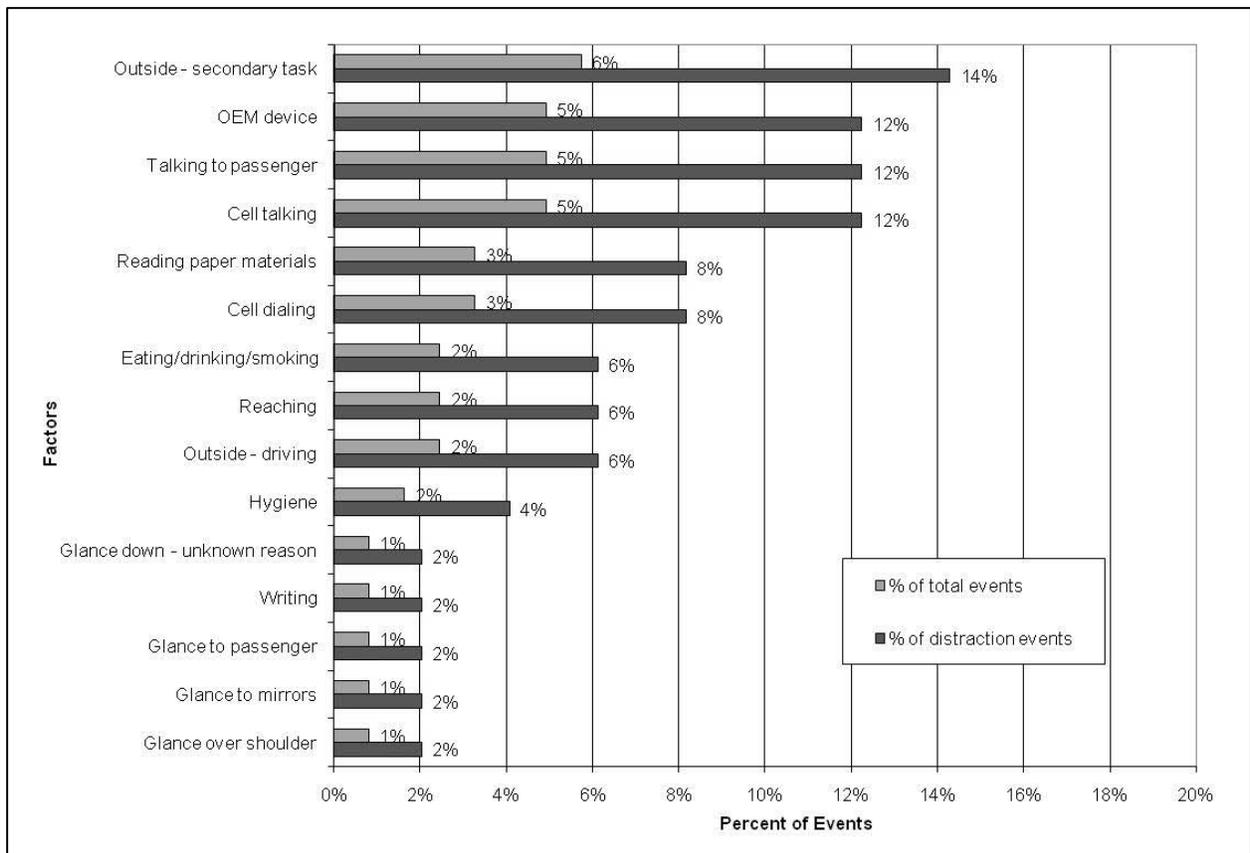


Figure 25. Percentage of ROR Events With Indicated Types of Distraction

The next most common grouping of factors was related to roadway boundaries. A change in roadway boundaries was considered a contributing factor in 22 percent of the events. Seven percent of these events involved the driver contacting (i.e., crashes) or almost contacting (i.e., near-crashes) the start of a median while traveling straight through an intersection. Five percent involved a change in the right lane boundary. Four percent involved the driver contacting or almost contacting the median while making a turn. Four percent involved loss of lane situations either for lane closures or in acceleration lanes. Two percent were attributed to atypical roadway geometry. In approximately half of the ROR cases where roadway boundaries were identified as a contributing factor, the roadway boundary alone is identified as the primary factor in the event. In the other half of the cases where the roadway boundary is identified as a contributing factor, another factor is also present. Table 11 breaks out the number of events into the different categories.

Table 11. Number of Events Involving Roadway Boundaries

| Factor Categories | Events |
|---|-----------|
| Roadway boundary is only factor identified | 13 |
| - Driver runs out of room in acceleration lane | 4 |
| - Driver strikes or almost strikes lane boundary encroaching from right | 3 |
| - Driver strikes or almost strikes median while traveling straight | 3 |
| - Driver strikes or almost strikes median while turning left | 2 |
| - Atypical roadway geometry | 1 |
| Roadway boundary and additional factor | 14 |
| - Secondary task distraction and roadway boundary | 10 |
| - Fatigue/Impairment and roadway boundary | 2 |
| - Driving-related inattention to forward roadway and roadway boundary | 2 |

Short following was not observed to be a contributing factor in any of the ROR crashes; however, it was a factor in 14 percent of ROR near-crashes. Fatigue or impairment, and events involving a low friction on the road surface each made up 11 percent of the ROR events.

Ten percent of the events were attributed to another vehicle encroaching on the SV's path of travel. These contributing factors were found in near-crashes, but not in crashes. In these cases, it was most common to involve vehicles that had been traveling in the same direction but in an adjacent lane (7% of ROR events). Vehicles approaching head-on were involved in 2 percent, and 1 percent involved a vehicle encroaching along a perpendicular path of travel.

Seven percent of the events are attributed to a failure to maintain lane. This category is composed of events where the driver overran lane boundaries but other contributing factors were difficult to identify. In many cases, excessive speed could be assigned as a factor in these events. However, in other cases, it appeared the driver was attentive and simply not attempting to maintain lane.

Five percent of the events occurred at low speed and appeared to be a result of the driver running into an object or off the road due to error in judgment of separation or speed. All of these cases were crashes. In 3 percent of the overall ROR event count, the driver either overran or nearly overran a curb on the side of the road when parking, or contacted or nearly contacted a parked car beside the road. In 2 percent of the ROR events, the driver drove forward into a boundary (either a roadway edge or an object separating parking spaces) at low speed.

Four percent of the events involved a driver departing the roadway in an attempt to avoid colliding with a decelerating lead vehicle. Three percent of events involved what appeared to be late route selection. In these four events, the driver changed course at a roadway division and drove over the gore point paint (i.e., painted road markings indicating start of a split in the roadway). Three of the four late-route-selection events shared either talking on a cell phone (one event) or talking to a passenger (two events) as contributing factors.

DISTRACTION MODALITY

In an effort to understand the impact of different modes of distraction, each of the 15 distraction categories was coded according to whether the observable interference with driving was visual, visual and manual, or cognitive. In many cases, tasks include elements of other modes. The classification used here is based on the mode that likely provides the greatest interference with driving. Table 12 provides the assignment of the distraction-related factors to the task modality categories.

