Investigating Factors Contributing to Large Truck Lane Departure Crashes Using the Federal Motor Carrier Safety Administration's Large Truck Crash Causation Study (LTCCS) Database

January 2009

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Investigating Factors Contributing to Large truck Lane Departure Crashes Using the Federal Motor Carrier Safety Administration's Large Truck Crash Causation Study (LTCCS) Database		**5. Report Date** January 2009 **6. Performing Organization Code**
7. Author(s) Shauna L. Hallmark, Yu-Yi Hsu, Tom Maze, Tom McDonald, and Eric Fitzsimmons		**8. Performing Organization Report No.**
9. Performing Organization Name and Address Center for Transportation Research and Education Iowa State University 2711 South Loop Drive, Suite 4700 Ames, IA 50010-8664		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.**
12. Sponsoring Organization Name and Address U.S. Department of Transportation Volpe National Transportation Systems Center Motor Carrier Division 55 Broadway Cambridge, MA 02142		**13. Type of Report and Period Covered** Final Report **14. Sponsoring Agency Code**

15. Supplementary Notes

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16. Abstract

Lane departure crashes account for a significant number of motor vehicle crashes and fatalities. However, information specific to large truck lane departures is not well documented. This project evaluated lane departure crashes and the related independent variables and attempted to derive causal relationships that can be used to identify preventative measures for reducing large truck lane departure crashes.

Data from the Federal Motor Carrier Safety Association's Large Truck Crash Causation Study (LTCCS) Database were evaluated to determine both the common causes and the circumstances leading to lane departure crashes. Causes and circumstances may include driver, vehicle, roadway, and environmental factors. Simple statistics, a simple odds ratio, and logistic regression were used to evaluate the crashes, and driver, vehicle, environmental, and roadway factors contributing to large truck lane departure crashes were identified.

17. Key Words		18. Distribution Statement	
large truck lane departure crashes—logistic regression—odds ratio—statistics		No restrictions.	
19. Security Classification (of this report)	**20. Security Classification (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified.	Unclassified.	64	NA

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

INVESTIGATING FACTORS CONTRIBUTING TO LARGE TRUCK LANE DEPARTURE CRASHES USING THE FEDERAL MOTOR CARRIER SAFETY ADMINISTRATION'S LARGE TRUCK CRASH CAUSATION STUDY (LTCCS) DATABASE

Final Report
January 2009

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ACKNOWLEDGMENTS

The authors would like to thank U.S. Department of Transportation's Volpe National Transportation Systems Center for sponsoring this research. The Midwest Transportation Consortium at Iowa State University also deserves thanks for funding the graduate research assistants on this project.

1. EXECUTIVE SUMMARY

1.1. Background

Lane departure crashes account for a significant number of motor vehicle crashes and fatalities. However, information specific to large truck lane departures is not well documented. By understanding the factors that contribute to large truck lane departures, transportation agencies can determine specific countermeasures to mitigate large truck lane departure events.

The objective of this study was to investigate the causes of lane departure crashes for large trucks. Data from the Federal Motor Carrier Safety Association's Large Truck Crash Causation Study (LTCCS) Database were evaluated to determine both the common causes and the circumstances leading to lane departure crashes. Causes and circumstances may include driver, vehicle, roadway, and environmental factors. This research evaluated lane departure crashes and the related independent variables and attempted to derive causal relationships that can be used to identify preventative measures for reducing large truck lane departure crashes.

The LTCCS data is especially useful for this type of analysis because the data provide a large amount of information about the physical events of each crash, as well as vehicle, driver, weather, and roadway condition information. The data also focus on pre-crash events, allowing the reasons for crashes to be determined and the corresponding countermeasures to be considered.

Large truck drivers/vehicles involved in a lane departure crash were extracted from the database, and responsibility for the crash was assigned. Drivers who were the most responsible in single- or multi-vehicle lane departure crashes were used as the case study, and non-responsible large truck drivers were used to determine exposure using the quasi-induced exposure method. Simple statistics, a simple odds ratio, and logistic regression were used to evaluate the crashes. Driver, vehicle, environmental, and roadway factors contributing to large truck lane departure crashes were identified.

1.2. Highlights from Descriptive Statistics

Highlights from the analysis using simple descriptive statistics include the following. The most common critical reasons for lane departure crashes for large truck drivers who were responsible in multi-vehicle lane departure crashes included inadequate surveillance (22.4%), driving too fast for conditions (13.2%), and inattention/distraction (12.5%). The main critical reason for drivers who were responsible in single-vehicle crashes was driving too fast for curve or turn (25.0%). Another 8.7% of these drivers were also traveling too fast for conditions. As a result, driving too fast for prevailing conditions accounted for more than one-third of all single-vehicle lane departure crashes. The next most critical reasons were "asleep" (14.7%) or "vehicle defect" (14.1%).

Large truck drivers responsible in multi-vehicle crashes were more likely to have been distracted by some internal or external event (15%) and were more likely to have been hurrying (10%) than drivers in single-vehicle crashes. Large truck drivers responsible in single-vehicle lane departure crashes were more likely to have been engaged in some aggressive behavior (13%), fatigued (33%), or upset (8%) than drivers responsible in multi-vehicle crashes.

Approximately 20% of large truck lane departure crashes for drivers responsible in single-vehicle crashes and 13% for drivers responsible in multi-vehicle crashes occurred on roadways with no paved shoulder. A horizontal curve was present for 65% of drivers responsible in a single-vehicle lane departure crash and for 26% of drivers in multi-vehicle crashes.

Twenty-four percent of large truck drivers responsible in a multi-vehicle lane departure crash were on wet roads, compared to drivers responsible in single-vehicle crashes (16%), while 3% for both categories of drivers were on roadways with snow, slush, or ice. Large truck drivers responsible in a single-vehicle lane departure crash were more likely to be traveling at night without street lighting (16%) than those drivers responsible in multi-vehicle crashes and were more likely than the drivers responsible in multi-vehicle crashes to be traveling at dusk or dawn (5%).

1.3. Highlights from Simple Odds Ratio

A simple odds ratio (OR) was used to calculate the odds for large truck drivers responsible in lane departure crashes as compared to non-responsible large truck drivers. Results of the simple odds ratio indicated that large truck drivers responsible in a single-vehicle lane departure crash were more likely to be in a crash in which a jackknife occurred (OR = 2.9), be fatigued (OR = 9.5), be upset (OR = 13.0), be unfamiliar with the roadway (OR = 2.1), be distracted (OR = 2.9), have a horizontal curve present (OR = 6.4), or have an up- or downgrade present (OR = 1.59). Large truck drivers responsible in a multi-vehicle lane departure crash were more likely to have a jackknife occur (OR = 3.1), be fatigued (OR = 4.6), be distracted (OR = 3.7), be in a work zone (OR = 4.4), or have congestion present (OR = 2.9) than non-responsible large truck drivers.

Odds ratios were also computed for large truck drivers responsible in single-vehicle lane departures as compared to large truck drivers responsible in multi-vehicle crashes. Single-vehicle responsible drivers were less likely to be in a crash where any drugs were involved (OR = 0.26), have flow restrictions due to a work zone (OR = 0.20), or have flow restrictions due to congestion (OR = 0.09) than large truck drivers responsible in multi-vehicle lane departure crashes. Single-vehicle responsible drivers were more likely to be fatigued (OR = 2.07); be upset (OR = 5.45); be driving at night, dawn, or dusk (OR = 2.97); have a curve present (OR = 5.43); or be on an up-grade or down-grade (OR = 1.65).

1.4. Highlights from Logistic Regression

Results of a logistic regression analysis indicated causal factors for large truck lane departure crashes that were similar to the factors indicated by the simple odds ratio. Results of the logistic regression indicated that large truck drivers responsible in a single-vehicle lane departure crash were less likely than large truck drivers not responsible in large truck lane departure crashes to be in a crash where any drugs were involved (OR = 0.41). They were more likely to have a cargo shift (OR = 10.0), experience a driver distraction (OR = 10.4), have a curve present (OR = 3.8), or be on a roadway with narrow shoulders. They were more likely to be on a freeway with four or fewer lanes than a two-lane roadway and were equally likely to be on a two-lane roadway, a freeway with more than four lanes, or a non-freeway multi-lane divided roadway. They were less likely to be on a non-freeway multi-lane undivided roadway than a two-lane roadway.

Results of the logistic regression indicated that large-truck drivers responsible in a multi-vehicle lane departure crash were more likely than non-responsible large truck drivers to be distracted (OR= 5.4). They were more likely to be on a freeway with more than four lanes than on a two-lane roadway (OR = 3.2). They were as equally likely as non-responsible drivers to be on a two-lane roadway, a freeway with four or fewer lanes, a non-freeway multi-lane divided roadway, or a non-freeway multi-lane undivided roadway. They were less likely to be driving at nighttime, dawn, or dusk than during the daytime (OR = 0.28).

2. BACKGROUND AND OBJECTIVES

The following sections summarize the results of a literature review that was designed to determine the magnitude and causes of large truck lane departure crashes. The terms "large truck" and "truck" are used synonymously throughout the report and refer to large commercial vehicles. These vehicles are also frequently referred to in the literature as "heavy trucks," but the term "large truck" was used for consistency throughout this report.

2.1. General Information about Truck Lane Departure Crashes

Lane departure crashes account for a significant number of motor vehicle crashes and fatalities. LeBlanc et al. (2006) estimated that road departure crashes account for 15,000 fatalities per year in the United States, and other sources estimate that run-off-road (ROR) crashes account for up to 42% of fatalities (Neuman et al. 2003; UMTRI 2006). Understanding the causes and events that lead to lane departure crashes is important for selecting the appropriate countermeasures. This understanding is especially important for large truck crashes because many countermeasures are geared towards passenger vehicles, and a better understanding of the factors leading to lane departures for large trucks improves the selection and application of countermeasures that are appropriate to both types of vehicles.

Information specific to lane departure crashes for large trucks is difficult to obtain. Lane departure crashes often fall under the category of non-collisions or single-vehicle crashes. Past research suggests that 25% of truck crashes each year are non-collisions (Chira-Chavala 1986), and large trucks are more likely to be involved in single-vehicle accidents than passenger vehicles (Polus 1985). The combination of ROR and single-vehicle crashes accounts for 20% of all fatal truck crashes (Spainhour et al. 2005). Most ROR crashes involve a loss of control, whether evasive action, fatigue, or speed too high for conditions (Spainhour et al. 2005). Other possible factors include avoiding a vehicle, object, or animal in the travel lane; inattentive driving due to distraction, fatigue, sleep, or drug use; pavement surface conditions due to weather; and traveling too fast through a curve or down a grade (Neuman et al. 2003).

Spainhour et al. (2005) evaluated the causes and factors for large truck fatal crashes. The study was prompted by the high number of highway fatalities in Florida. In 1999, Florida had 40% more fatalities per vehicle mile than the national average, and the percentage of fatalities involving heavy trucks was twice the percentage of fatalities involving passenger cars. The researchers also found that ROR and single-vehicle crashes accounted for 20% of all fatal truck crashes. When comparing large truck crashes to total crashes, however, they found that trucks were less likely than other vehicles to be involved in ROR crashes. Eight percent of large truck fatal crashes were right roadside departure or right roadside departure with loss of control, while 19% of other crashes fit into that category. A total of 10% of fatal truck crashes were left roadside departure or left roadside departure with loss of control, compared to 16% for other vehicles. The study concluded that trucks were at fault in only 30% of the fatal crashes in which they were involved, but were most likely to be at fault in rear-end, run-off- road, and intersection turning crashes.

Agent and Pigman (2002) compared crashes involving trucks on Interstates to all crashes on Interstates. They found that the percentage of single-vehicle crashes was lower for trucks and that trucks were more likely to be involved in a same-direction sideswipe with another truck. Trucks were also more likely to be involved in a crash with another motor vehicle.

2.2. Factors for Lane Departure and Large truck Crashes

The following sections summarize information about the factors related to lane departure crashes. The information is arranged by factor. Many cases studies report factors related to lane departures for all vehicles without breaking the data out by vehicle type. In some cases, information that applies to all large truck crashes is presented without indicating type of crash. Since all the information was relevant, it is included in the following sections. An attempt was made to note when the data applied to all vehicles or just large trucks or when the information applied to all types of large vehicle crashes.

2.2.1. Driver and Trip Factors

Very little information was available about trip factors for large truck crashes. In one study, however, Agent and Pigman (2002) compared Interstate truck crashes to total Interstate crashes and found that on weekends there was a lower percentage of fatal truck crashes than all fatal crashes, indicating that trucks were less likely to be involved in fatal crashes on weekends.

A number of studies have demonstrated that driver-related factors contribute to truck crashes. Driver experience is a stronger indicator than driver age, with crash rates dropping significantly when experience is greater than four years (Chira-Chavala 1985). Drivers under the age of 21 have a crash rate approximately five times greater than that of the average driver (Steiff 1990). Driver familiarity is also significant. One study found that the majority of crashes occur on roadways that drivers know very well (Gander et al. 2006). The same study found that as driver familiarity decreases, so does the number of crashes (Gander et al. 2006). However, this is likely to be related to exposure. Single drivers are more likely to be distracted than team drivers (Hanowski et al. 2005).

Chira-Chavala (1986) applied discrete multivariate analysis to the Bureau of Motor Carrier Safety (BMCS) and Highway Cost Allocation Study (HCAS) data sets. The BMCS data set includes 74 variables and over 30,000 crashes every year. The HCAS data set includes 96 variables from questionnaires completed by truck operators selected by a stratified random sample. The study used two separate methods: a causal model (accident-involvement model) and deductive modeling. Trip length was identified as a causal variable. Over-the-road service showed considerably lower crash rates than local service.

Deductive modeling was used to assess the influence of variables not included in the data sets. This allowed the researchers to consider additional variables of interest, including driver experience and age. Driver experience was found to be a stronger indicator of crash rate than age. Drivers with more than four years of experience showed significantly lower crash rates than those with one year of experience. When driver age was considered as a variable, drivers younger than 30 or older than 45 years old showed higher crash rates than drivers between the ages of 30 to 45 years old. This information is for all truck crashes, not just ROR (Chira-Chavala 1986).

A study by Spainhour et al. (2005) reported human factors as the most common contributing factors in truck crashes when the truck was found to be at fault. Inattention was listed as a contributing factor (primary or other) in over 50% of crashes where a large truck was at fault. Decision errors were the primary contributing factor (12%) of crashes, followed by speed (9%). Alcohol and fatigue were also common contributing factors.

Hanowski et al. (2005) evaluated critical events, which include crashes, near-crashes, and crash-relevant conflicts. Crash-relevant conflicts involve a safety risk but do not require an evasive maneuver. The main objective of the study was to use a naturalistic approach to study driver distraction. Driver distraction occurs when "inattention leads to a delay in the recognition of information that is necessary to accomplish the driving task safely." The study used two tractors equipped to videotape and record essential data. Forty-one long-haul truck drivers used the tractors for a total of 140,000 miles and experienced a total of 2,737 critical incidents. Judgment error was the most common cause, contributing to 77% of all events. Other vehicles were deemed responsible for 9.7% of events, and 6.5% of event were attributed to driver distraction. Single drivers were more likely (64.6%) to be distracted than team drivers.

Driver fatigue or drowsiness has also been reported as a common contributing factor in large truck crashes. All of the studies that discuss driver fatigue or drowsiness are for all truck crashes, not just lane departure. In one study, TranSafety (1998) reported on a survey used to obtain a more comprehensive picture of the link between driver fatigue and large truck crashes. The survey interviewed truckers regarding work and rest patterns. They found that nearly two-thirds of drivers reported episodes of drowsy driving within the past month, while almost 5% reported episodes of drowsy driving on most, if not all, days. Almost half admitted to having fallen asleep at the wheel at least once ever, and about 25% reported having fallen asleep at the wheel at least once during the past year. The survey also indicated that almost 20% of drivers reported that they always or often exceed the 10-hour driving limit in the Federal Highway Administration hours-of-service (HOS) regulations. Almost 20% are regularly off-duty for fewer than 8 hours, and just over 21% drive longer than their records indicate.

McCartt et al. (2000) conducted face-to-face interviews with 593 long-distance truck drivers who were randomly selected at rest areas and truck safety inspection stations that travel New York's in-state roadways. A total of 47.1% of long-distance drivers reported that they had ever fallen asleep at the wheel, while 25.4% reported having fallen asleep during the past year. The authors conducted a multivariate logistic regression and found six independent factors that were predictive of self-reported falling asleep at the wheel. These factors include greater daytime sleepiness, more hours of work and fewer hours off duty, older and more experienced drivers, shorter and poorer sleep on the road, symptoms of sleep disorder, and greater tendency for nighttime drowsy driving.

Haworth et al. (1989) evaluated coroner reports in fatal crashes to determine the degree to which fatigue was involved in fatal crashes involving a large truck. The researchers found that the coroner had indicated fatigue was a contributing factor in 9.1% of the crashes evaluated. The researchers estimated that fatigue was prevalent in 5.4% of crashes for car drivers and 3.7% for truck drivers.

Haworth et al. (1989) also evaluated other factors related to fatigue, which included extended driving hours, evidence of falling asleep at the wheel, comments about tiredness, driving right of the center in the absence of an elevated blood alcohol level, and nighttime driving. Including these factors as fatigue-related, the authors concluded that fatigue was a factor in 19.9% of the fatal crashes evaluated. Car driver fatigue was a factor in 12.4%, and truck driver fatigue was a factor in 7.6% of fatal crashes that involved a truck.

Gander et al. (2006) used anonymous surveys to investigate the role of driver fatigue in truck crashes in New Zealand. Study packages, including a questionnaire, were given to drivers involved in truck crashes by the police officers who attend each crash. Once the questionnaires were returned, they were matched with official truck crash reports. Only those that could be successfully matched were used for the study. The results from their study were compared to statistics measured from the general population of New Zealand and to comparable crash data from the United States. The study found that the drivers reported "better sleep and less sleepiness" than the general population. When compared to the United States crash data, New Zealand data indicated that a significant number of New Zealand drivers involved in crashes had less total sleep in the 24 and 48 hour periods before the crash. Overall, 17.6% of crashes were deemed fatigue-related.

Massie et al. (1997) evaluated short-haul truck crashes in the United States. The authors created a definition of short-haul trucks and examined the prevalence of driver fatigue as it relates to short-haul trucking using three data sources: travel data from the 1992 Truck Inventory and Use Survey, crash statistics from the 1991 to 1993 Trucks Involved in Fatal Accidents File, and 1995 SafetyNet data. The authors found that fatigue was coded as a factor in 1.9% of fatal truck crashes and in 1.3% of personal injury or tow-away crashes. Seventy one percent of fatal fatigue-related crashes were single-vehicle crashes, and roll-over and fixed object crashes were common types of fatigue-related fatal crashes. The authors found a peak in fatal crash involvements from 4 a.m. to 7 a.m. and a peak from 3 a.m. to 7 a.m. for less severe involvements. They also found that driver fatigue-related non-fatal crashes peaked from 3 a.m. to 7 a.m. The authors also found that medium- and large-duty trucks were equally involved in fatigue-related crashes. They also found that driver fatigue was indicated as a factor for only 0.4% of truck crashes when the trip was 50 miles or less and 3.0% of truck crashes when the trip was greater than 50 miles.

Knipling and Wang (1994) summarized information from the National Highway Traffic Safety Administration (NHTSA) General Estimates System (GES) from 1989 to 1993 and the Fatal Accident Reporting System (FARS) about the number and types of crashes that involve driver fatigue, drowsiness, or "asleep at the wheel." For all vehicles, the authors found that approximately 1% of crashes have driver drowsiness or fatigue indicated on the crash report.

Several of the studies reviewed in this research indicated that it is difficult to determine the extent to which drowsiness and fatigue contribute to a crash because states do not uniformly report drowsiness/fatigue, it is difficult for an officer to determine whether fatigue is a factor, and drivers themselves may not be aware that fatigue or drowsiness plays a role.

Knipling and Wang (1994) evaluated 182 fatal large truck crashes and reported that 31% of the crashes were related to fatigue. The authors also cited results from the NHTSA, which indicated that a driver being inattentive, drowsy, or asleep was the major factor in 31.5% of combination-unit and single-unit truck crashes that were single-vehicle road departure crashes. The authors use the terms “driver fatigue,” “drowsiness,” or “asleep at the wheel” synonymously. They estimate that when exposure is considered, combination-unit truck drivers were 4.5 times more likely to be involved in a drowsy driver crash than passenger vehicle drivers, and the fatality-to-crash ratio is 1.7 times greater for combination truck drivers than for passenger vehicle drivers.

Agent and Pigman (2002), in their study of Interstate crashes mentioned above, found that trucks were more likely than all vehicles to be involved in a crash that involved failure to yield and misjudging clearance. Additionally, a lower percentage of trucks had a contributing factor of following too close, speeding, or alcohol. Truck crashes were also more likely than other crashes to involve driver inattention and weaving in traffic as a contributing factor.

As described above, Spainhour et al. (2005) evaluated 600 crashes in Florida that involved large trucks. The authors found that trucks were at fault in 178 of the 600 crashes. Of those, trucks were at fault in 43 ROR crashes. The authors found that the common critical factors included the following:

- Evasive action due to slow/stopped traffic (16.3%)
- Fatigue or falling asleep (14%)
- Loss of control for unknown reason (11.6%)
- Loss of control—unsafe speed for conditions (9%)
- Failed to negotiate curve (7%)
- Incapacitation due to medical condition (7%)
- Incapacitation due to alcohol or drugs (7%)
- Evasive action due to vehicle intrusion on travel lane (5%)
- Vehicle defect (5%)
- Tire blowout (5%)
- Loss of control—load shift (5%)
- Drift-off-road—overcorrect (5%)
- Evasive action due to obstruction (2%)
- Jackknife—excessive braking (2%)

2.2.2. Vehicle Factors

Like driver and trip factors, vehicle factors are an indicator for truck crashes. A relationship between truck weight and involvement in fatal crashes has also been identified. As truck weight increases, involvement in fatal crashes also increases (Polus 1985). Mechanical errors are not frequently cited as causal factors, but these may be influential as secondary factors.

Chira-Chavala (1986), as described above, applied discrete multivariate analysis to the BMCS and HCAS data sets. The study included a causal model, which explored the relationship between various independent variables and the probability of a crash. Five variables were identified as compatible between the two data sets: vehicle configuration, trailer body style, number of axles of power, model year, and trip length.

Agent and Pigman (2002), in their Interstate crash study, found that trucks were more likely to experience problems with the vehicle, such as brakes, load securement, and oversize load, than vehicles involved in non-truck crashes.

Spainhour et al. (2005) summarized results from 43 ROR crashes in Florida in which a truck was at fault. The authors found that the common critical vehicle factors included the following:

- Vehicle defect (5%)
- Tire blowout (5%)
- Loss of control—load shift (5%)

2.2.3. Roadway Factors

As indicators for truck crashes, roadway factors are the focus of many studies. One of the most significant variables in these studies is location: urban versus rural. Urban roads generally have higher crash rates than rural roads. This difference reflects the higher traffic volumes on urban roads but also the different road type. In terms of other locations, large trucks are more likely to be involved in crashes of all severity levels on Interstates than on other roads (Agent and Pigman 2002), while limited-access highways are the safest road type and are four times safer than other highways (Steiff 1990). Vallette et al. (1981) found that 16% of truck crashes occur at interchanges, and between 40% and 50% of fatal crashes happen on straight and level road sections (Garber and Joshua 1989). Side-slope also has a significant effect on crash rates, with steeper side-slopes having higher rates of single-vehicle crashes than flatter side-slopes (Zeeger et al. 1988).

Daniel and Chien (2003) evaluated truck crashes in New Jersey to identify statistically significant factors that contribute to truck crashes. The authors found that single-vehicle truck crashes are more likely than multi-vehicle truck crashes to occur on a curve or grade. The authors also found that ROR crashes were indicated as an event in 40% of truck crashes.

Chira-Chavala (1986) identified possible causes of combination-truck accidents that result from loss of control and identified roadway factors among these causes. They evaluated four types of crashes (jackknife, overturn, ROR, and separation of unit) and found that ten variables play a significant role in the severity of these types of crashes. Roadway variables included road class and whether the crash occurred on a ramp.

Spainhour et al. (2005) reported that about 30% of fatal truck crashes occur on four- to five-lane highways and that about 30% of fatal truck crashes occur on limited-access facilities. The authors also summarized truck crashes by geographic area and found that the following percentage of crashes occurred by facility:

- Rural 55%
- Urban 25%
- Suburban 20%

Some driver-related factors also involve roadway characteristics. Ninety-eight percent of driver error–related fatal crashes occur on curves (Garber and Joshua 1989).

Agent and Pigman (2002), in their Interstate crash study, found that the percent of truck crashes on curves was slightly lower than it was for other vehicles. Additionally, trucks were much less likely to be involved in a fixed object crash or in a crash on a ramp, and trucks were more likely to be involved in a crash in a construction zone.

2.2.4. Environmental Factors

Environmental factors can also play a role in large truck crashes. Maze et al. (2006) evaluated crash data between 1996 and 2005 and found that large trucks represent a higher percentage of the traffic stream during snowstorms than they do on clear days. The authors also reported that, on Iowa's rural Interstates roads, large trucks were involved in 6% of total crashes but were involved in 12% of crashes when the responding officer indicated that the roadway was snow or ice covered.

Maze et al. (2006) also evaluated winter weather–related crashes in terms of severity and roadway type. In Iowa, all U.S., state, and Interstate routes are primary highways. Table 2-1 shows the percentages of all winter weather–related crashes that occurred during the winter weather season (between October 15 and April 15) by crash severity and by roadway type. Results are shown for all vehicles. The category for urban Interstates and freeways includes multi-lane and access-controlled highways. As shown, 26% of all crashes in Iowa during the winter weather season involved winter weather. In both urban and rural areas, higher design standard facilities (Interstates and freeways) experience higher percentages of crashes (36% and 45%, respectively) and higher percentages of fatal and major injury crashes during winter weather than two-lane facilities. Although the actual reasons for this are unknown, Maze et al. (2006) speculated that higher design standard facilities and less congested facilities (rural roads) provide drivers more opportunity to drive at speeds that are unsafe for the conditions.

Table 2-1. Rural versus urban versus road type winter weather crash severity (Maze et al. 2006)

Crash Severity	Urban Primary			Rural Primary		
	Interstate /Freeway	Two-lane	Overall	Interstate / Freeway	Two-lane	Overall
All	36%	25%	26%	45%	26%	31%
Fatal	21%	19%	18%	38%	34%	33%
Major Injury	34%	25%	23%	52%	35%	39%

Chira-Chavala (1986), identifying the possible causes of combination-truck accidents that result from loss of control, examined environmental variables. The authors evaluated four types of crashes (jackknife, overturn, ROR, and separation of unit_ and found that 10 variables play a significant role in the severity of these types of crashes. The environmental variables included whether it was daytime or nighttime and whether the pavement was wet or dry.

Spainhour et al. (2005) reported that the most common environmental factor in large truck fatal crashes is weather. The authors also found that 67.8% of truck crashes occur in clear weather, 87.3% of truck crashes occur on dry roads, and 51.7% of truck crashes occur in the daytime.

Probably the most dramatic findings of increased crash rates under poor environmental conditions were those found by Khattak et al. (2001). The authors compared crash rates on Interstate highways for periods when more than 0.2 in. of snow fell per hour to crash rates during clear conditions in the same time period, on the same day of the week, and during the same month. By comparing crash rates during non-snow and snow periods in this way, the researchers hoped to reduce the impact of seasonal and weekly variations on their findings. They gathered data across 54 snowstorms and found a storm crash rate of 5.86 crashes per million vehicle kilometers on rural Interstate highways. During non-storm periods, the crash rate was 0.41 crashes per million vehicle kilometers. That is, the crash rate increased by 13 times during snowy weather. The authors went on to estimate a Poisson model in which the dependent variable was the probability of the observed number of crashes and the independent variables were the characteristics of the storm (snowfall intensity, wind speed, etc.). The authors found that snowfall duration and intensity have a positive and statistically significant relationship to the number of crashes.

Agent and Pigman (2002), in their Interstate crash study, found that the percent of truck crashes on a wet or snowy surface was lower than it was for all crashes. The authors also reported that trucks were slightly more likely to be involved in a crash at night when no roadway lighting was present and that fatal truck crashes were less likely on a wet or snowy surface.

However, other studies have not found the same relationship between weather and truck crashes. Garber and Joshua (1989) have suggested that large truck crashes are evenly distributed throughout all months of the year and that seasonal effects did not significantly affect large truck crashes.

As some of the studies described above have already indicated, time of day is also an environmental factor. When this variable is added to road type, Stieff (1990) has found, nighttime driving on non-limited access highways in rural areas has the highest crash rate.

Daniel and Chien (2003), in their evaluation of truck crashes from 1998 to 2000 in New Jersey, found that most truck crashes occur in daylight conditions. However, 18% of single-vehicle truck crashes occur during dark conditions, compared to 14% of multi-vehicle crashes. The authors also found that a smaller percentage of fatal truck crashes occurred at night, compared to all fatal crashes, and fatal truck crashes were more likely to involve a collision with a non-fixed object (87.8% for fatal truck crashes versus 64.4% for all crashes).

Agent and Pigman (2002), in their comparison of Interstates crashes, found that trucks were slightly more likely than all traffic to be involved in a crash at night when no roadway lighting was present.

2.3. Project Objectives

The objective of the present study was to investigate the causes of lane departure crashes for large trucks. Data from the Federal Motor Carrier Safety Association's (FMCSA's) Large truck Crash Causation Study (LTCCS) Database were evaluated to determine both the common causes and the circumstances leading to large truck lane departure crashes. Causes and circumstances may include driver, vehicle, roadway, and environmental factors, as described in the literature review above.

The LTCCS data are especially useful for this type of analysis since they provide a large amount of information about the physical events of each crash, as well as vehicle, driver, weather, and roadway condition information. The data also focus on pre-crash events so that reasons for crashes can be determined and corresponding countermeasures can be considered.

This research evaluated the large truck lane departure crashes and their related independent variables and attempted to derive causal relationships that could be used to identify preventative measures for reducing large truck lane departure crashes.

3. DESCRIPTION OF LTCCS DATA

One of the primary goals of the LTCCS has been to increase knowledge about truck crash factors by making data available for analysis by universities, private groups, government agencies, and individuals. To create the LTCCS data set, the FMCSA and the NHTSA jointly collected a sample of injury and fatal large truck crashes that occurred between April 2001 and December 2003. A total of 963 crashes were included in the sample (FMCSA 2007). Over 1,000 data elements were collected for each crash, including information about drivers, vehicles, and weather conditions. The study also included detailed descriptions of each crash. The resulting LTCCS data set is a nationally representative sample of all injury and fatal large truck crashes. It is the only national study that examines all factors relevant to the causation of large truck crashes (USDOT 2006).

LTCCS data were collected at 24 data collection sites in 17 states by researchers from NHTSA's National Automotive Sampling System (NASS), as well as by NHTSA's state truck inspectors. Crashes were included if they involved at least one fatality, an incapacitating injury, or non-incapacitating injury between April 2001 and December 2003 (Blower et al. 2005). A dataset of over 1,000 injury and fatal crashes that involved at least one large truck (gross vehicle weight regulation of 1,000 lbs or more) resulted.

Concerns have been raised about the completeness of the LTCCS database, specifically the lack of causal inference and the accuracy of information. It has been suggested that field staff who collected the data lacked the authority to "compel accurate testimony" from those involved in the crashes (McKnight 2004). Another concern is that staff members were not encouraged to make causal inferences, instead relying on witness testimony and physical evidence (McKnight 2004). Because the LTCCS focused on causation factors, both of these criticisms are relevant. However, the LTCCS data set is by far the most complete of its kind and provides the best picture of truck crashes on a national level.

4. DATA HANDLING

The LTCCS data were used determine roadway, environmental, driver, and vehicle factors that are associated with large truck lane departure crashes. In order to accomplish this, lane departure crashes were defined and then a methodology was determined for extracting data from the numerous data sets available in the LTCCS data. The data were evaluated by driver/vehicle rather than crash so that driver and vehicle characteristics could be included in the analysis. A record was defined as a row of data containing information for one particular driver/vehicle in a crash. Once drivers/vehicles involved in lane departure crashes were identified, relevant independent variables were extracted for each record. The researchers also decided that it was important to evaluate the factors according to whether a driver/vehicle was the most responsible for the crash. Consequently, a method for assigning responsibility was determined. Finally, a single data set that included all of the relevant data for the analysis was created. The following sections describe each of the data handling steps.

The LTCCS database contains data for different vehicles, including vehicles other than large trucks, that were involved in large truck crashes. As a result, large trucks had to be identified. A large truck was defined as "GVEVehicleClass" codes 60 to 79, which included medium- and large-duty trucks. Buses made up only a very small number of large vehicles in the LTSCCS database and were not included in the analysis.

4.1. Extraction of Lane Departures

Because the focus of the study was lane departure crashes, it was important to define what is meant by lane departure or ROR. ROR crashes are a subset of lane departure, so ROR crashes will be defined before the more generic lane departure crashes are defined.

A ROR crash is frequently defined as one in which the first or most harmful event occurs off the roadway. Campbell et al. (2003) define a ROR crash as one in which a single vehicle leaves the traveled lanes and encroaches upon the shoulder, median, or roadside and either collides with an object, overturns, or both. Pomerleau et al. (1999) define a road departure crash as any single-vehicle crash where the first harmful event occurs off the roadway, except for backing and pedestrian crashes. Najm et al. (2002) define an off-roadway crash as one in which the first harmful event happens off the roadway. Off-roadway locations include the shoulder or parking lane, median, channel island, or any other location that is not within a travel lane. LeBlanc et al. (2006) also define a road departure crash as any crash in which the first harmful event occurs off the roadway.

The above definitions may be restrictive because they are limited to crashes where the first or most harmful event happened off the roadway. However, the main purpose of evaluating ROR crashes is to determine the factors that lead to a vehicle leaving the roadway so that countermeasures can be considered to prevent the road departure. Consider the situation where a vehicle leaves the roadway and, as it returns to the roadway, loses control, resulting in a head-on or sideswipe collision, as shown in Figure 4-1. Some characteristic of the roadside (e.g., edge drop-off or loose shoulder material) may have been a main contributor to the crash, and countermeasures such as edgeline rumble strips or paved shoulders may have prevented the crash. However, in this situation the first or most harmful event did not occur off the traveled way, so according some definitions the crash would not be considered to be ROR.