Table 12. Tasks and Modes of Distraction Categories

| | Primary Mode | | |
|---------|----------------------|---------------------------------------|-------------------------|
| | Cognitive | Visual | Visual and Manual |
| Factors | Talking to passenger | Glance over shoulder | Hygiene |
| | Cell talking | Glance to mirrors | Writing |
| | | Outside – driving-related inattention | Reaching |
| | | Glance to passenger | Eating/drinking/smoking |
| | | Glance down – unknown reason | Cell dialing |
| | | Reading paper materials | OEM device |
| | | Outside – secondary task distraction | |

Figure 26 presents the percentages of the ROR events, and of the distracted ROR events, according to the task mode.

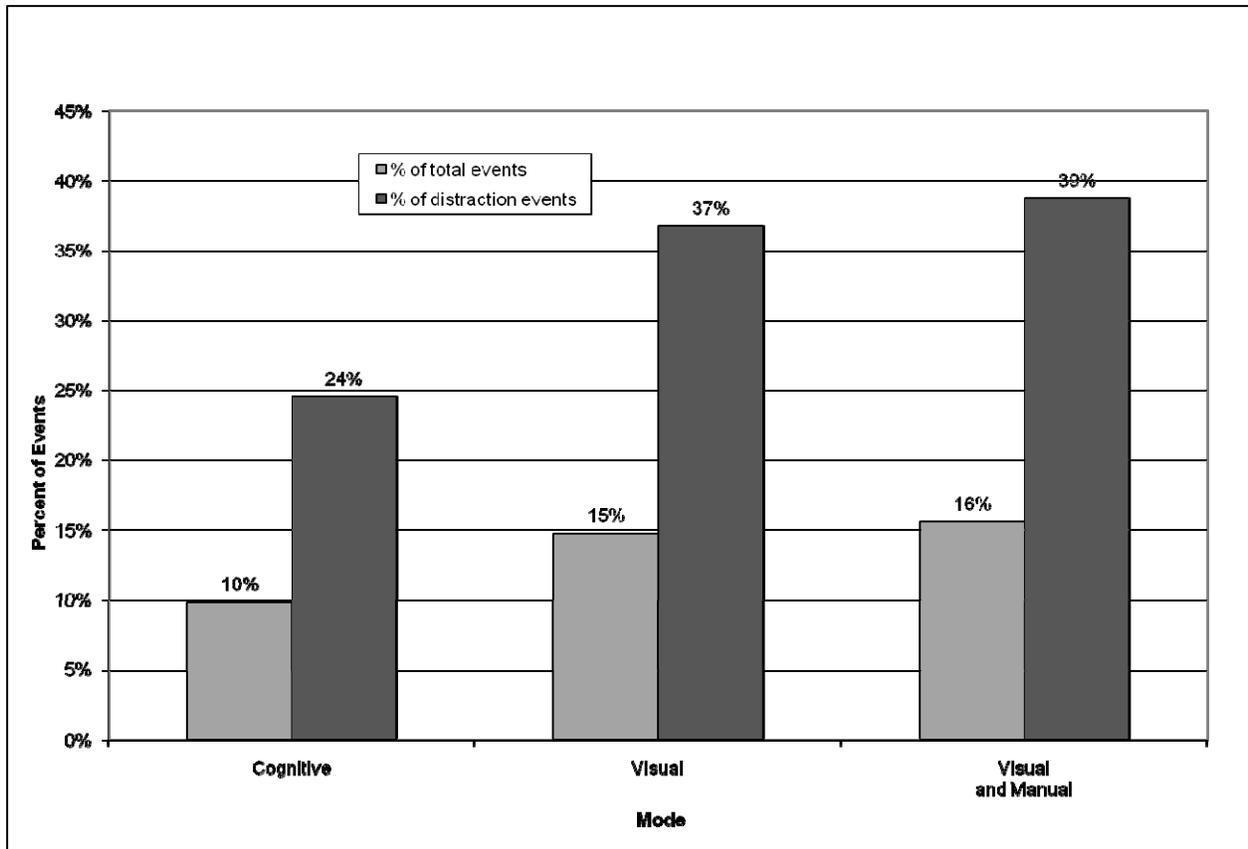


Figure 26. Percentage of ROR Events by Mode of Distraction

Distractions that are considered primarily visual were represented in the data in similar numbers to ones that involve both visual and manual elements, with the visual distractions making up 15 percent of the events and visual and manual distractions making up 16 percent of the events. Twelve events included cognitive contributing factors (i.e., talking on the cell phone or talking to a passenger). Due to the challenge of evaluating the contribution of a cognitive distraction, further description of these events is appropriate. In 6 of these 12 events, no other contributing factor beyond talking on the phone or talking to a passenger could be identified as to why the ROR event occurred. Three of the 12 cognitive events also were assigned late route selection as the contributing factor in the event. Contact with a median during an intersection turn, lead-vehicle braking, and a low friction were present as contributing factors with cognitive distraction in one event each.

ROR Maneuver

Figure 27 illustrates the results of an investigation of what hand or hands the driver was using to steer prior to the event and during the ROR maneuver.