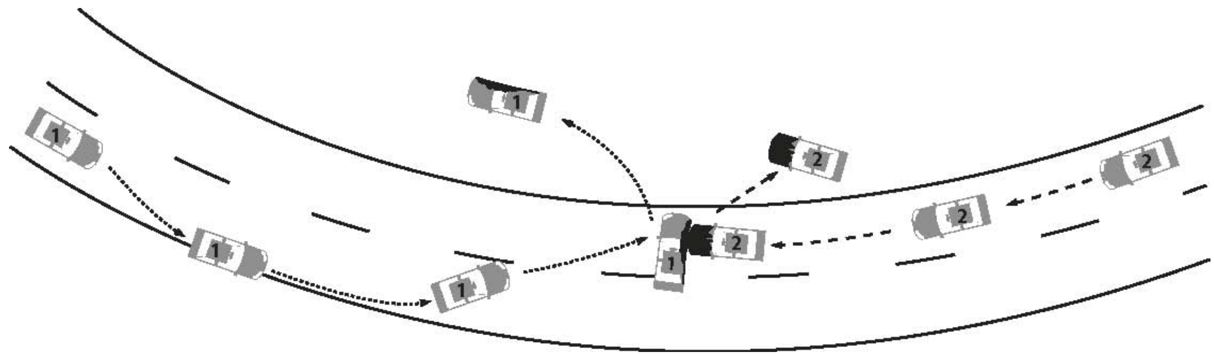


Figure 4-1. Crash diagram showing series of actions leading to a ROR crash (first action is run-off-road, followed by loss of control, and then a head-on collision with another vehicle). Note that the most harmful event does not occur off the roadway.

After careful consideration of the goals of this research, ROR was defined for the purposes of this study as a vehicle inadvertently leaving the roadway at some point in the crash sequence. Lane departure was defined as a vehicle advertently (such as a vehicle steering out of its lane to avoid another vehicle during the crash envelop) or inadvertently leaving its lane during the crash sequence. Lane departures were further defined by the action leading to the lane departure, according to the reason the vehicle initially left its original travel lane during the crash envelope, and were defined according to the categories described below (each is mutually exclusive). The type of lane departure that occurred was also included as the variable "ROR_Type" in the researchers' data. Large trucks were considered lane departures and grouped according to the following categories:

- **Unintentional lane departure.** This category included situations in which the vehicle unintentionally left the lane or roadway (e.g., driver fell asleep or lost control on curve) on its own. The category also includes lane departures in which the vehicle was forced out of its original travel lane due to the force of impact with another vehicle (e.g., vehicle was struck from behind and was forced into the median barrier).
- **Intentional lane departure.** This category includes lane departures in which the driver intentionally left his/her original lane of travel, which resulted in a crash. This was typically an intentional merge or lane change (e.g., driver changed lanes and sideswiped another vehicle). The category also includes situations in which the driver initiated a lane change, steered left, or steered right as an evasive maneuver during a crash.

Crashes in which the vehicle did not leave its lane during the crash envelope but pulled over to the shoulder or adjacent lane to get out of the way after the end of the crash sequence were not included as lane departures. Instances in which the vehicle was parked or stalled off the roadway before the crash envelope started were also not included as lane departures.

In order to determine crashes in which a large truck lane departure occurred, the narrative for each of the 1,070 crashes in the LTCSS database was reviewed. Each driver/vehicle record for which the vehicle fell into one of the lane departure categories listed above was extracted from the crash database. A total of 506 large trucks were involved in lane departures. Each driver/vehicle record was assigned to one of the lane departure categories described above.

It was noted during the course of evaluating crash narratives that medical conditions were occasionally the main contributors to a lane departure. In particular, some crash envelopes were initiated because the driver had a heart attack, resulting in the vehicle leaving the roadway, drifting from its lane, etc. However, the main goal of the research was to determine causal factors so that agencies can better apply policies and countermeasures to mitigate large truck lane departures. A crash that results from a severe medical condition is rare and cannot be addressed by normal countermeasures. As a result, it was decided not to include crashes for which the main factor in the crash was the driver suffering from a severe medical condition. For instance, in several cases the driver had a heart attack and died, resulting in a lane or roadway departure. In such cases, even a forgiving roadside would not have mitigated the outcome. Contribution of severe medical condition was determined by reviewing the crash narrative and main cause assigned by the field staff worker who collected information for a particular crash. Vehicle/driver records for which the staff worker assigned the immediate reason for the crash to the vehicle/driver in question and for which the critical reason for the crash was indicated as "heart attack or other physical impairment of the ability to act" were removed from the analysis.

4.2. Extraction of Independent Variables

The previous two steps resulted in an initial database with large truck driver/vehicle records for which it was determined that the large truck was involved in a lane departure. The next step was to extract independent variables to be included in the analysis.

Factors that are likely to contribute to large truck lane departures were determined from a literature review, which is summarized in Section 2.2 of this report. Factors were also identified based on the research team's experience. The LTCCS database has 43 associated datasets, available to the public, containing over 750 variables. Variables include information about the crash, roadway, vehicle, driver, occupants, etc. Many of the variables are highly correlated. For instance, there are at least 10 variables that provide information on whether drugs were involved in a crash, including type of drug, whether the driver was given a drug test, etc. When multiple variables were available for a factor of interest, the one that best provided the information desired was selected.

Each driver/vehicle record was uniquely identified in the LTCCS datasets using the variables "CaseID" and "VehicleNumber." Data were extracted from the various datasets using a relational database. A total of 33 variables were included in the initial analysis, as shown in Table 4-1. Several variables were either created to include new information (e.g., ROR_Type) or were combined to reflect data from several variables from the LTCCS database. For instance, the variable "Was_Hurrying" combined information about whether the driver was hurrying to work, was late for a business appointment, etc., into one variable that indicated whether the driver was hurrying or was late for some reason (0 if not hurrying, 1 if hurrying or late). The variable

"Was_Ill" indicated whether the driver had some type of illness prior to the crash, such as a cold, seizure, etc., but the study did not include records when the main cause of the crash was a major medical event. As a result, the information in this variable would indicate a driver having some type of illness that may have contributed to the crash but did not render the driver incapable of acting.

Table 4-1. Variables included in analysis

Name	Definition	Type
CaseID	Number used to identify the case (identifies the crash)	Numeric
CaseID_Vehicle	Number that uniquely identifies a particular vehicle in the crash	Numeric
ROR_Type	Type of lane departure event (described in Section 4.2 of this report)	Categorical
ACRJackknife	Indicates whether vehicle jackknifed	Categorical
ACRCargoshift	Indicates whether a cargo shift occurred for the vehicle	Categorical
CrashRESSevCode	Highest injury that occurs in the vehicle	Categorical
AlcoholUse	Indicates presence of alcohol for the driver	Categorical
DrugUse	Indicates results of a drug test given to the driver (positive, negative, or unknown)	Categorical
AnyDrugsCrash	Indicates whether any drugs (legal or illegal) were present or involved in the crash	Categorical
Fault	Indicates whether the driver was most responsible in a crash (described in Section 6.1 of this report)	Categorical
Fatigue	Indicates whether driver was fatigued at the time of the crash	Categorical
Upset	Indicates whether the driver was upset prior to the crash	Categorical
Was_Hurrying	Indicates whether the driver was hurrying or was late prior to the crash	Categorical
KnewVehicle	Indicates how familiar the driver was with the vehicle they were driving at the time of the crash	Categorical
KnewRoad	Indicates how familiar the driver was with the roadway	Categorical
AggressionCount	Total number of aggressive behaviors displayed by the driver during the crash envelope	Numerical
Was_Distracted	Indicates whether the driver was distracted by an interior or exterior factor	Categorical

Table 4-1. Variables included in analysis (continued)

Name	Definition	Type
Was_Ill	Indicates that driver had some illness prior to the crash envelop (e.g., diabetic blackout, cold) but did not include cases where the driver was rendered incapable	Categorical
Has_Vision	Indicates that driver had some type of vision limitation such as glaucoma, color blind, myopic, etc.	Categorical
HearingImpairment	Indicates whether a driver has been diagnosed with some type of hearing impairment	Categorical
HoursSinceSleep	Number of hours since the driver last slept prior to the crash	Numeric
HoursDriving	Number of hours the driver had been driving since their last break of eight hours	Numeric
FlowRestriction	Indicates whether there was some type of flow restriction present prior to the crash (e.g., work zone, prior crash, congestion)	Categorical
Daylight	Ambient conditions at the time of the crash (i.e., daylight, dark, dark but lighted, dawn, dusk, or unknown)	Categorical
RoadwayClass	Type of roadway (e.g., rural four-lane freeway, rural two-lane, urban freeway with more than four lanes)	Categorical
RoadAlignment	Roadway alignment (straight, curve, or unknown)	Categorical
RoadProfile	Roadway grade (e.g., level, uphill more than 2%, hill crest)	Categorical
RoadSurface	Type of roadway surface (e.g., concrete, asphalt, gravel)	Categorical
SurfaceCondition	Roadway surface condition prior to crash (e.g., dry, wet, snow, ice)	Categorical
ShoulderType	Type of shoulder present (e.g., no shoulder, concrete, asphalt)	Categorical
ShoulderWidth	Shoulder width (e.g., no shoulder, more than 1 meter, 1 to 2 meters)	Categorical
RumbleStrip	Presence of rumble strip (present or not present)	Categorical
Atmospheric	Atmospheric conditions prior to crash (e.g., dry, rain, snow)	Categorical
GVEPostedSpeed	Posted speed limit at crash location (km/hr)	Numerical
TotalCrashes	Number of DMV-reported crashes driver has been involved in for the past five years	Numerical
GVETotalViolations	Number of CMV and non-CMV violations received by driver in the last five years, as reported by the DMV	Numerical

5. ANALYSIS AND RESULTS

The final dataset used to evaluate large truck lane departures consisted of 505 records. Each record represents a single large truck/driver in a crash. A total of 33 variables were included, as described in the Section 4.3 of this report. The goal of the research was to determine which factors contributed to large truck lane departure crashes. Descriptive statistics, simple odds ratio, and a logistic regression analysis were used to evaluate the data, as described in the following sections.

The intent of the analysis was to assess why large trucks are involved in lane departure crashes. In order to accomplish this goal, it was necessary to have some measure of exposure specific to large trucks or large truck drivers. Volume data for the roadways where large truck crashes occurred, such as annual average daily traffic (AADT), were not included with the LTCCS data. Reliable exposure data specific to large trucks/drivers, such as vehicle miles traveled (VMT) for large trucks or number of licensed truck drivers, were also not available.

Additionally, some measure of exposure was necessary to determine whether a factor was over-represented. For example, if 25% of crashes involved truck drivers who were fatigued but 25% of truck drivers on the road are also fatigued, then truck drivers who are fatigued are no more likely to be involved in a crash than other drivers. However, if 40% of crashes involved truck drivers who were fatigued and only 25% of drivers on the road are fatigued, truck drivers who are tired appear to be more likely to be involved in a crash than other drivers.

One method that has been used to address lack of traffic volume as well as to evaluate whether a factor is over-represented is induced exposure. Induced exposure or quasi-induced exposure methods are used to evaluate the risk associated with specific factors, such as driver, roadway, environmental, or vehicle factors, when no direct measures of exposure are available (Lardelli-Claret et al. 2005).

Using this method, the number of drivers in a particular driver group for a particular situation can be determined and used as a measure of exposure. The method assigns “responsibility” or “fault” in multiple vehicle crashes. It assumes that drivers who were “not responsible” for the crash are randomly “chosen” from the population of drivers and the distribution of not at-fault drivers approximates the distribution of all drivers in that group. This distribution is then used to account for exposure. The quasi-induced exposure method uses drivers who are not responsible as controls. Risk can be assessed by comparing whether the factor appears more frequently in the population of responsible drivers than non-responsible drivers.

Quasi-induced exposure has been used by a number of researchers in crash analyses. Hing et al. (2003), for instance, used quasi-induced exposure to evaluate the effect of passengers, gender, time of crash, roadway curvature, road grade, and number of lanes, on older driver crash involvement. In that study, accident ratio was calculated by dividing the percentage of responsible drivers for both single- and multiple-vehicle crashes by the percentage of non-responsible drivers for a specific subgroup. Binary logistic regression was used to test significance. Lenguerrand et al. (2008) compared the standard case control approach to quasi-induced exposure to calculate whether drivers under the influence of alcohol or cannabis were at an increased risk of causing a fatal crash. Green and Woodroofe (2006) used induced exposure to evaluate the effect of electronic stability control on crashes involving loss of control for sport utility vehicles. The authors calculated the odds of a loss-of-control crash and used logistic regression to test the effect of surface condition. Stamatiadis et al. (1999) used the quasi-induced exposure method to calculate the relative accident involvement ratio for crashes on low-volume roads in Kentucky and North Carolina. The authors considered driver age, gender, vehicle type, and year and measured how those variables were affected by roadway factors, such as speed limit, shoulder width, lane width, curvature, and volume, for single-vehicle and two-vehicle crashes.

5.1. Assigning Responsibility

In the quasi-induced exposure method, responsibility for a crash is assigned in multiple-vehicle crashes. A basic requirement of the quasi-induced exposure method is that only one driver can be responsible in a crash (Hing et al. 2003). In many quasi-induced exposure models, only two-vehicle crashes (clean crashes) are included because assignment of fault is less clear in multiple-vehicle crashes (Hing et al. 2003). However, due to a limited sample size for the present study, it was decided to include all multiple-vehicle crashes. A random effects variable was used to account for the fact that more than one non-responsible vehicle/driver record was involved in the same crash in the logistic regression analysis described in Section 5.4 of this report. This was done to account for oversampling from crashes in which more than two vehicles were involved.

Responsibility was assigned for each crash that involved at least one large truck lane departure. Crashes for which fault could not be assigned to a single driver were not included. The crash narrative for each crash was reviewed, and the driver or vehicle that contributed the most significant error was noted. If a vehicle failure in the crash, such as failed brakes, was the main contributor to the crash, responsibility was assigned to that driver's vehicle. The LTCCS datasets contain a variable, "ACRReason," that establishes the critical reason for the occurrence of the critical event, which is the event which made the crash imminent. This variable does not assign fault but provides information about the crash. The driver or vehicle identified as the most responsible from a review of the crash narrative was compared to the "ACRReason" variable. In the majority of the cases, the driver/vehicle determined to be most responsible based on the crash narrative was also assigned the critical "ACRReason." When this was not the case, a decision was made as to which driver/vehicle was the most likely to have been responsible.

Each driver/vehicle was assigned to one of three categories, which were also used as dependent variables in the logistic regression. The categories were

- single-vehicle crash responsible,
- multiple-vehicle crash responsible, and
- multiple-vehicle crash not responsible.

A total of 173 driver/vehicle records that were determined to be not responsible, 149 were determined to be responsible in multi-vehicle crashes, and 183 were determined to be responsible in single-vehicle crashes.

5.2. Descriptive Statistics to Evaluate Large truck Lane Departure Crashes

This section provides simple descriptive statistics about large truck lane departure crashes which were identified in Section 4 of this report. Information is provided by driver/vehicle for a number of factors. The information provides simple descriptive statistics, and further analysis of the data is provided in Section 5.3 and 5.4 of this report. Data are presented for all large truck drivers involved in a lane departure crash, large truck drivers who were determined to be the most responsible in multi-vehicle lane departure crashes, and large truck drivers who were responsible in single-vehicle lane departure crashes. A total of 505 large truck drivers/vehicles were involved in a lane departure crash, so 505 records were available for each variable. When a data field was listed as unknown or was not recorded, it was not included in the analysis. For instance, the variable "Hurry" had a total of 380 records in which the driver was not indicated as being in a hurry, 24 records in which the driver was indicated as being in a hurry, and 102 records in which it was unknown whether the driver was hurrying. Records for which it was unknown whether the driver was hurrying were not included. As a result, it was known whether 404 drivers were hurrying. Of those, 24 were hurrying (5.9%) and 380 were not hurrying (94.1%).

5.2.1. Critical Reason for Crash

The critical reason variables that led to the events that made the crashes imminent are summarized in Tables 5-1 and 5-2. The critical reason was determined by LTCCS case reviewers using all available information, such as the police report, driver interviews, witness interviews, vehicle inspection results, etc. The critical reason does not assign fault for the crash. This information is provided for drivers who were determined to be the most responsible for the lane departure crash (single- and multi-vehicle). The category of all large truck drivers involved in a lane departure crash is not included because these drivers were not assigned the critical reason for the crash.

As indicated in Table 5-1, the most common critical reasons for drivers responsible in multi-vehicle crashes included inadequate surveillance (22.4%), driving too fast for conditions (13.2%), and inattention/distraction (12.5%), which includes inattention and external and internal distractions.

The main critical reason for drivers responsible in single-vehicle crashes was too fast for curve or turn (25.0%). Another 8.7% of these drivers were also classified as driving too fast for conditions. As a result, driving too fast for prevailing conditions accounted for more than one-third of single-vehicle lane departure crashes. The next most critical reasons were "asleep" (14.7%) or "vehicle defect" (14.1%).