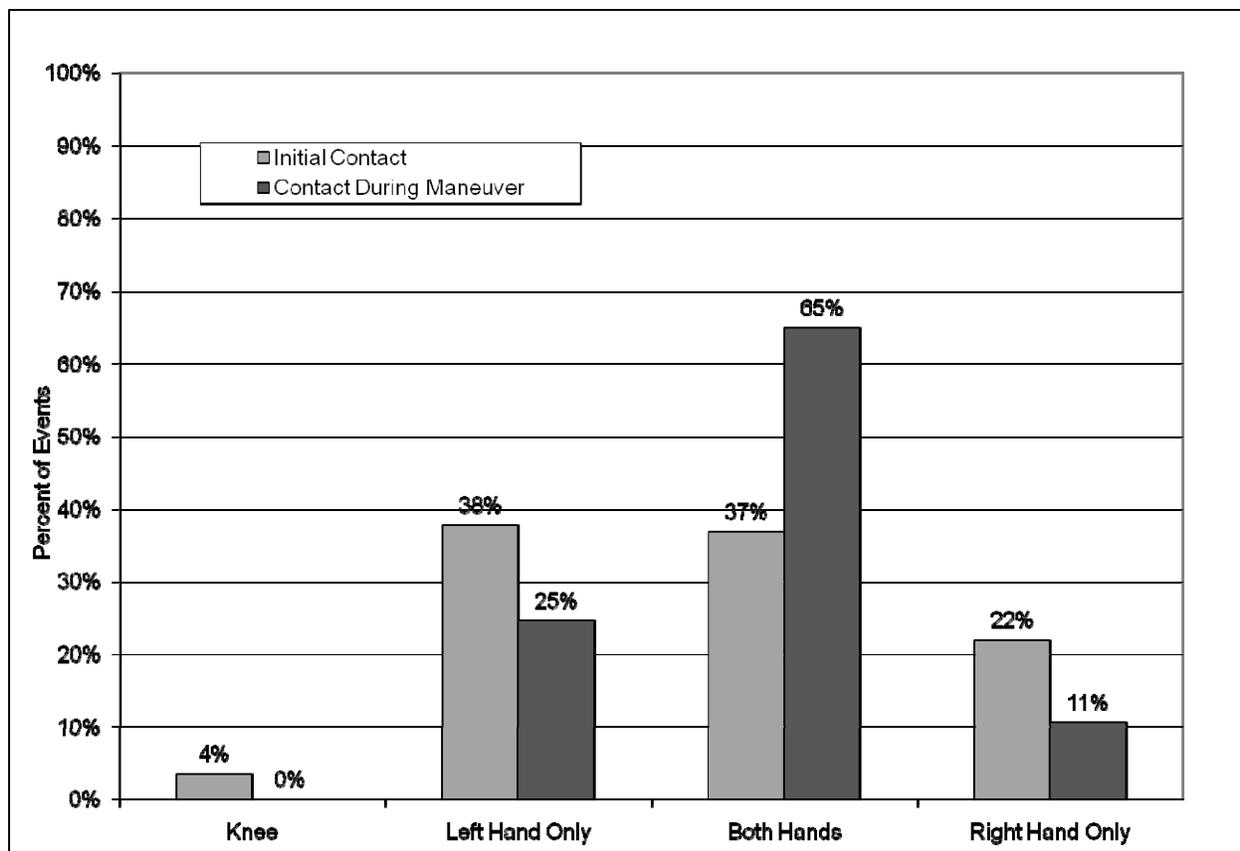


Figure 27. Percentage of ROR Events by Steering Wheel Contact Before Event and During Maneuver

Both hands were being used for steering prior to the event in 37 percent of the events. The left hand was the only hand in contact with the steering wheel in 38 percent of the events. In 22 percent, only the right hand was in contact with the wheel. In 4 percent, only the driver's knee was in contact with the steering wheel before the event. During the maneuver, drivers put both hands on the wheel in 65 percent of the events. Conversely, and counter to what might be expected, in 35 percent of the events, the driver never put a second hand on the wheel. In some cases this may be an effect of reaction time – the event may have been over before the driver could get the other hand to the wheel. Or, driver performance with one hand may be acceptable to drivers, even in these ROR events.

CHAPTER 4: CONCLUSIONS

ROR Event Frequency

On a per-mile-driven basis, an ROR event during times of fog, mist, or rain is approximately 2.5 times more likely than in clear conditions. Similarly, ROR events are approximately 2.5 times more likely per mile driven on dark roads than in daylight and approximately 1.5 times more likely at night on lighted roads. Based on the rates of ROR events, it appears that the ROR event is approximately 1.8 times more likely per mile driven in wet surface conditions compared to dry surface conditions, and seven times more likely per mile driven on roads with snow or ice present. The average time driving in the vehicle does not appear to indicate the likelihood of an ROR event.

Of the roadway departure events, approximately 30 percent occurred in curves, while 56 percent occurred on straight roadways. The remaining 14 percent occurred as participants made turns at intersections. The findings of Pomerleau et al. (1999) that most ROR crashes occur on straight road segments appears to be in alignment with these results and the 14 percent of events occurring at intersections agrees with the findings of Wang and Knipling (1994). Exposure may account for greater counts in straight sections versus curved sections, since it is likely that drivers travel more miles on straight segments than in curves. In the present study, approximately 66 percent of the ROR events were found to be departures to the right and 31 percent were to the left. Frequency of departures to the left also agrees with the work of Wang and Knipling. The higher number of departures to the right found in the present study as compared to the work of Wang and Knipling could be due to the types of events included in FARS and GES versus the types of events recorded here. Many departures to the right are simply corrected, and would not generate FARS or GES reporting. The ability of the present study to include non-crashes would tend to raise the percentage of these events over that found in FARS and GES.

ROR Maneuver

ROR events occurring in curves and on straight roadways had the highest speeds prior to the ROR maneuver. The mean speed in curves and straightaways was approximately 40 mph, while the mean speed in intersection turns was less than 20 mph. Mean steering wheel travel varied the most for intersection turns to the left, where one standard deviation on either side of the mean included approximately 600 deg of variation across the events. In the cases occurring in curves, straights, and right turns at intersections, one standard deviation on either side of the mean included approximately 100 to 200 deg of variation. The yaw rate during the maneuver differed furthest from the yaw rate prior to the maneuver during events occurring in intersection turns. In approximately half of the ROR events, the driver applied the brakes. The ranges of values collected here, for example, in steering rotations and yaw rate provide boundaries that may assist in post-processing evaluation of data and potentially in real-time, to identify deviations from baseline driving. Selection of values or combinations of values will depend on the algorithms used in the application. It is likely that boundaries such as these, as well as additional monitoring of measures over time will provide the best results.

Contributing Factors

Distraction can clearly be seen as a leading contributing factor in ROR events. Thirty-six percent of the ROR events included distraction by a non-driving task as a contributing factor. The more common non-driving-related distractions include glances to objects outside the car that were not related to driving, interacting with OEM devices, talking to passengers or on a cell phone, reading, or dialing a cell phone. Other distractions included eating/drinking/smoking, reaching for objects, personal hygiene, and glances to other locations in the vehicle. Driving-related inattention to the forward roadway was also found in 4 percent of these ROR events. These events tend to arise in specific roadway locations, such as in acceleration lanes or intersections. In these situations, the driving task requires glances to locations away from forward; for example, to check for a gap in traffic, to check mirrors, or to monitor other traffic while turning.

Though specification of roadway boundaries is difficult to consider as a contributing factor if at a particular location most drivers are successful in negotiating a roadway feature, the frequency of this general type of ROR event indicates that consideration is warranted. This is particularly true because in half of these roadway boundary events, no other clear contributing factor was observed. In situations where drivers are traveling straight, or where the right roadway boundary changes, it appears driver expectancies are violated or potentially some grade or other physical aspect of the road challenges the performance or judgment capabilities of the driver. Selection of potential countermeasures for these cases depends on the point at which intervention is feasible. Possible countermeasures include changing roadway geometry, signage before the roadway element, lowering speed limits, and in-vehicle warning systems. Where another factor and roadway boundaries contribute to the event, the other factor is most often some form of distraction.

Encroaching vehicles and late route selection are contributing factors that occur in lower frequencies, but may also provide new insight into the ROR crash problem. Ten percent of the events involved vehicles encroaching on the SV path of travel. Late route selection was a factor in 3 percent of the events.

Some conclusions may be drawn by what is not seen in the list of factors, or what is seen in lower numbers than would be expected. Excessive speed is not included in the list of factors possibly due to difficulty in determining exactly at what point speed was too much for the driver to stay on the road. However, where excessive speed is a factor, it would be included mostly in the 7 percent of events classified as failure to maintain lane and possibly in some of the low-friction events. If both of these categories were recast as speed-related, the factor still appears to be lower than expected (e.g., compared with the 32% identified in Pomerleau et al. [1999]). This difference may be a result of study-related factors. The instrumentation used in the 100-Car Study provides more complete understanding of events as compared to the available information in crash databases. This may permit a clearer understanding of pre-event speeds or factors that go unrecognized in studies using accident reports. The difference also may be due to the inclusion of less-severe events (e.g., near-crashes or non-police-reported crashes) in the 100-Car data as compared to what is recorded in crash databases. Low friction and failure to maintain lane were identified in 27 percent of the crashes, which if interpreted as excessive speed, is

closer to the 32 percent value identified by Pomerleau. Vehicle failures, which accounted for a small percentage of events in the Pomerleau work, were not observed in this work.

Although Dingus et al. (2006) found that headway was greater than 2.0 s in 86 percent of lead-vehicle crashes, in these ROR events short following (defined here as less than 1.5 s headway) occurs more frequently as a contributing factor than does lead-vehicle braking. This may be due to details of the ROR event. Steering is available as a successful response at shorter TTC and headway, than braking. It may be that short following is represented in ROR events in greater proportion than in other types of crash events because the only remaining avoidance response in short-following situations is to depart the roadway.

FUTURE WORK

Based on this work, there are a number of areas in which further investigation appears warranted. Roadway boundaries were frequently found as a contributing factor in the present work. For this reason, further investigation of this factor is appropriate. Various departments of transportation are currently recording more specific crash location data than has previously been available. This type of data, combined with site investigations or naturalistic driving data could be used to evaluate the involvement of roadway geometry in crashes.

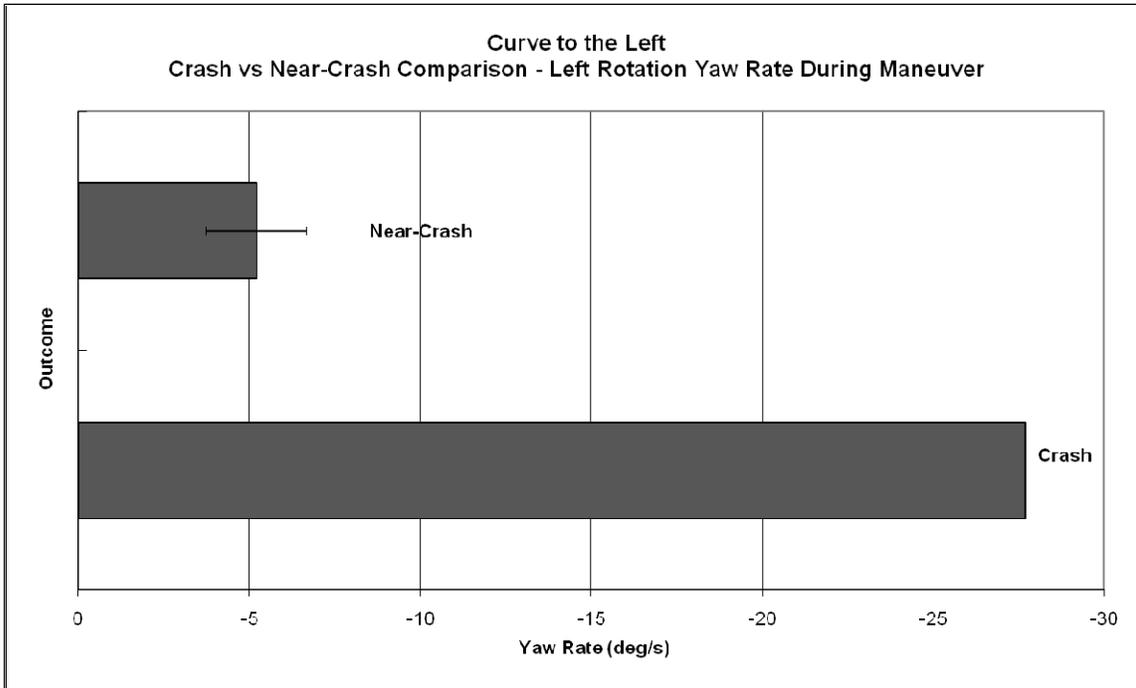
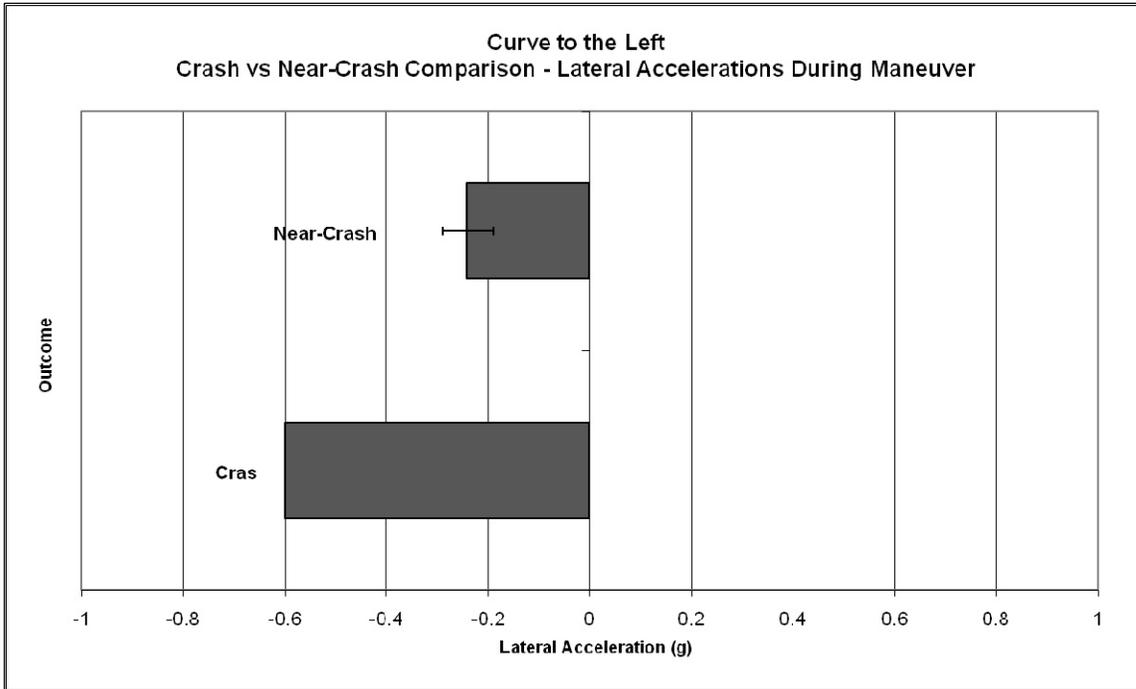
Having explored contributing factors in ROR events overall, there are several analyses that can provide additional understanding. Kinematic quantification of the crashes and near-crashes could be used to investigate the relationships between the factors identified here and event severity. For near-crashes, analyses could be conducted that explore alternative outcomes. For example, one alternative to the near-crash would explore a situation in which the driver had not intervened. This analysis could be used to estimate an impact speed that could be translated into estimates of injury. For crashes, actual impact speeds could be used for driver and occupant injury information if available.