Table 5-1. Critical reason for large truck drivers responsible in multi-vehicle crashes

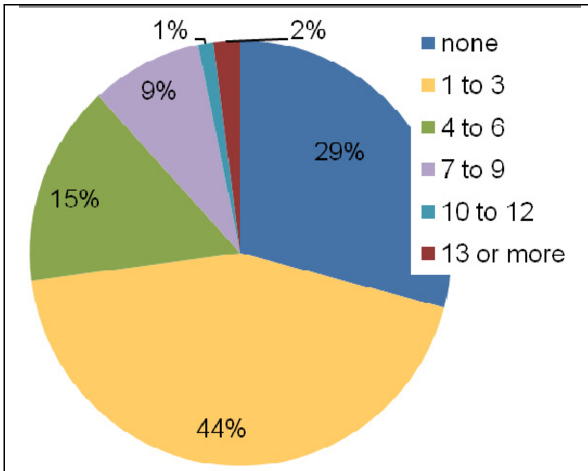
Critical reason	Percentage
Inadequate surveillance	22.4%
Too fast for conditions	13.2%
inattention/distraction	12.5%
unknown driver error	6.6%
vehicle defect	5.3%
unknown recognition error	4.6%
following too closely to respond to unexpected actions	4.6%
too fast for curve/turn	4.6%
overcompensation	3.9%
poor directional control	3.9%
misjudged gap or others speed	3.3%
degraded braking capability	3.3%
other	3.3%
inadequate evasive action	2.6%
asleep	2.0%
other/unknown decision error	1.3%
slick roads	1.3%
false assumption of other road users actions	0.7%
panic/freezing	0.7%

Table 5-2. Critical reason for large truck drivers responsible in single-vehicle crashes

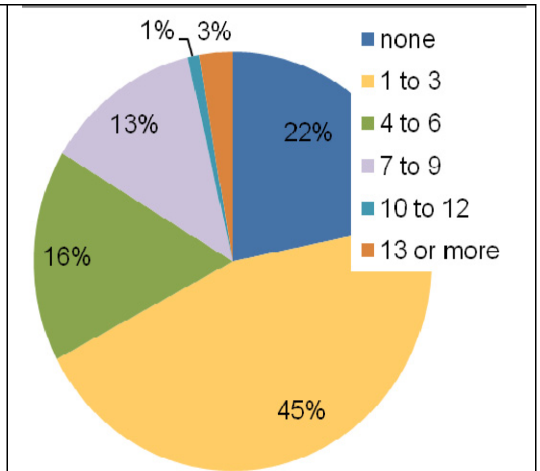
Critical reason	Percentage
too fast for curve/turn	25.0%
asleep	14.7%
vehicle defect	14.1%
too fast for conditions	8.7%
overcompensation	7.1%
poor directional control	6.5%
inattention/distraction	3.8%
unknown driver error	3.8%
slick roads	3.3%
other	2.7%
heart attack or other physical impairment of the ability to act	2.2%
other/unknown critical non-performance	1.6%
inadequate surveillance	1.6%
unknown recognition error	1.6%
aggressive driving behavior	1.6%
following too closely to respond to unexpected actions	1.1%
other decision error	1.1%
roadway	1.1%

5.2.2. Driver Characteristics

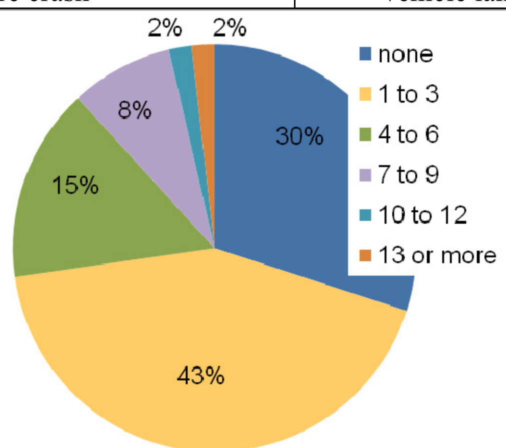
The following sections describe the characteristics of large truck drivers involved in lane departure crashes. Figure 5-1 shows the number of traffic violations received by a driver in the last five years before the crash occurred. These charts include both commercial and non-commercial vehicle violations. The percentage of drivers in the various violation ranges was similar for the three categories of drivers. Between 22% and 29% of drivers had received no violations, 43%–45% had received 1 to 3 violations, 15% or 16% had received 4 to 6 violations, 8% to 13% had received 7 to 9 violations, and 1% to 3% had received between 10 and 12 violations.



All large truck drivers involved in a lane departure crash



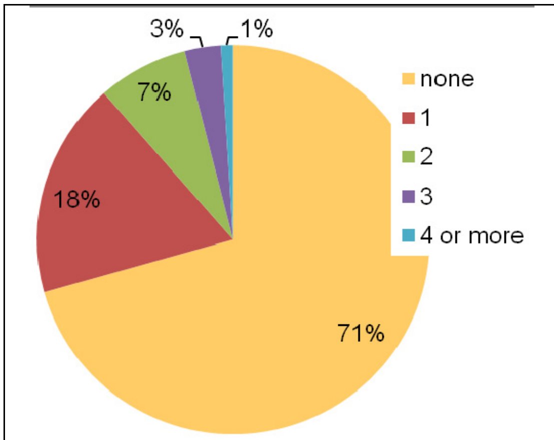
Large truck drivers responsible in multi-vehicle lane departure crashes



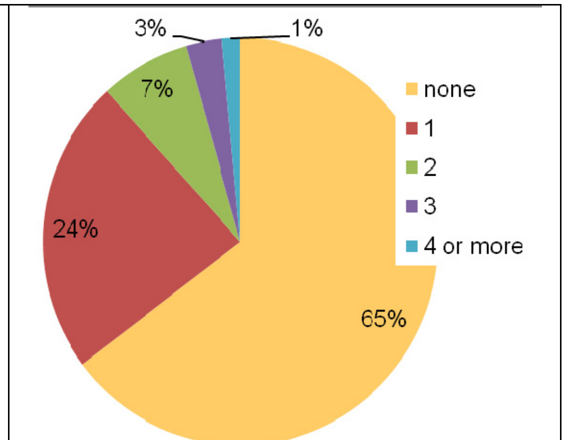
Large truck drivers responsible in single-vehicle lane departure crashes

Figure 5-1. Number of violations

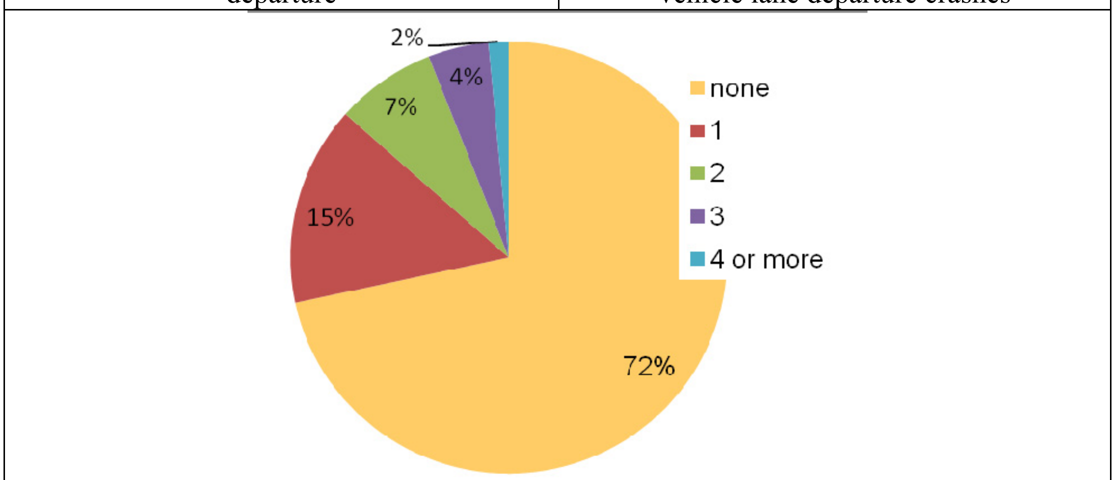
Figure 5-2 shows the number of crashes individual large truck drivers had been involved in for the five years previous to the crash. These charts include all crashes reported to a department of motor vehicles (DMV). All truck drivers and single-vehicle responsible drivers had similar percentages for having had no crash or one crash, while a slightly higher percentage of large truck drivers responsible in multi-vehicle lane departures had been involved in one crash and a slightly lower percentage of drivers had not been involved in a crash. A total of 7% of drivers for all three categories had been involved in two crashes, and 3% to 4% had been involved in three crashes. One to two percent of drivers had also been involved in four or more crashes.



All large truck drivers involved in a lane departure



Large truck drivers responsible in multi-vehicle lane departure crashes



Large truck drivers responsible in single-vehicle lane departure crashes

Figure 5-2. Number of crashes

Figure 5-3 provides a breakdown of the time that had elapsed between the crash and the time at which the large truck driver had awoken from his/her last sleep interval prior to the crash. As shown, the majority of drivers had been awake for 8 hours or less prior to the crash for all three categories of drivers, while around 20% had been awake for 9 to 12 hours for all three categories. Large truck drivers who were the responsible in single-vehicle crashes had the highest percentage of drivers (around 5%) who had gone 17 or more hours without sleep.

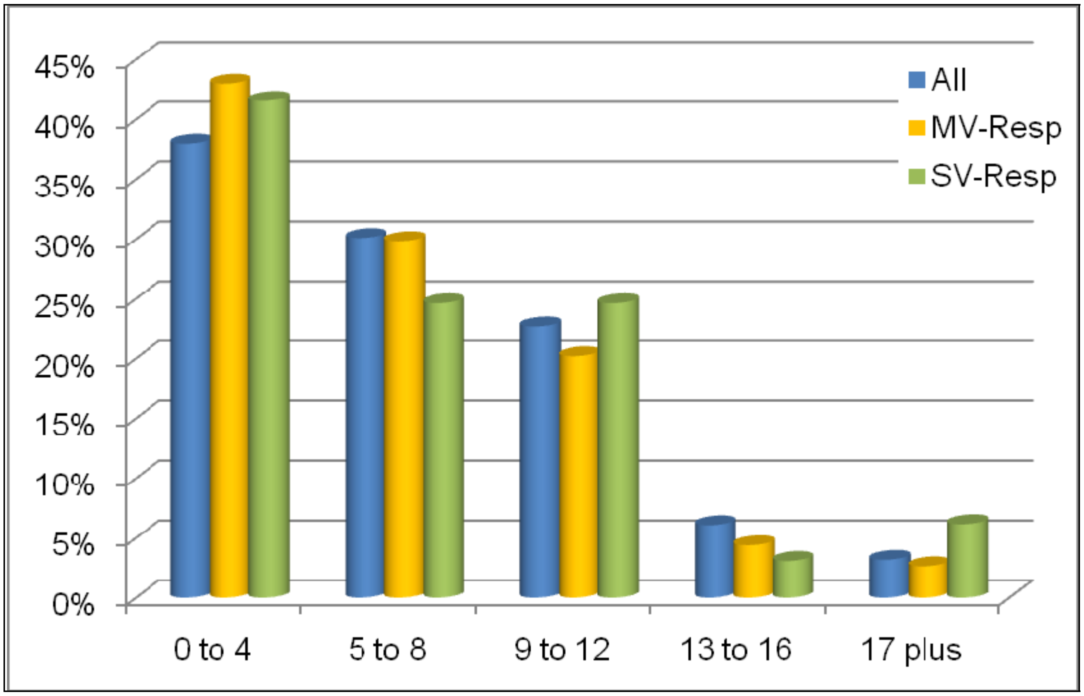


Figure 5-3. Hours since driver had slept prior to crash

Figure 5-4 shows the number of hours that large truck drivers had been driving prior to the crash. The majority of drivers for all three categories had been driving 8 hours or less prior to the crash, while 7% to 9% had been driving 9 to 12 hours. Large truck drivers who were responsible in multi-vehicle lane departure crashes were more likely to have been driving 13 or more hours than the other two categories of drivers (3% versus 1% or 2%).

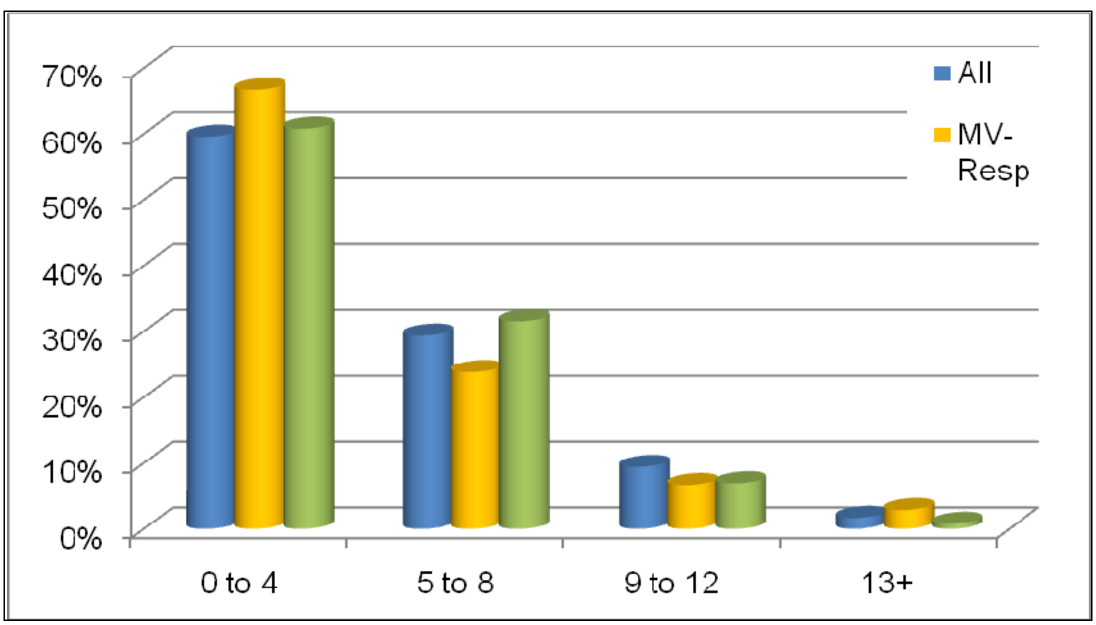


Figure 5-4. Hours driving

Several variables regarding driver factors are combined in Figure 5-5. The first set of columns shows the fraction of drivers who were indicated as being distracted by either an internal or external event prior to the crash. Internal distractions included whether the driver was distracted by occupants of the vehicle, dialing a phone, adjusting controls in the vehicle, retrieving an object from the floor or other location, or some other unspecified internal distraction. External distractions included the driver being distracted by a prior crash, by approaching traffic, while searching for a street address, by looking at a person or building outside the vehicle, or by some other unspecified distraction.

The second set of columns shows the percentage of drivers who exhibited one or more aggressive behaviors, including speeding, tailgating, weaving in and out of traffic, violating a red signal phase or stop sign, repeated accelerating/braking, honking the horn or flashing their lights, making obscene gestures, using their vehicle to physically obstruct another vehicle by pulling in front of the other vehicle, or engaging in some other unspecified aggressive behavior. The third set of columns indicates the percentage of drivers who were fatigued at the time of the crash. The fourth set of columns shows the percentage of drivers in each category who were indicated as being upset at the time of the crash due to a preceding argument with a spouse, family member, or other person; financial problems; family problems; or other unspecified problems. The last set of columns shows the percentage of drivers who were hurrying, which included hurrying due to a work-related schedule, being late for a business appointment, being late for a social appointment, being late for the start of work or a shift, hurrying as part of the driver's normal driving pattern, or hurrying due to some other unspecified reason. These categories are not mutually exclusive. For example, a driver could have been both distracted and fatigued.

As shown in Figure 5-5, large truck drivers who were responsible in multi-vehicle lane departure crashes were more likely to have been distracted by some internal or external event (15%) and were more likely to have been hurrying (10%) than the other two categories of drivers. Drivers responsible in single-vehicle crashes were more likely to have been engaged in some aggressive behavior (13%), fatigued (33%), or upset (8%) than the other two categories of drivers.

Overall, drivers were more likely to have been distracted or fatigued than they were to have been engaged in some aggressive behavior, to have been upset, or to have been hurrying.

Figure 5-6 summarizes information about drivers' vision problems, hearing problems, and illnesses. The first set of columns shows the percentage of large truck drivers involved in a lane departure who were indicated as having at least one vision problem, including myopia, hyperopia, glaucoma, color blindness, astigmatism, or other unspecified vision problems. The second set of columns indicates whether the driver had been diagnosed with some type of hearing problem. The last set of columns indicates whether the driver had some illness just prior to the crash, including an epileptic seizure, other type of seizure, diabetic blackout, other blackout, a cold or flu, or some other type of illness. Crashes in which the illness left the driver incapable of functioning were not included in the analysis.

As shown, drivers overall were much more likely to have some type of vision problem than a hearing problem or some type of illness. A higher percentage of large truck drivers responsible in multi-vehicle lane departure crashes were indicated as having a vision problem (28%) or a hearing problem (3%), compared to the percentages for the other two categories of drivers. Drivers who were responsible in single-vehicle lane departure crashes were more likely than other drivers to have been suffering some type of illness just prior to the crash (4%).