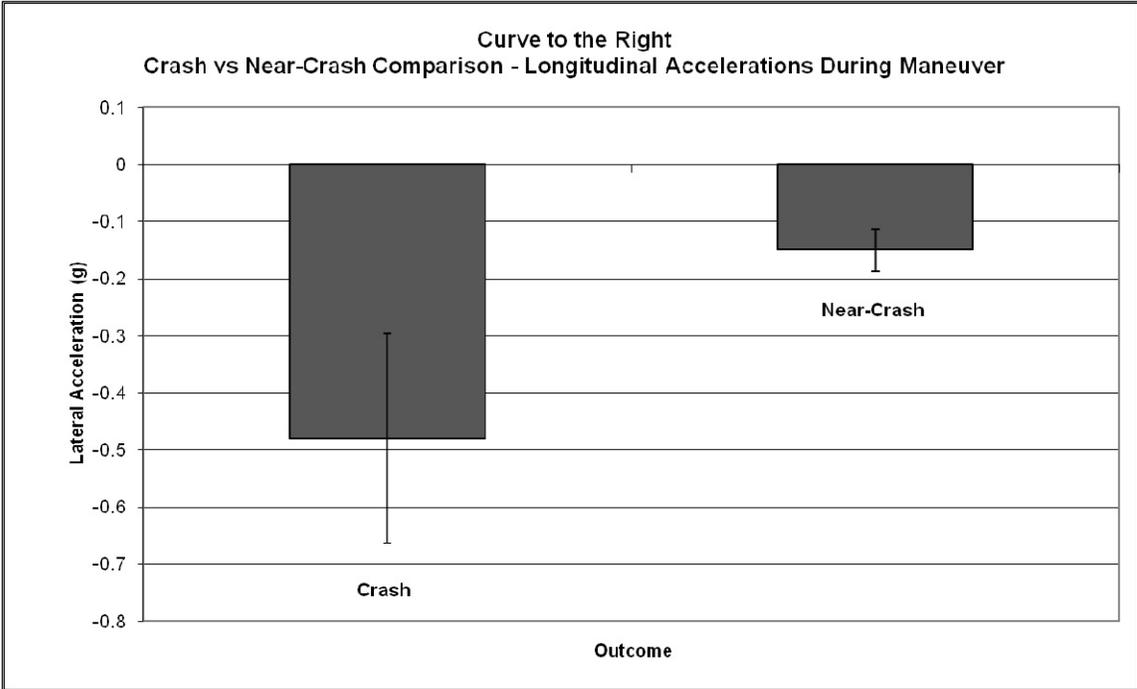
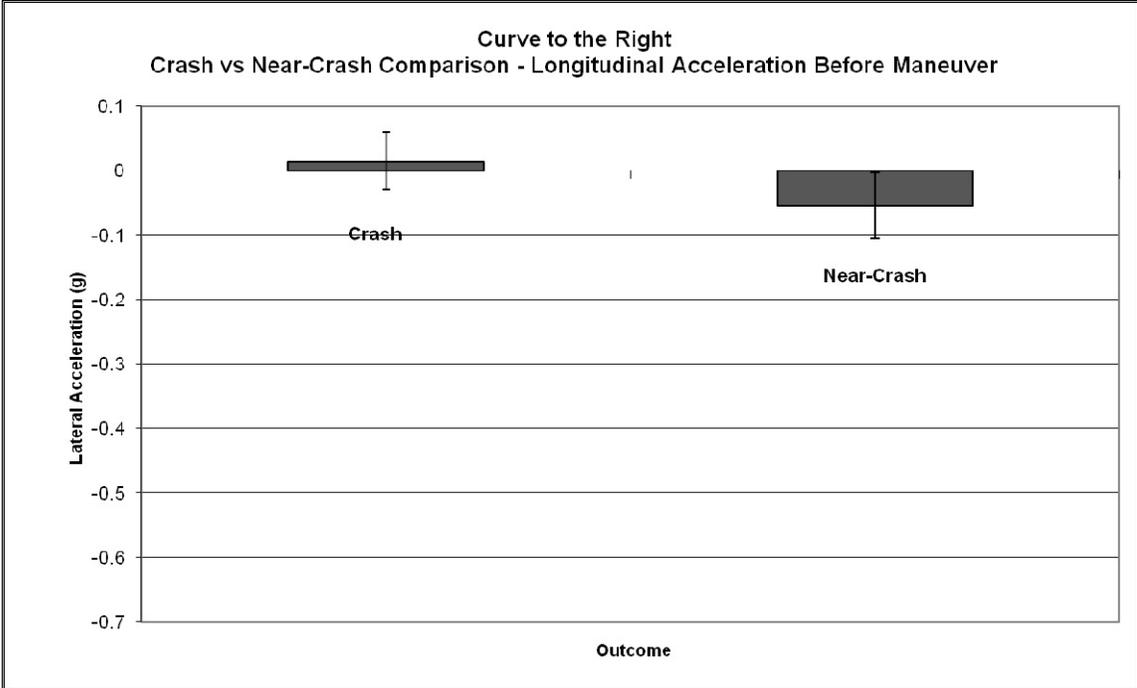
The involvement of driver individual differences in the ROR crash problem could also be explored further. As was observed here, there is a wide range in the rates of ROR events from one driver to another. These types of differences have been observed in other work as well (Knipling et al., 2004). Factors identified here could be analyzed to develop rates of involvement for different drivers. Potential relationships between individual drivers and different contributing factors could then be explored.

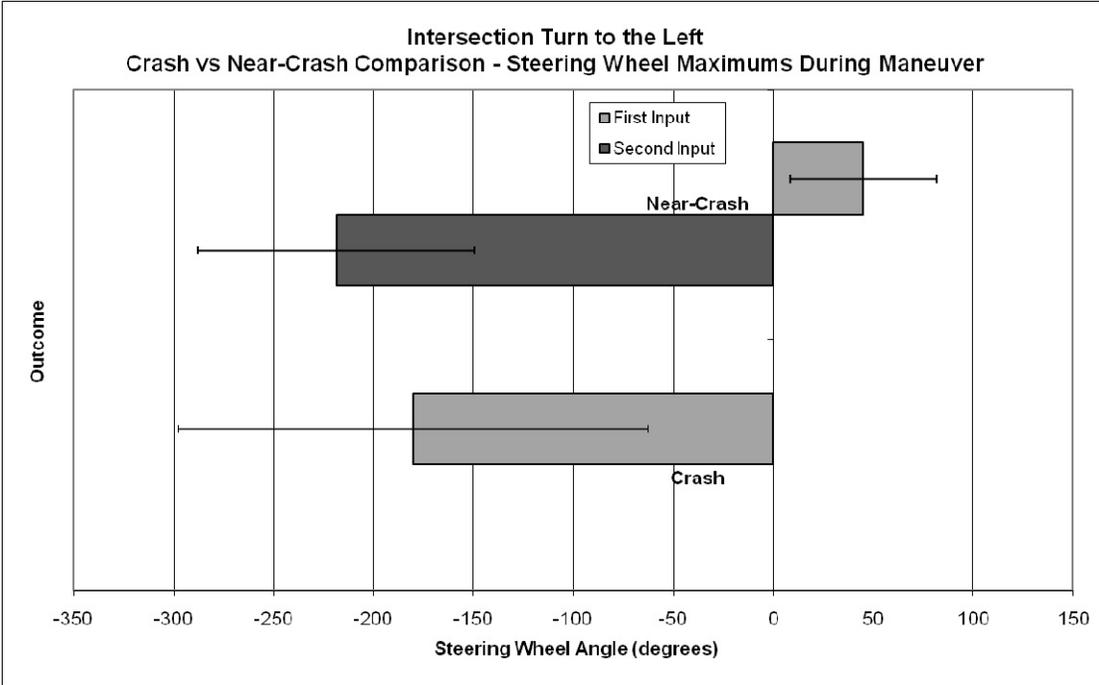
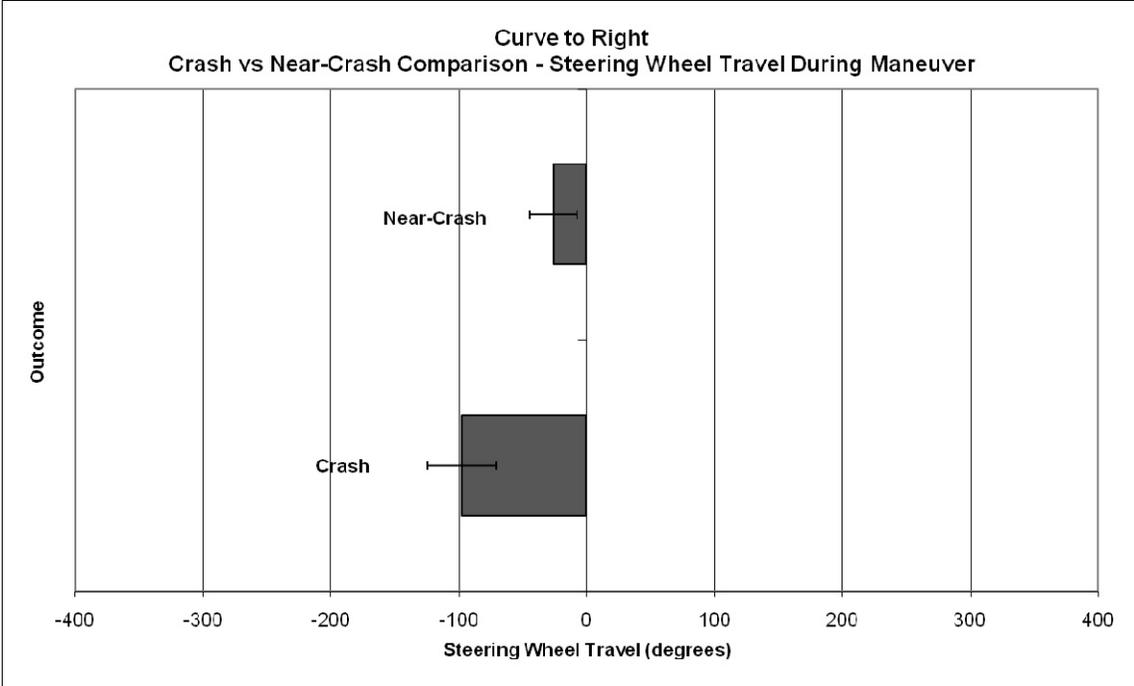
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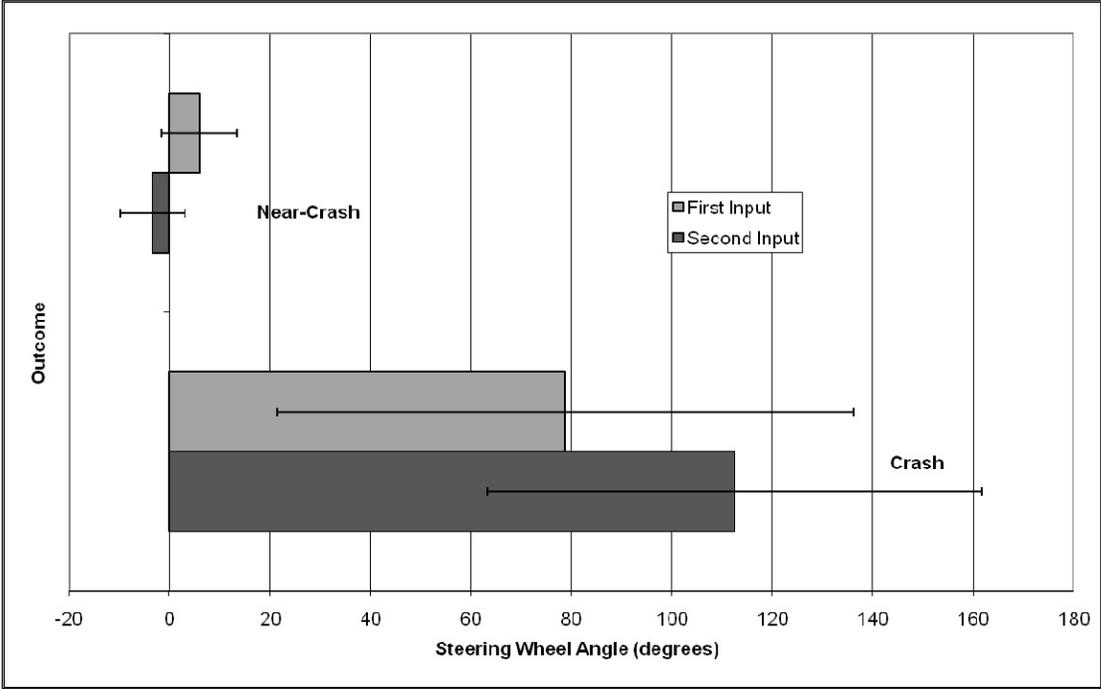