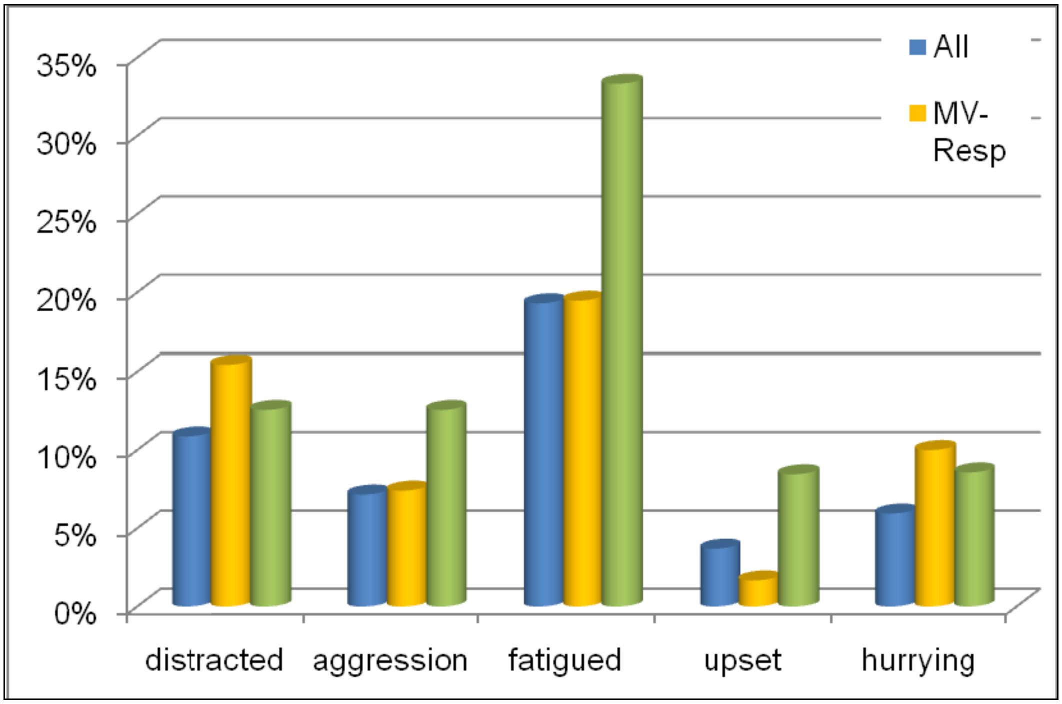


Figure 5-5. Various driver factors

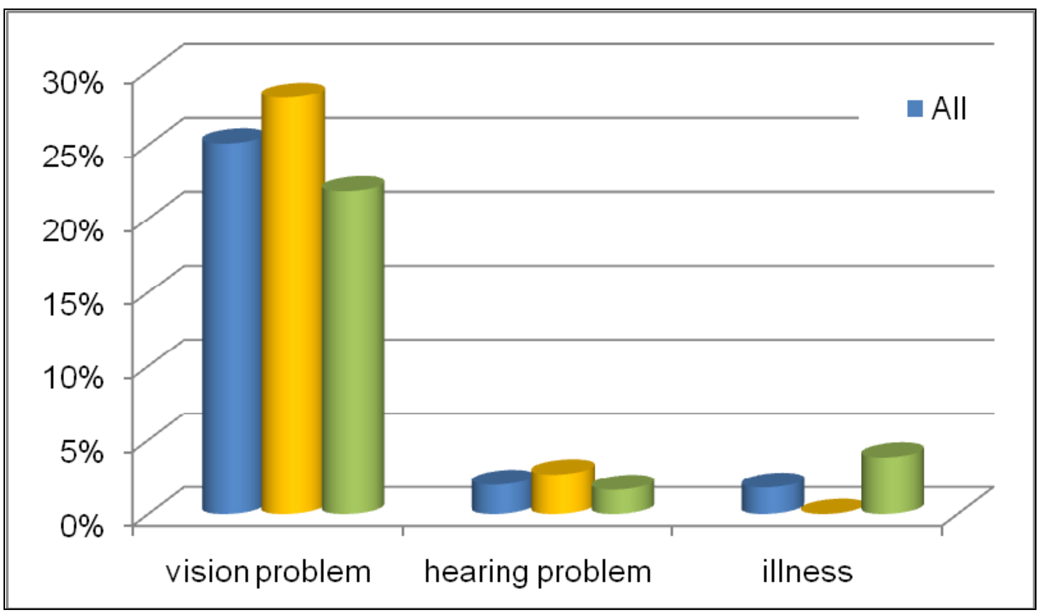


Figure 5-6. Factors related to hearing, vision, and illness

Figure 5-7 shows alcohol and drug involvement for large truck drivers. The first set of columns shows the percentage of drivers who were indicated as having alcohol present. As shown, only around 1% of any group of drivers had alcohol present. The second set of columns shows the percentage of drivers who tested positive in a drug test. Percentages were similar for all three driver categories, with 10% to 11% of drivers testing positive for illegal drugs. Consequently, drivers were more likely to be using illegal drugs than alcohol.

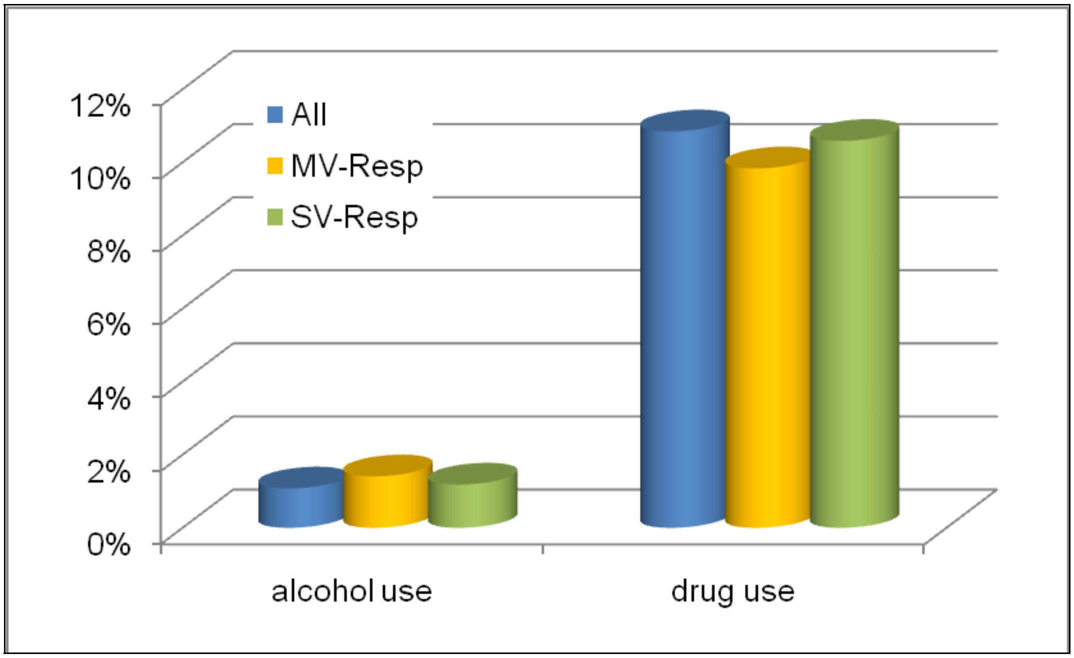
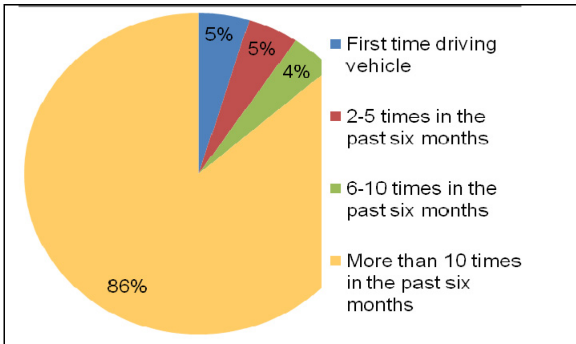


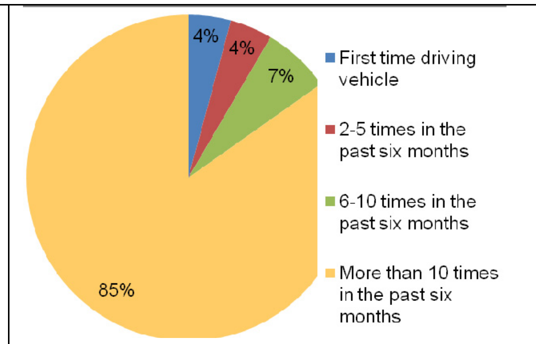
Figure 5-7. Factors related to alcohol or drugs

Figure 5-8 shows the extent to which a driver was familiar with his/her vehicle at the time of a crash. Results are similar for all three driver categories. Between 85% and 87% of drivers had driven the vehicle more than 10 times in the past 6 months, while 4% to 7% had driven the vehicle 6 to 10 times. Around 4% or 5% had only driven the vehicle 2 to 5 times in the past 6 months or had driven the vehicle only once.

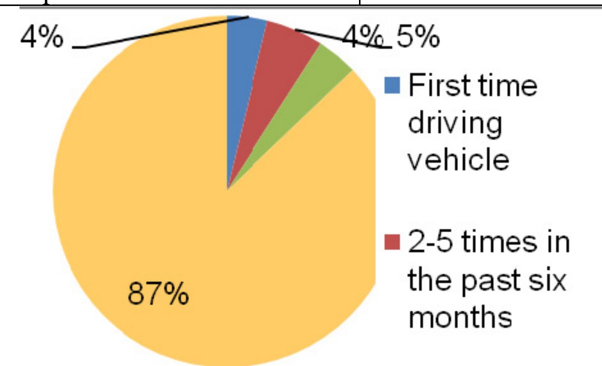
Figure 5-9 shows the extent to which a large-truck driver involved in a lane departure was familiar with the roadway he/she was driving at the time of the crash. Large truck drivers who were responsible in a single-vehicle crash were more likely than the other two categories of drivers to be unfamiliar with the roadway they were driving at the time of the crash. A total of 25% of these drivers rarely drove the roadway. The categories of all drivers and the drivers responsible in multi-vehicle crashes were similar and were more likely to have driven the road one to several times a month, daily, or weekly.



All large truck drivers involved in a lane departure



Large truck drivers responsible in multi-vehicle lane departure crashes



Large truck drivers responsible in single-vehicle lane departure crashes

Figure 5-8. Driver familiarity with vehicle

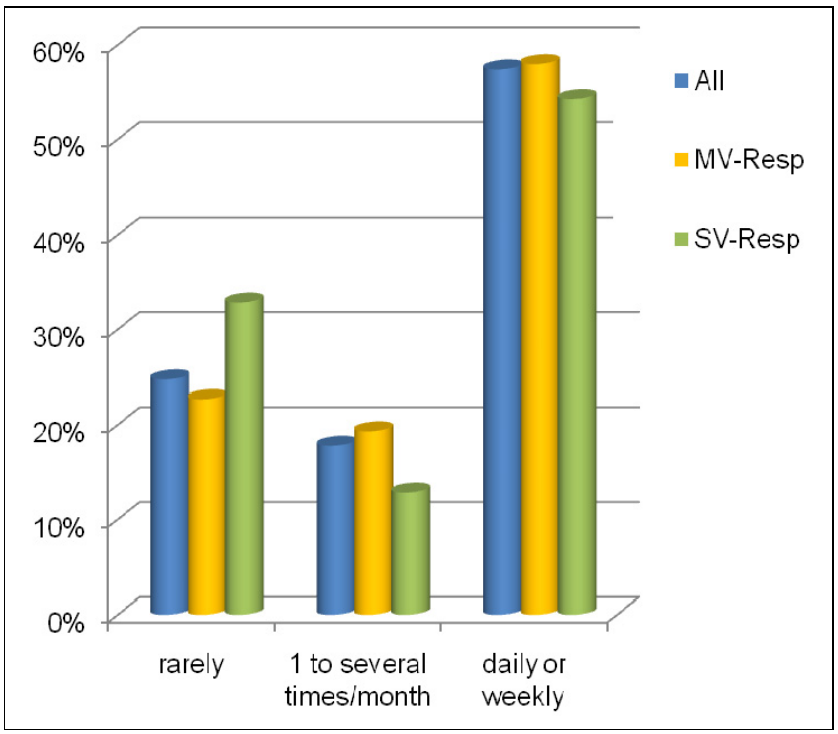


Figure 5-9. Driver familiarity with roadway

5.2.3. Vehicle Characteristics

The two characteristics of interest for vehicles that were evaluated, whether a cargo shift occurred and whether a jackknife occurred, are provided in Figure 5-10. The first set of columns shows the percentage of vehicles for which a cargo shift had occurred. As indicated, large trucks in which the driver was determined to be responsible in a single-vehicle lane departure crash were much more likely to have experienced a cargo shift (15%) than the vehicles for the other two driver categories. A jackknife occurred for 15% of vehicles in which the driver was responsible in a multi-vehicle crash and 14% for single-vehicle crashes.

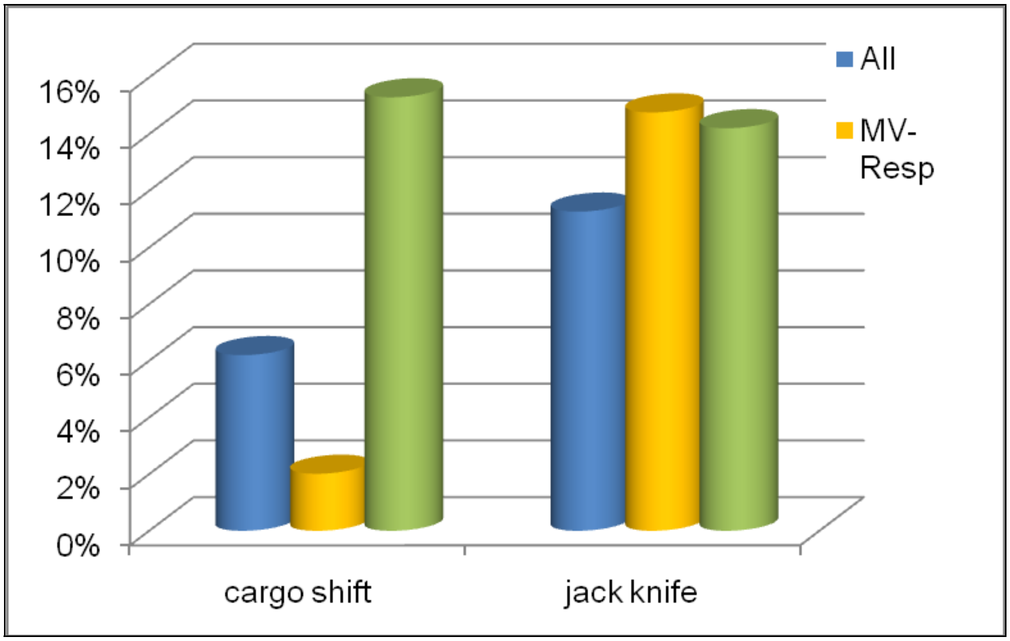
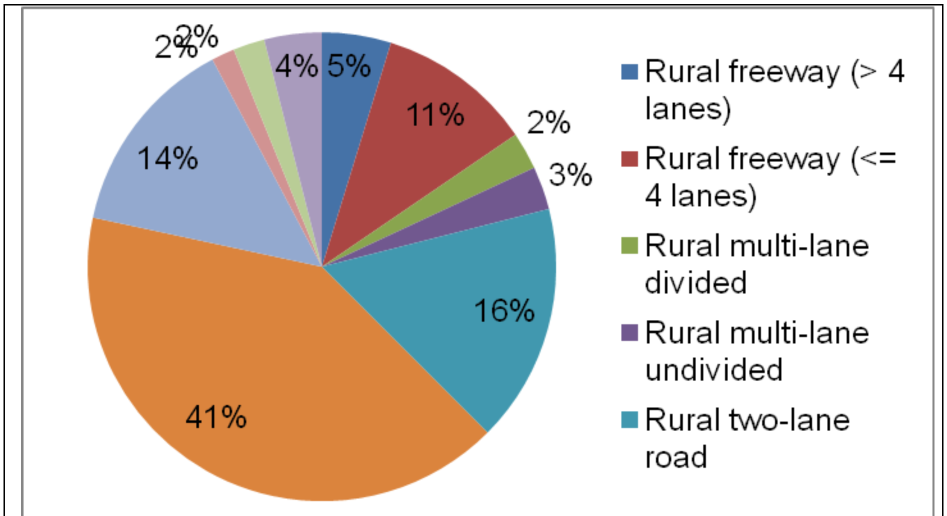


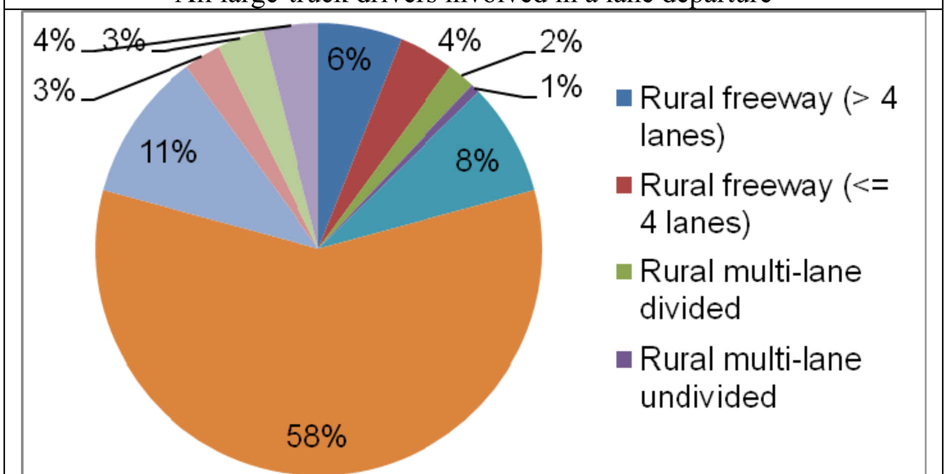
Figure 5-10. Cargo shift and jackknife

5.2.4. Roadway Characteristics

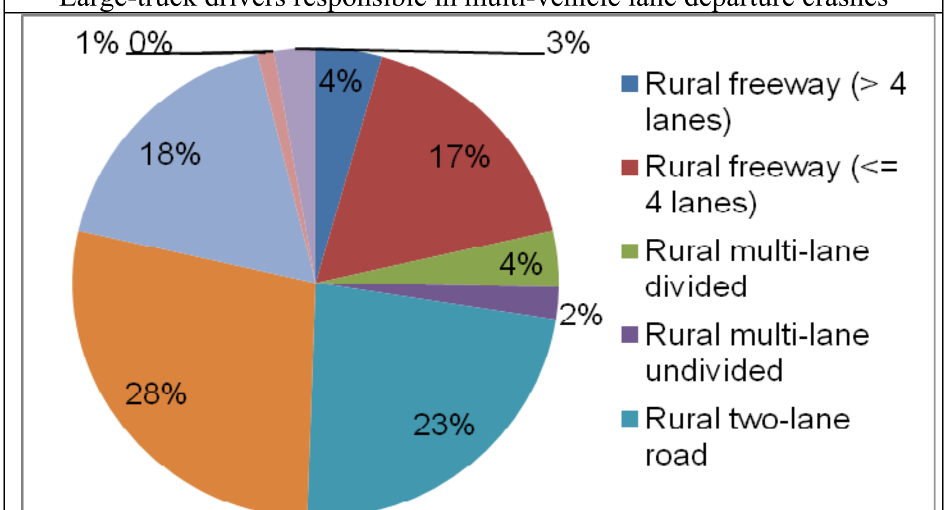
In addition to driver and vehicle characteristics, a number of roadway characteristics were evaluated. Roadway characteristics include factors related to the physical infrastructure of the roadway, such as grade, shoulder type, etc. Figure 5-11 shows the types of roadway on which large truck drivers were involved in lane departure crashes. As shown, the majority of all large truck drivers involved in lane departure crashes were on urban freeways with more than four lanes (41%), rural two-lane roadways (16%), or urban freeways with four or fewer lanes. The majority of large truck drivers responsible in multi-vehicle crashes were driving on urban freeways with more than four lanes (58%), urban freeways with four or fewer lanes (11%), or rural two-lane roadways (8%). The majority of large truck drivers responsible in single-vehicle lane departure crashes were located on urban freeways with more than four lanes (28%), rural two-lane roadways (23%), urban freeways with four or fewer lanes (18%), or rural freeways with four or fewer lanes (17%).