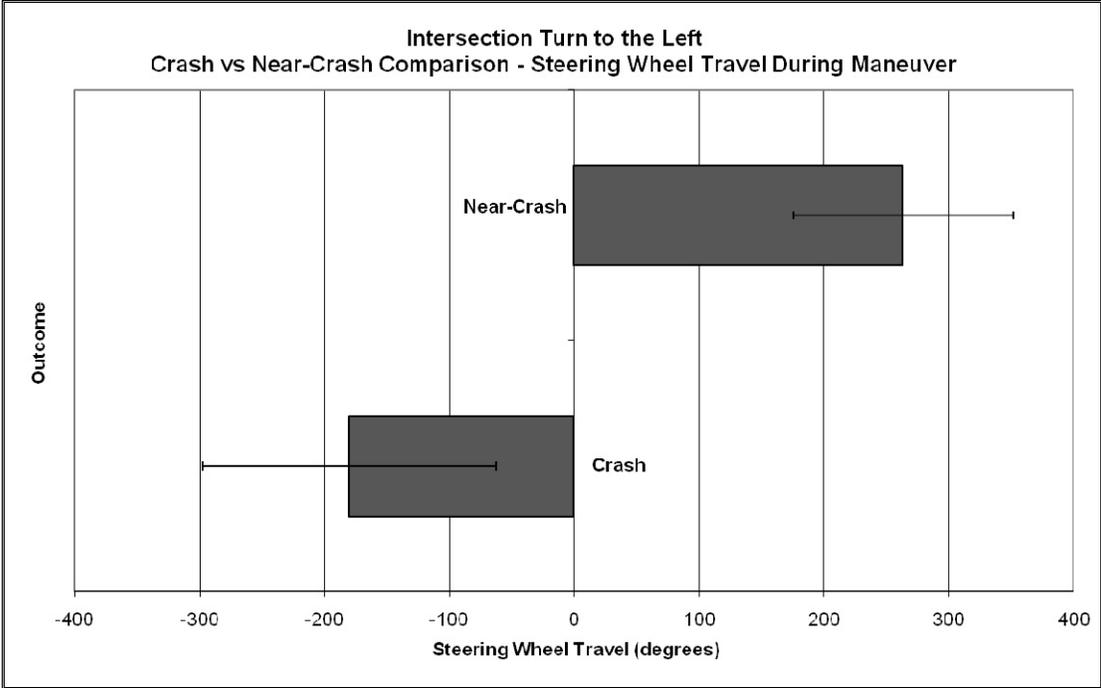
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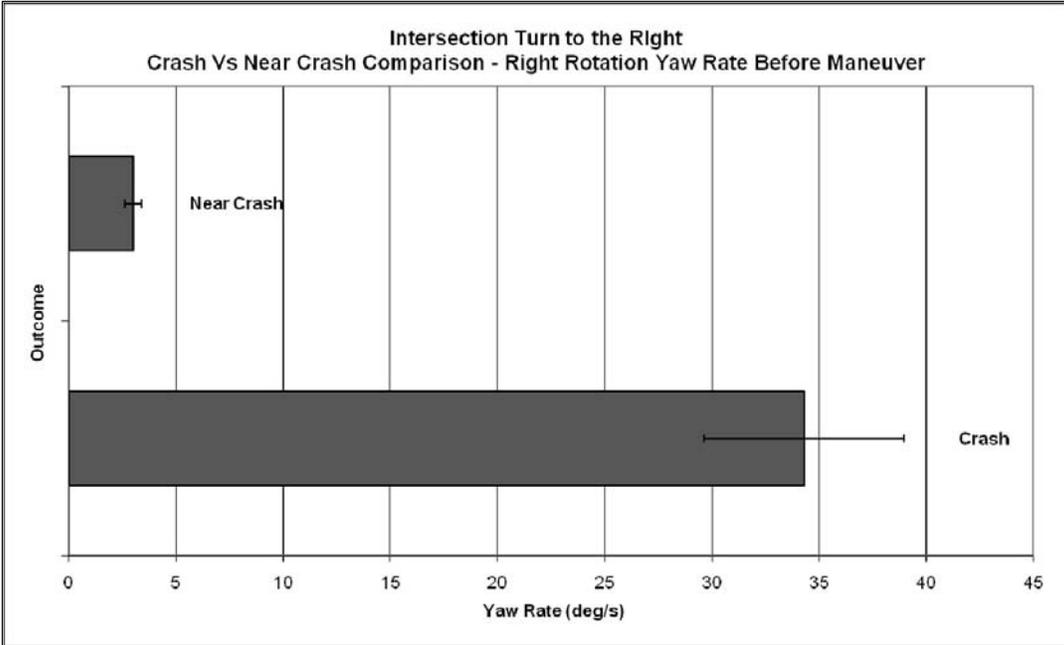
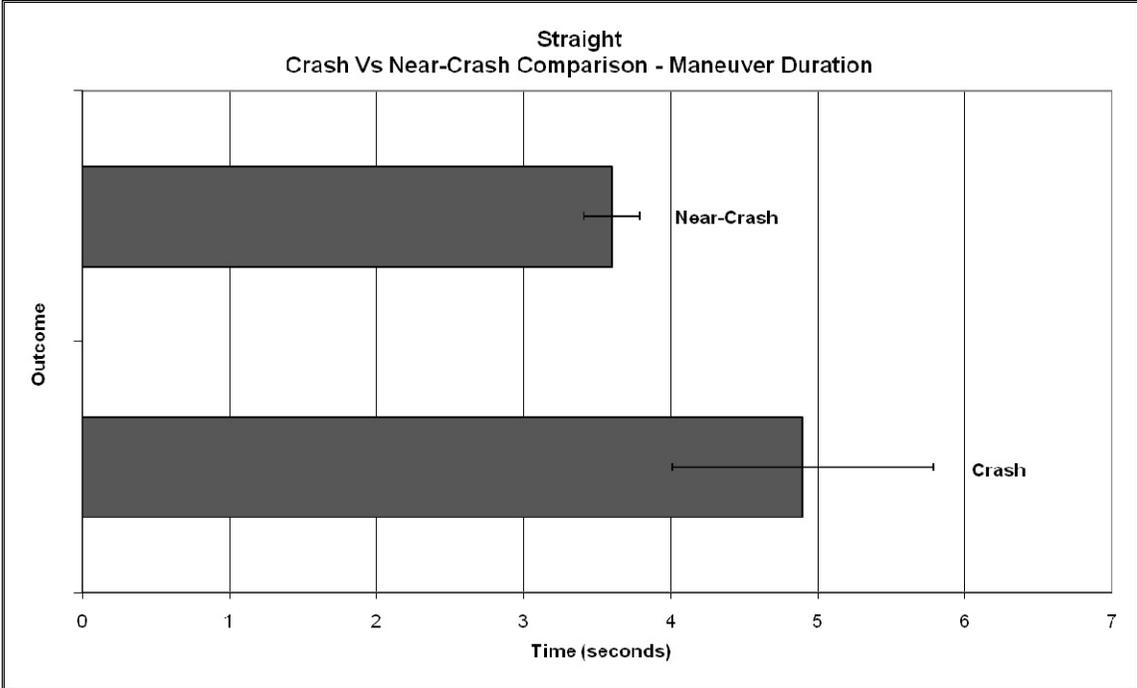
APPENDIX A