All large-truck drivers involved in a lane departure



Large-truck drivers responsible in multi-vehicle lane departure crashes



Large-truck drivers responsible in single-vehicle lane departure crashes

Figure 5-11. Roadway type

Figure 5-12 shows whether a rumble strip was present on the roadway where a large truck driver was involved in a lane departure crash. Rumble strips were present for 19% of all large truck drivers, for 15% of drivers who were responsible in multi-vehicle lane departure crashes, and for 21% of drivers who were responsible in single-vehicle lane departure crashes.

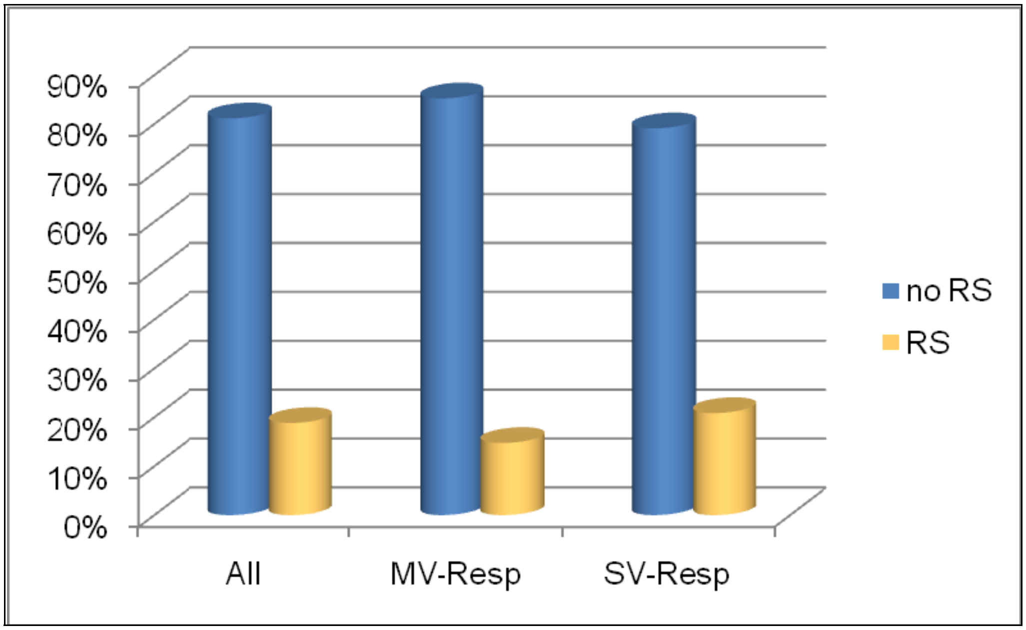
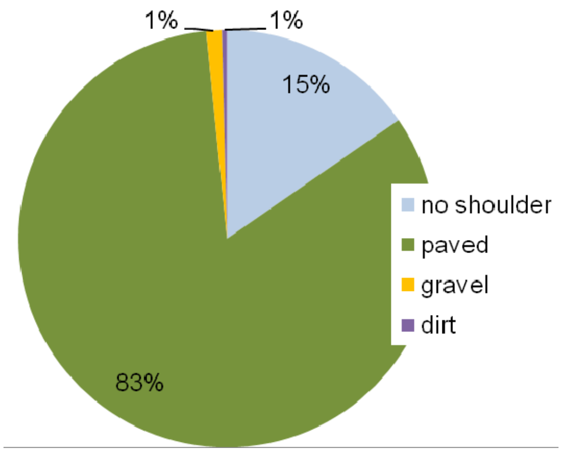
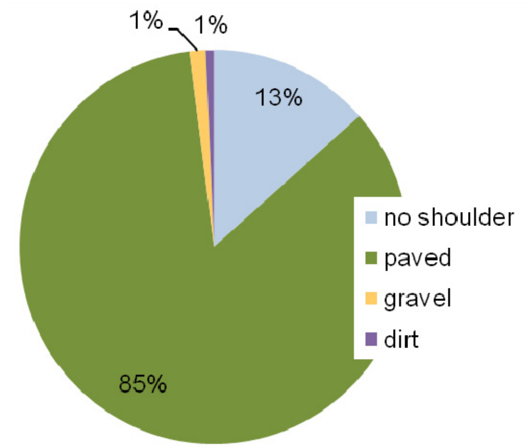


Figure 5-12. Presence of rumble strip

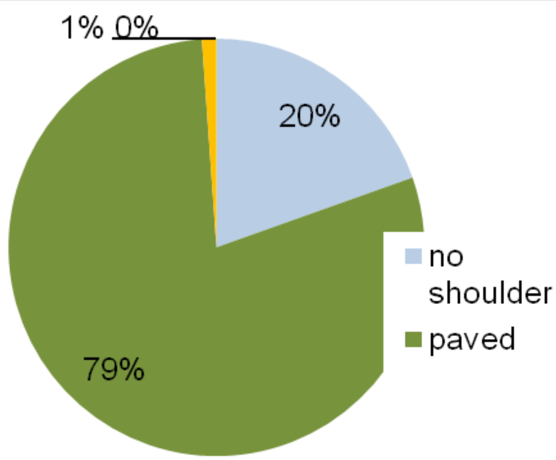
Figure 5-13 shows the type of shoulder present on roadways where large truck drivers were involved in a lane departure. Shoulder type was similar for all three driver categories. A paved shoulder was present in 79% to 85% of crashes, and no stabilized shoulders were present for 13% to 20% of crashes. Gravel and dirt shoulders only accounted for around 1% of the locations where drivers were involved in lane departure crashes.



All large-truck drivers involved in a lane departure



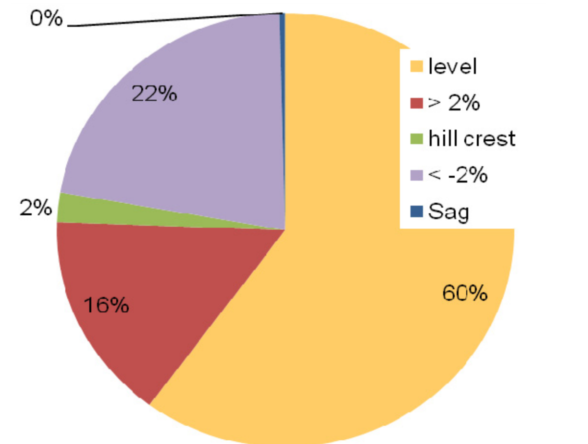
Large-truck drivers responsible in multi-vehicle lane departure crashes



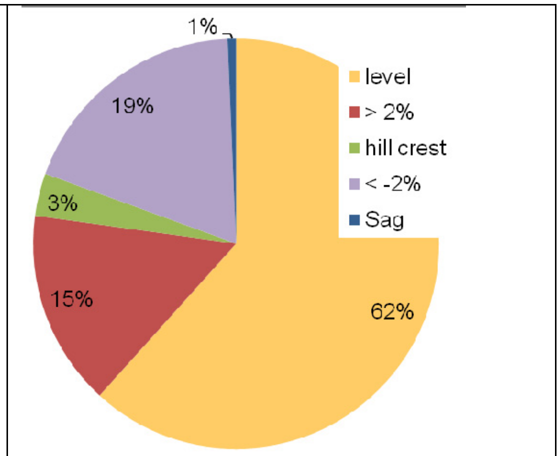
Large-truck drivers responsible in single-vehicle lane departure crashes

Figure 5-13. Shoulder type

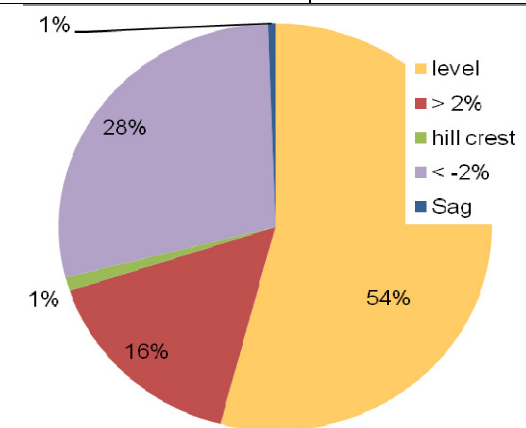
Figure 5-14 shows the type of road alignment present when a large-truck driver was involved in a lane departure crash. The majority of drivers were on a level section of roadway, but a much larger percentage of drivers responsible in single-vehicle crashes were on a downgrade that was less than -2%. Around 16% of drivers in all three categories were on an upgrade that was greater than 2%. Only 1% to 2% of drivers were in the sag or crest of a vertical curve.



All large truck drivers involved in a lane departure



Large truck drivers responsible in multi-vehicle lane departure crashes



Large truck drivers responsible in single-vehicle lane departure crashes

Figure 5-14. Vertical alignment

Figure 5-15 indicates whether a horizontal curve was present for the lane departure crashes examined in this research. The categories of all drivers and drivers responsible in a single-vehicle lane departure crash were much more likely to have been on a horizontal curve (61% and 65%) than the category of drivers responsible in a multi-vehicle crash (26%).

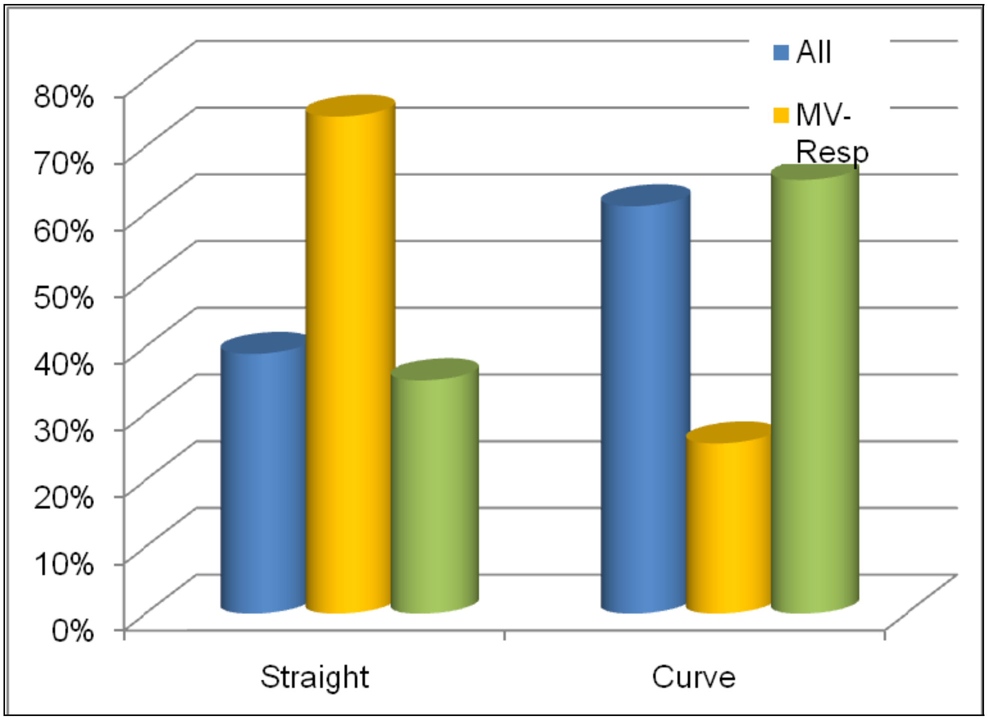
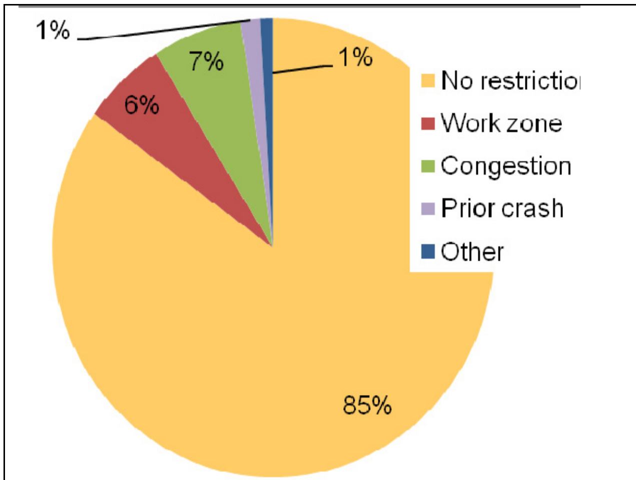


Figure 5-15. Presence of horizontal curve

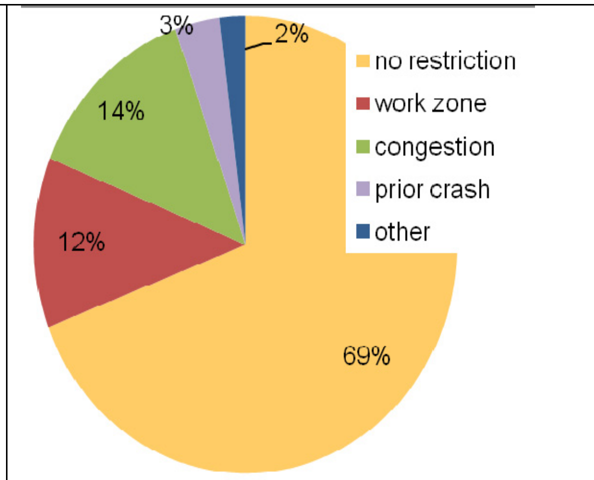
5.2.5. Environmental Characteristics

This section summarizes the environmental characteristics present during large truck lane departures, including atmospheric conditions, ambient lighting, etc.

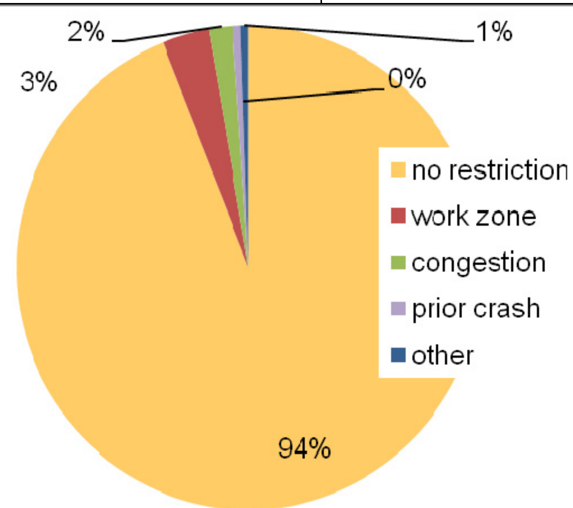
Traffic flow conditions during large truck lane departure crashes are shown in Figure 5-16. Flow restrictions are defined as restrictions to traffic flow that existed before the crash occurred and hindered the general flow of traffic in some way. Flow restrictions may be due to the presence of a work zone, congestion, a prior crash, or some other unspecified condition. The most common condition during large truck lane departure crashes was no flow restriction (85%), with 6% and 7% of crashes having restrictions in flow due to a work zone and congestion. Only 1% of drivers experienced flow restrictions due to a prior crash or other condition. Drivers responsible in a multi-vehicle crash were more likely than other drivers to have some flow restriction in place, with 14% experiencing flow restriction due congestion, 12% due to a work zone, and 3% due to a prior crash. The majority of large truck drivers responsible in a single-vehicle crash had no flow restriction (94%).



All large-truck drivers involved in a lane departure



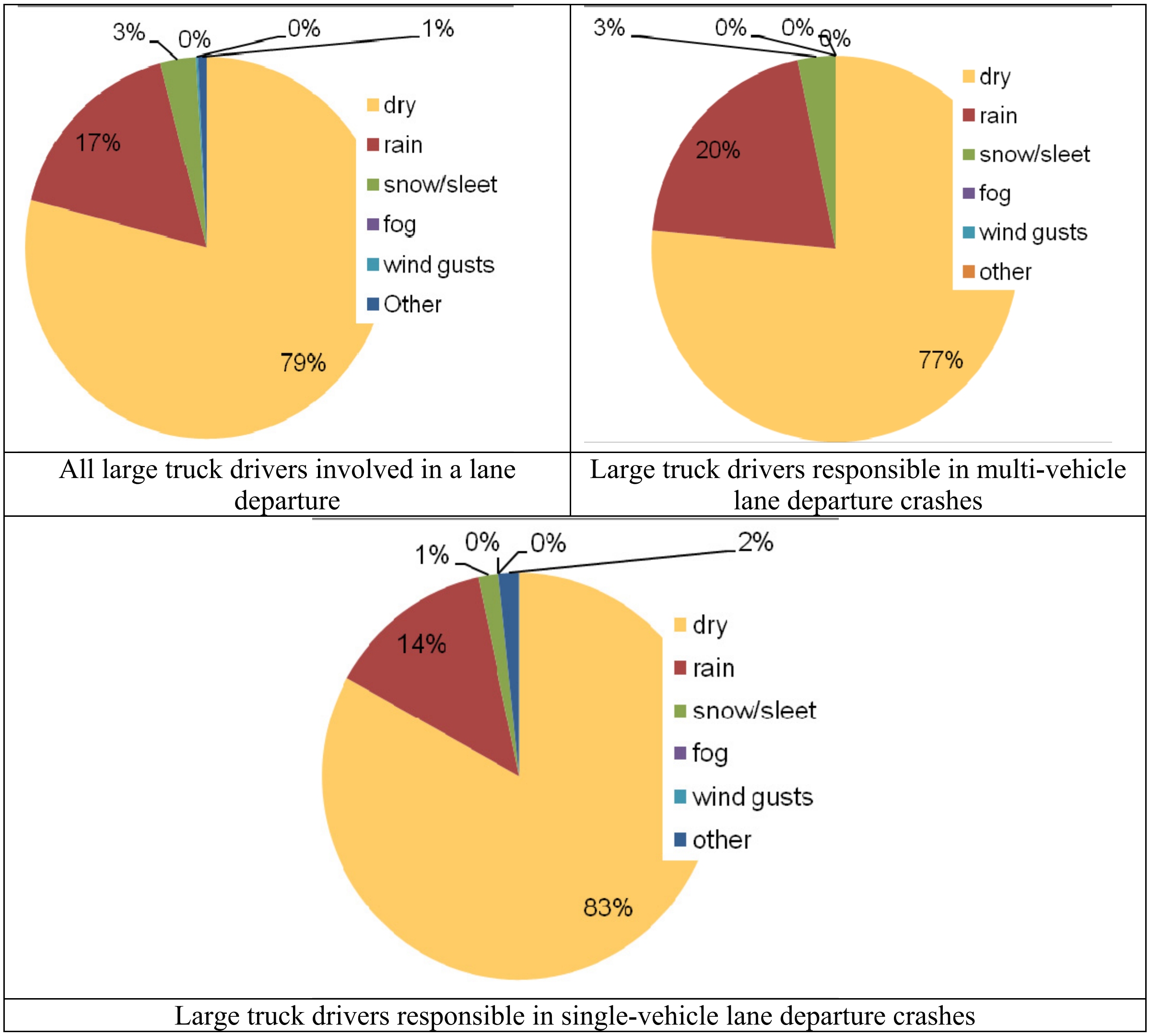
Large-truck drivers responsible in multi-vehicle lane departure crashes



Large-truck drivers responsible in single-vehicle lane departure crashes

Figure 5-16. Traffic flow conditions

As Figure 5-17 shows, the majority of drivers involved in lane departures were in dry atmospheric conditions at the time of the crash. Rain was more likely for drivers responsible in multi-vehicle crashes than for the other two categories of drivers (20% versus 17% and 14%). Snow/sleet, fog, and wind gusts were prevalent for only a small percentage of the time for any category of driver.



All large truck drivers involved in a lane departure

Large truck drivers responsible in multi-vehicle lane departure crashes

Large truck drivers responsible in single-vehicle lane departure crashes

Figure 5-17. Atmospheric conditions

The prevailing roadway surface conditions at the time of the lane departure crashes are shown in Figure 5-18. As indicated, the majority of drivers in all three categories of drivers were on dry roads (72% to 81%). Drivers determined to be responsible in multi-vehicle crashes were the most likely to be on wet roadways (24%) when the lane departure occurred. For each of the three driver categories, snow, slush, or ice was present for around 3% of crashes.

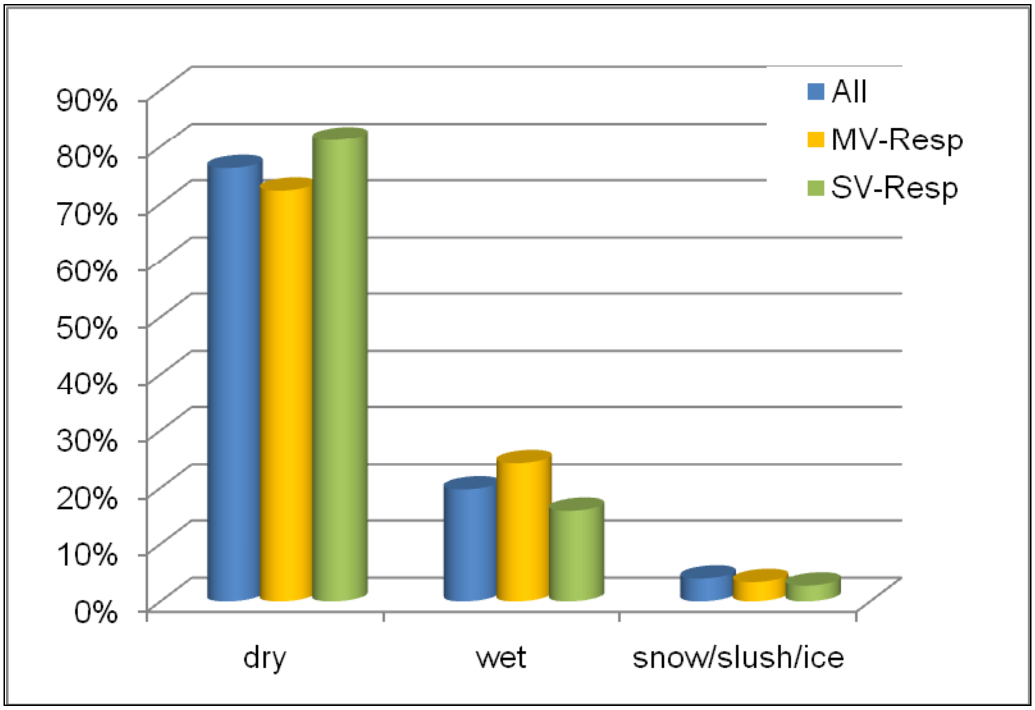


Figure 5-18. Roadway surface conditions

Ambient light conditions at the time of the lane departure crashes are provided in Figure 5-19. Large truck drivers responsible in single-vehicle crashes were more likely to be traveling at night without street lighting (16%) than the other two categories of drivers and were more likely to be traveling at dusk or dawn (5%).

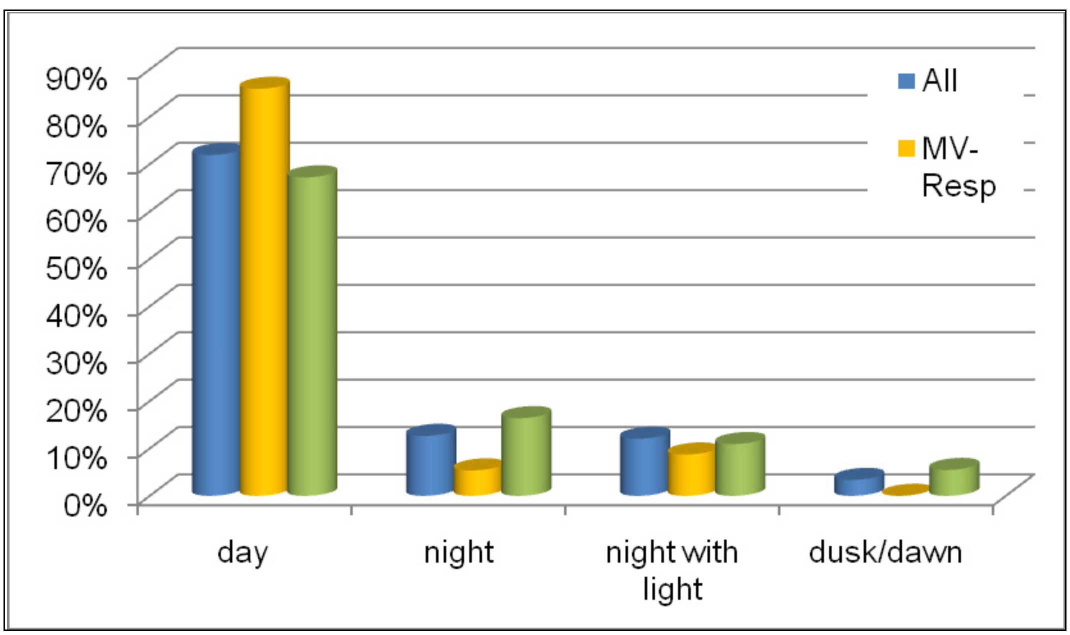


Figure 5-19. Ambient light conditions

5.3. Simple Odds Ratio

In addition to the logistic regression, a simple odds ratio was calculated to identify crash characteristics. The odds ratio only allows for two responses within a variable (e.g., rumble strips present or not). Therefore, when a variable had several responses, an odds ratio was calculated for each response if there were sufficient values. If sufficient values were not available, responses were combined. For instance, the variable "Daylight" has six responses (daylight, dark, dark but lighted, dawn, dusk, or unknown). Since there were only a few values in the responses "dark but lighted," "dawn," and "dusk" for each of the categories of drivers, these categories were combined into one response, "night," which was compared to "day." Data cells for which there was no information (indicated as unknown) were not included in the analysis. Odds ratios were not calculated for numeric variables, such as shoulder width, when the variables could not easily be combined into two responses.

Odds ratios were calculated using Equation 5-1.

$$OR = \frac{RD_i/RD_k}{ND_j/NDk} \qquad \text{(Equation 5-1)}$$

Where,

OR = odds ratio
RDj = number of responsible drivers for response j
RD_k = number of responsible drivers for response k
ND_j = number of non-responsible drivers for response j
ND_k = number of non-responsible drivers for response k

The 95 confidence interval is given by the following:

CI of OR is exp(log(OR) ±1.96*sd)

and

standard deviation of log(odds ratio) = $(1/A + 1/B + 1/C + 1/D)^{0.5}$

Odds ratios were calculated separately for drivers involved in single-vehicle lane departure crashes and for drivers responsible in multiple-vehicle crashes. Results are presented in Table 5-3. Odds ratios are highlighted in blue text when the responsible drivers were over-represented or under represented for a particular factor and the value was statistically significant.

As shown in Table 5-3, responsible large truck drivers in single-vehicle crashes are 2.9 more likely than non-responsible large truck drivers to have a jackknife occur during the crash envelope. Single-vehicle responsible drivers are also 9.5 times more likely to be fatigued, 13.0 times more likely to be upset, 2.1 times more likely to be unfamiliar with the road they were driving on, and 2.9 times more likely to be distracted. These drivers are 6.4 times more likely than non-responsible drivers to have a crash on a horizontal curve and 1.6 times more likely to have a crash on a grade. Single-vehicle responsible drivers are also less likely to be in a crash that involved drugs (OR = 0.28), to have been driving 8 or more hours (OR = 0.44), or to be in a location where traffic flow is restricted due to congestion (OR = 0.26).

As shown in Table 5-3, responsible large truck drivers in multi-vehicle crashes are 3.1 times more likely than non-responsible large truck drivers to have a jackknife occur during the crash envelope, 4.6 times more likely to be fatigued, and 3.7 times more likely to be distracted. Multi-vehicle responsible drivers are also 4.4 times more likely than non-responsible drivers to be in a work zone and 2.9 times more likely to be in a congested area and are less likely to be driving at night (OR = 0.31).

The category of large-truck drivers responsible in single-vehicle lane departure crashes was also compared to large truck drivers responsible in multi-vehicle crashes, as shown in the right-hand column of Table 5-3. Single-vehicle responsible drivers are less likely than multi-vehicle responsible drivers to be involved in a crash that involved any drugs (OR = 0.26), that had flow restrictions due to a work zone (OR = 0.20), or that had flow restrictions due to congestion (OR = 0.09). Single-vehicle responsible drivers are also more likely than multi-vehicle responsible drivers to have a cargo shift (OR = 8.8); be fatigued (OR = 2.07); be upset (OR = 5.45); be driving at night, dawn, or dusk (OR = 2.97); have a curve present (OR = 5.43); or be on an up-grade or down-grade (OR = 1.65).

Table 5-3. Simple odds ratios

Name	Description	Odds ratio (95% confidence intervals) Responsible drivers vs. non-responsible: Single-vehicle	Odds ratio (95% confidence intervals) Responsible drivers vs. non-responsible: Multi-vehicle	Odds ratio (95% confidence intervals) Single-vehicle responsible drivers vs. multi-vehicle responsible
ACRJackknife	Jackknife occurred versus jackknife did not occur	**2.93 (1.33, 6.44)**	**3.06 (1.36, 6.88)**	0.96 (0.51, 1.77)
ACRCargoshift	No "non-responsible drivers" had instances of cargo shift, so odds ratio could not be calculated			**8.79 (2.62, 29.54)**
AlcoholUse	Alcohol present for driver	1.82 (0.16, 20.28)	2.17 (0.19, 24.21)	0.84 (0.12, 6.03)
DrugUse	Driver tested positive for illegal drugs	0.86 (0.31, 2.36)	0.79 (0.26, 2.42)	1.09 (0.37, 3.23)
AnyDrugsCrash	Any drugs present in crash versus no present	**0.28 (0.18, 0.44)**	1.09 (0.68, 1.75)	**0.26 (0.16, 0.41)**
Fatigue	Driver was fatigued versus not fatigued	**9.5 (4.12, 21.90)**	**4.59 (1.88, 11.20)**	**2.07 (1.16, 2.70)**
Was_Hurrying	No "non-responsible drivers" had instances of hurrying, so odds ratio could not be calculated			0.84 (0.36, 1.95)
Upset	Driver upset due to family, financial, etc versus not upset	**13.02 (1.67, 101.50)**	2.39 (0.21, 26.69)	**5.45 (1.19, 24.84)**
KnewVehicle	Had driven vehicle 5 or fewer times in past 6 months versus had driven vehicle 6 or more times	0.88 (0.39, 2.02)	0.82 (0.34, 1.95)	1.08 (0.45, 2.60)
KnewRoad	First time or rarely on road versus driver is on road at least several times per month	**2.08 (1.21, 3.60)**	1.25 (0.69, 2.28)	1.67 (0.96, 2.91)

Table 5-3. Simple odds ratios (continued)

Name	Description	Odds ratio (95% confidence intervals) Responsible drivers vs. non-responsible: Single-vehicle	Odds ratio (95% confidence intervals) Responsible drivers vs. non-responsible: Multi-vehicle	Odds ratio (95% confidence intervals) Single-vehicle responsible drivers vs. multi-vehicle responsible
AggressionCount	Had at least one aggression count versus no counts of aggression	2.46 (0.99, 6.09)	1.81 (0.67, 4.91)	1.35 (0.60, 3.06)
Was_Distracted	Had some distraction versus no distractions	**2.88 (1.25, 6.62)**	**3.65 (1.58, 8.43)**	0.79 (0.42, 1.47)
Was_Ill	Had some illness compared to no illness	3.30 (0.68, 16.12)	None had condition of interest, could not calculate odds ratio	No multi-vehicle had condition of interest
Has_Vision	Has vision problem compared to no vision problem	0.79 (0.48, 1.29)	1.11 (0.67, 1.82)	0.71 (0.43, 1.18)
HearingImpair	Had hearing impairment compare to no hearing impairment	0.92 (0.18, 4.61)	1.52 (0.33, 6.89)	0.60 (0.13, 2.74)
HoursDriving	Driving more than 8 hours compared to driving 8 hours or less	**0.44 (0.20, 0.99)**	0.56 (0.25, 1.25)	0.79 (0.32, 1.98)
FlowRestriction	Presence of work zone versus no flow restrictions	0.87 (0.28, 2.76)	**4.37 (1.68, 11.38)**	**0.20 (0.08, 0.51)**
	Presence of congestion versus no flow restrictions	**0.26 (0.07, 0.97)**	**2.91 (1.31, 6.48)**	**0.09 (0.03, 0.31)**
Daylight	Occurred during night, dusk or dawn compared to daylight	0.93 (0.59, 1.44)	**0.31 (0.18, 0.55)**	**2.97 (1.71, 5.18)**

Table 5-3. Simple odds ratios (continued)

Name	Description	Odds ratio (95% confidence intervals)		
		Responsible drivers vs. non-responsible		Single-vehicle responsible drivers vs. multi-vehicle responsible
		Single-vehicle	Multi-vehicle	
RoadAlignment	Presence of curve versus no curve	**6.36 (3.97, 10.20)**	1.17 (0.70, 1.96)	**5.43 (3.37, 3.76)**
RoadProfile	Presence of grade versus no grade	**1.59 (1.04, 2.45)**	0.96 (0.61, 1.52)	**1.65 (1.07, 2.54)**
SurfaceCondition	Compared presence of ice, snow, or slush versus dry	0.42 (0.14, 1.28)	0.58 (0.19, 1.76)	0.73 (0.21, 2.58)
	Compared wet pavement versus dry	0.80 (0.45, 1.39)	1.36 (0.79, 2.34)	0.59 (0.34, 1.02)
ShoulderType	Compared unpaved to paved	1.55 (0.88, 2.73)	1.09 (0.59, 2.02)	1.43 (0.80, 2.53)
RumbleStrip	Compared absence of rumble strip to presence of rumble strip	0.97 (0.58, 1.63)	1.48 (0.82, 2.66)	0.66 (0.37, 1.17)
Atmospheric	Compared presence of rain, snow, fog, or wind gusts to no adverse atmospheric conditions	0.70 (0.41, 1.18)	1.05 (0.62, 1.77)	0.66 (0.39, 1.14)
TotalCrashes	Compared drivers involved in 1 or more crash in one year to drivers not involved in a crash	1.29 (0.59, 2.83)	1.78 (0.83, 3.82)	0.73 (0.35, 1.50)
Violations	Compared drivers with 6 or more violations to drivers with 5 or fewer violations in one year	1.18 (0.53, 2.63)	2.02 (0.96, 4.24)	0.58 (0.28, 1.2)

5.4. Results from Logistic Regression

Independent logistic regression using stepwise selection was used to evaluate whether a driver responsible for a crash was more likely to be involved in a lane departure in relation to a particular variable. Two models were created. One used single-vehicle records where the driver was responsible as the case and non-responsible drivers as the control. The other used multi-vehicle records where the driver was responsible as the case and non-responsible drivers as the control. The models were created using SAS, version 9.1.3.