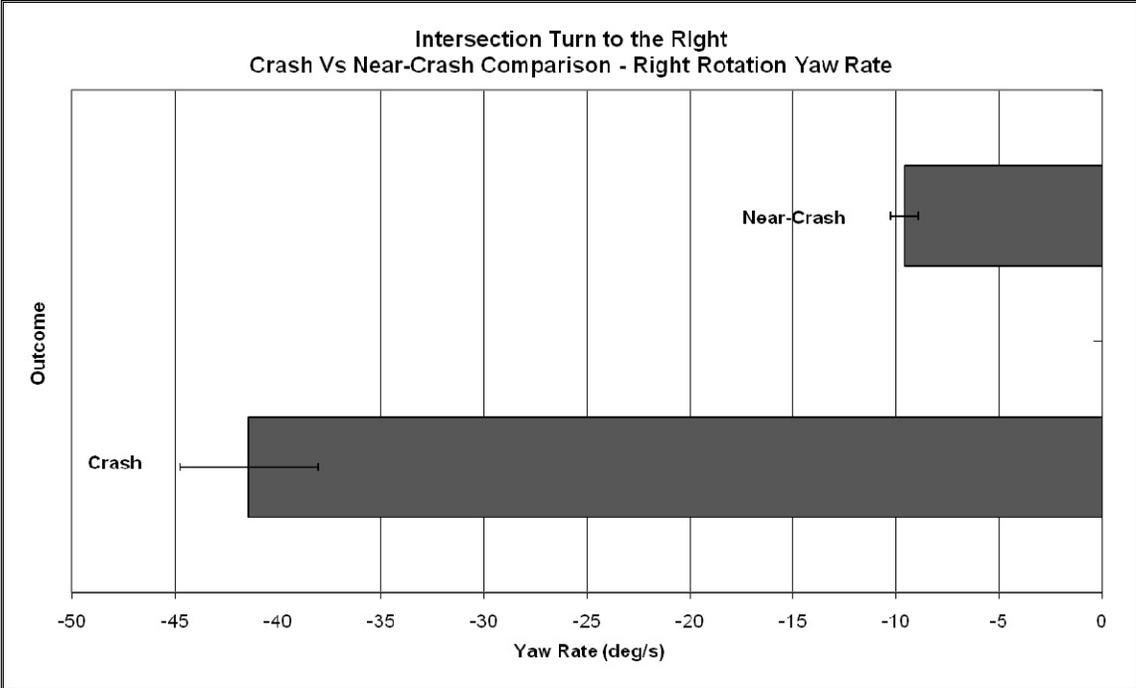




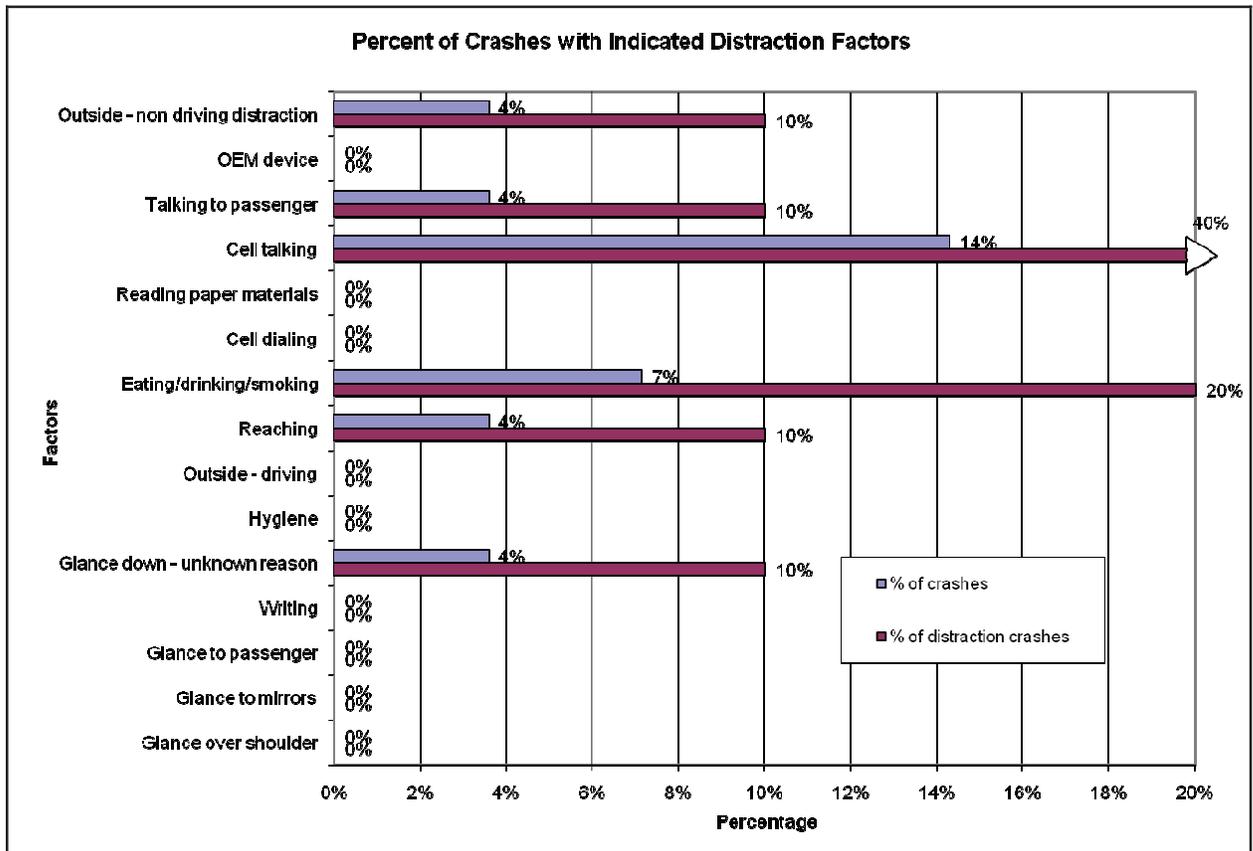


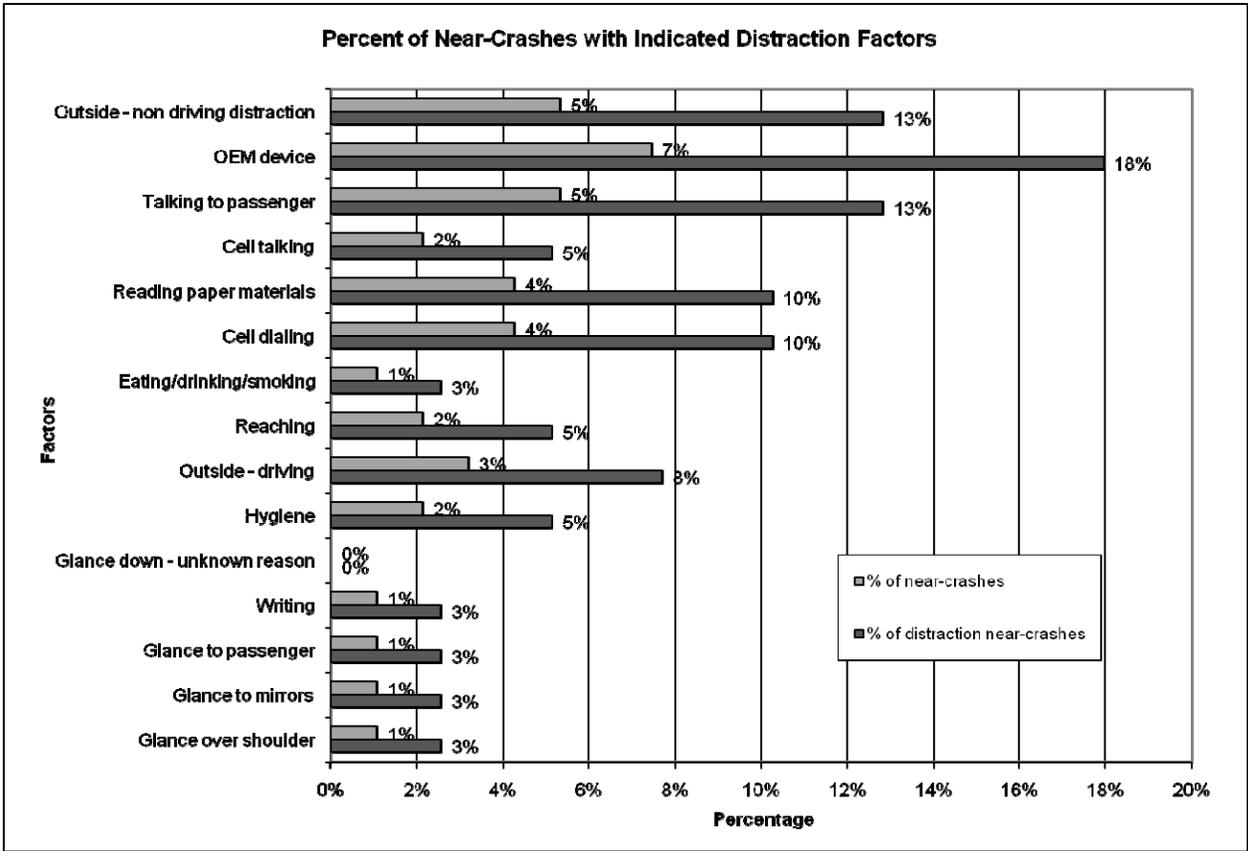






APPENDIX B





DOT HS 811 079
January 2009



U.S. Department
of Transportation
**National Highway
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