Multivariate logistic regression was used to assess which factors were associated with the risk of a driver being responsible in a single-vehicle or multi-vehicle lane departure crash. The model was developed according to the following logic. Let Y=1 if the vehicle is responsible and Y=0 if the vehicle is not responsible, and let p= P(Y=1) be the probability of Y=1 and X be the corresponding measurements of the vehicle. Y is a random variable with Bernoulli distribution, and the probability mass function of Y is $P(Y=y|p) = p^y(1-p)^{1-y}$. The log likelihood of p is $\log L(p) = y\log(p)+(1-y)\log(1-p) = y\log(p/(1-p))+\log(1-p)$. The generalized linear model with logit link was used for modeling. This model connection logit of unknown parameter is XXX and the linear combination of Xs is given as follows: $\text{logit}(p) = \log(p/(1-p)) = \beta_0+\beta_1X_1+\ldots.. \beta_kX_k$. The model is specially suited to a case-control study because the population odds ratio for two types of vehicles can be estimated by $\text{logit}(p_i) - \text{logit}(p_j)$, which is a linear combination of Xs.

Independence among vehicles was necessary for correct estimates, so a random effects variable was added to deal with the correlation between vehicles involved in the same crash. In the case-control study, the parameters explain the increase of log-odds when a vehicle in a specific group (e.g., X_{fatigue} =1) was related to another vehicle outside this group.

Stepwise selection was used to determine which variables should be included in the final model. For the stepwise process, covariates were added and the chi-square statistic was computed. If the covariate satisfied a specified significance-level (0.1 was used), it was included in the model. The Akaike Information Criteria (AIC) was used to compare models and determine which variables to include in the final model.

The interaction between variables was also evaluated but was determined not to be significant. Therefore, interaction did not need to be accounted for in the final model.

The Hosmer and Lemeshow chi-square goodness of fit test was used to test the null hypothesis that there was no difference between the observed data and the fitted model. For this test, a higher p-value indicates that there is not sufficient evidence to say the data and the model are different. Maximum likelihood estimation (MLE) was used to calculate the logit coefficients, and the Wald statistic was used to test the significance of covariates.

Odds ratios assess whether responsible drivers in a specific situation are more or less likely to be involved in a lane departure crash. An odds ratio greater than 1 indicates that the odds of being involved are higher, and an odds ratio less than one indicates that the odds are lower.

It was determined in the course of modeling that a number of variables were missing values (usually indicated as "unknown" in the LTCCS databases). Including variables that had a large number of missing values would have reduced the number of observations available to fit the logistic regression model. As a result, variables that were missing 65 or more values were not included in the model. A simple odds ratio was used to compare whether responsible drivers were over-represented for these variables, as discussed in Section 5.3 in this report. Variables with large numbers of missing values included the following:

- "CRAAlcohol"
- "Fatigue"
- "Upset"
- "Knew_Vehicle"
- "KnewRoad"
- "HoursSinceSleep"
- "HoursDriving"
- "TotalCrashes"
- " GVETotalViolations"
- "DrugUse"

In order to fit the data to the best model, the decision to remove variables from the final model was also based on a consideration of the variables that were determined not to be significant in the simple odds ratio test.

The final models for single- and multi-vehicle lane departure events are presented in the following sections.

5.4.1. Single-vehicle Lane Departure Events

Below is the final model selected for single-vehicle lane departure events in which large truck drivers that were responsible in single-vehicle crashes were the case and non-responsible large truck drivers served as the control. The final model for large truck drivers who were determined to be the most responsible in a single-vehicle lane departure crash is given by the following:

The estimated log(odds) of a vehicle is given by

Log(odds) = Intercept + 1.2270 * I(ROR_Type=0) - 0.8992 * I(AnyDrugsCrash=2)
- 2.3434 * I(Was_Distracted=0) - 2.2982 * I(ACRCargoshift=0)
- 0.0692 * I(RoadwayClass=1) + 1.0648 * I(RoadwayClass=2)
+ 0.0220 * I(RoadwayClass=3) - 2.9219 * I(RoadwayClass=4)
+ 1.3462 * I(RoadAlignment=0) - 0.3058 * ShoulderWidth

Model statistics are provided in Table 5-4.

The odds ratio for any variable is calculated by assuming all other variables are held constant. For example, the odds ratio for Driver A, who was not distracted (condition 0), compared to that of Driver B, who was distracted (condition 1), with the same ROR type, cargo shift, roadway type, road alignment, and shoulder width, can be calculated by the following:

$\log(OR) = \log(odds_A) - \log(odds_B) = \text{logit}(p_A)\text{-logit}(p_B) = -2.3434$

$OR = \exp(-2.3434) = 0.096$

As a result, a driver who was the most responsible in a single-vehicle lane departure crash is 0.096 times less likely not to be distracted. The odds ratio for being distracted can be computed by (1/0.096) = 10.41. Therefore, drivers responsible in a single-vehicle crash are 10.4 times more likely to have been distracted than non-responsible drivers.

Table 5-4. Results for single-vehicle model

Variable	Condition	Estimate	Std error	p-value	OR	OR 95% lower	OR 95% upper
ROR_Type	0vs.1	1.2270	0.3529	**0.0005**	3.411	**1.708**	**6.812**
AnyDrugsCrash	1vs.2	-0.8992	0.2939	**0.0022**	0.407	**0.229**	**0.724**
Was_Distracted	0vs.1	-2.3434	0.7317	**0.0014**	0.096	**0.023**	**0.403**
ACRCargoshift	0vs.1	-2.2982	1.1249	**0.0411**	0.100	**0.011**	**0.911**
RoadwayClass	1vs.5	-0.0692	0.4147	0.3129	0.933	0.414	2.103
RoadwayClass	2vs.5	1.0648	0.4480	**<.0001**	2.900	**1.205**	**6.979**
RoadwayClass	3vs.5	0.0220	0.7327	0.4748	1.022	0.243	4.298
RoadwayClass	4vs.5	-2.9219	0.8375	**0.0001**	0.054	**0.010**	**0.278**
RoadAlignment	0vs.1	1.3462	0.3175	**<.0001**	3.843	**2.062**	**7.161**
ShoulderWidth	1	-0.3058	0.1261	**0.0153**	0.737	**0.575**	**0.943**

The first variable, "ROR_Type," evaluated whether lane departure was intentional or unintentional. The first condition (0) included situations where the vehicle inadvertently left the lane due to factors such as loss of control, the driver falling asleep, etc. The second condition (1) included situations where the driver left the lane intentionally to change or merge lanes or in an accident-avoidance maneuver. Results indicate that drivers responsible in single-vehicle lane departure crashes were more 3.4 times more likely to have unintentionally left the roadway than to have left the roadway due to an intentional merge or lane change.

The variable "AnyDrugsCrash" indicated whether a driver was involved in a crash where drugs were present for any drivers. The variable "DriverDrugs" would have been a better measure because it indicates illegal drug use for that specific driver. However there were too many missing values for that variable, so "AnyDrugsCrash" was evaluated instead. The condition evaluated was whether any illegal drugs were involved in the crash (case 1) versus no illegal drugs involved in the crash. The odds ratio is 0.64, indicating that drivers responsible in single-vehicle lane departure crashes were less likely than non-responsible drivers to have drugs involved.

The odds ratio of 0.1 for "ACRCargoShift" compared no cargo shift (condition 0) to a cargo shift (condition 1). This odds ratio indicates that responsible drivers are 0.10 times less likely to have no cargo shift or are 10.0 times more likely to have experienced a cargo shift.

The categories for roadway class are given in Table 5-5. Results indicate that a driver responsible in a single-vehicle crash has a similar likelihood of being on a freeway with more than four lanes (condition 1) and being on a two-lane roadway (condition 5). The OR is 0.93, which is not statistically significant at the 95% confidence level. These drivers are 2.9 times more likely to be on a freeway with four or fewer lanes (condition 2) than on a two-lane roadway, and they are equally likely (OR = 1.02, not statistically significant at the 95% confidence level) to be on a non-freeway multi-lane divided roadway (condition 3) as on a two-lane roadway. These drivers are also 0.05 times less likely to be on a non-freeway multi-lane undivided roadway (condition 4) than on a two-lane roadway, or conversely they are 18.5 times more likely to be on a two-lane roadway.

Table 5-5. Description of roadway class

Roadway Class	Description
1	freeway, > 4 lanes
2	freeway, <=4 lanes
3	non-freeway, multi-lane divided
4	non-freeway, multi-lane undivided
5	two-lane road

The variable "RoadAlignment" indicates the presence of a curve. Drivers responsible in a single-vehicle lane departure crash were 3.8 times more likely to be on a curve (condition 0) than on a straight section (condition 1) of roadway.

Finally, the variable "ShoulderWidth" was calculated using actual shoulder width. As shoulder width increases, the odds ratio for this category of drivers decreases, indicating that narrower shoulder widths increase the likelihood of a crash.

5.4.2. Multiple-vehicle Lane Departure Events

Below is the final model selected for multi-vehicle lane departure events, in which large truck drivers responsible in multi-vehicle lane departure crashes were the case and non-responsible large truck drivers served as the control. The final model is given by the following:

Logit(p) = 1.4470 - 1.2581*I(DAYLIGHT=0)
+ 1.6856*I(Was_Distracted=1) + 1.0046*I(ROR_Type=1)
+ 1.1714*I(RoadwayClass=1) + 0.4116*I(RoadwayClass=2)
+ 0.8743*I(RoadwayClass=3) - 0.6049*I(RoadwayClass=4)

Model statistics are given in Table 5-6.

Table 5-6. Results for multi-vehicle model

Variable	Condition	Estimate	Std error	p-value	p-value	OR	OR 95% lower	OR 95% upper
ROR_Type	0 vs. 1	-1.0046	0.2666	283	0.0002	0.36620	0.21667	0.6189
DAYLIGHT	0 vs. 1	-1.2581	0.3248	283	0.0001	0.28420	0.14996	0.5386
Was_Distracted	0 vs. 1	-1.6856	0.5369	283	0.0019	0.18533	0.06441	0.5333
RoadwayClass	1 vs. 5	1.1714	0.3663	283	0.0015	3.22650	1.56901	6.6349
RoadwayClass	2 vs. 5	0.4116	0.4380	283	0.3482	1.50917	0.63731	3.5734
RoadwayClass	3 vs. 5	0.8743	0.7548	283	0.2477	2.39716	0.54255	10.5896
RoadwayClass	4 vs. 5	-0.6049	0.7081	283	0.3937	0.54615	0.13553	2.2006

The first variable indicates that large truck drivers responsible in multi-vehicle lane departure crashes were 0.37 times less likely to have inadvertently left the lane due to factors such as loss of control, driver falling asleep, etc. (condition 0) than they were to have left the lane intentionally to change lanes, to merge, or in an accident avoidance maneuver (condition 1). Conversely, these drivers were 2.7 times more likely to have left the lane intentionally.

The model also indicates that drivers who were not distracted (condition 0) were 0.18 times less likely to be involved in a lane departure crash than drivers who were distracted (condition 1). Alternatively, responsible drivers were 5.4 times more likely to be distracted than drivers who were not responsible.

Large-truck drivers who were determined to be the most responsible in a multi-vehicle lane departure crash were 0.28 times less likely to be driving at night (condition 0), which included nighttime with or without street lighting, dawn, or dusk, than during the daytime (condition 1). Conversely, drivers were 3.5 times more likely to be driving during daytime conditions.

Large truck drivers responsible in a multi-vehicle lane departure crash were 3.2 times more likely to be on a freeway with more than four lanes than on a two-lane roadway. (All roadway types are shown in Table 5-5.) The odds ratios for the other conditions (roadway class 2 versus 5, 3 versus 5, and 4 versus 5) were not statistically significant at the 95% confidence level, but these other conditions were included in this report to show all roadway types. These odds ratios indicate that drivers involved in crashes were equally likely to be on a two-lane roadway as on the other roadway types (2, 3, 4).

6. SUMMARY

6.1. Summary of Project Objectives

Lane departure crashes account for a significant number of motor vehicle crashes and fatalities. However, information specific to large truck lane departures is not well documented.

Understanding the causes and events that lead to lane departure crashes is important if the appropriate countermeasures are to be selected. This is especially important for large trucks because many countermeasures are geared towards passenger vehicles, while a better understanding of factors leading to lane departures for large trucks can improve the selection and application of countermeasures that are appropriate to both types of vehicles.

The objective of this study was to investigate the causes of lane departure crashes for large trucks. The LTCCS data were evaluated to determine both common the causes and circumstances leading to lane departure crashes. These causes and circumstances may include driver condition, driver distraction, driver error, driver accident avoidance, vehicle conditions, roadway conditions, and environmental conditions.

To determine these causes and circumstances, this research evaluated lane departure crashes and their related independent variables and attempted to derive causal relationships that can be used to identify preventative measures for reducing large truck lane departure crashes.

The LTCCS data are especially useful for this type of analysis because the data provide a large amount of information about the physical events of each crash, as well as vehicle, driver, weather, and roadway condition information. The data also focus on pre-crash events so that the reasons for crashes can be determined and corresponding countermeasures can be considered.

6.2. Project Results

Large-truck drivers/vehicles involved in a lane departure crash were extracted from the LTCCS database, and responsibility for the crash was assigned. Drivers who were determined to be the most responsible in single- or multi-vehicle lane departure crashes were then used as the case study, and non-responsible large truck drivers involved in lane departure crashes were used to determine exposure using the quasi-induced exposure method. Simple statistics, a simple odds ratio, and logistic regression were used to evaluate the crashes. Driver, vehicle, environmental, and roadway factors contributing to large truck lane departure crashes were identified.

Highlights from the analysis using simple descriptive statistics include the following. The most common critical reasons for lane departure crashes for large truck drivers who were responsible in multi-vehicle lane departure crashes included inadequate surveillance (22.4%), driving too fast for conditions (13.2%), and inattention/distraction (12.5%). The main critical reason for drivers who were responsible in single-vehicle crashes was driving too fast for curve or turn (25.0%). Another 8.7% of these drivers were also traveling too fast for conditions. As a result, driving too fast for prevailing conditions accounted for more than one-third of all single-vehicle lane departure crashes. The next most critical reasons were “asleep” (14.7%) or “vehicle defect” (14.1%).

Large truck drivers responsible in multi-vehicle crashes were more likely to have been distracted by some internal or external event (15%) and were more likely to have been hurrying (10%) than drivers in single-vehicle crashes. Large truck drivers responsible in single-vehicle lane departure crashes were more likely to have been engaged in some aggressive behavior (13%), fatigued (33%), or upset (8%) than drivers responsible in multi-vehicle crashes.

Approximately 20% of large truck lane departure crashes for drivers responsible in single-vehicle crashes and 13% for drivers responsible in multi-vehicle crashes occurred on roadways with no paved shoulder. A horizontal curve was present for 65% of drivers responsible in a single-vehicle lane departure crash and for 26% of drivers in multi-vehicle crashes.

Twenty-four percent of large truck drivers responsible in a multi-vehicle lane departure crashes were on wet roads, compared to drivers responsible in single-vehicle crashes (16%), while 3% for both categories of drivers were on roadways with snow, slush, or ice. Large truck drivers responsible in a single-vehicle lane departure crash were more likely to be traveling at night without lights (16%) than those drivers responsible in multi-vehicle crashes and were more likely than the drivers responsible in multi-vehicle crashes to be traveling at dusk or dawn (5%).

A simple odds ratio was used to calculate the odds for large truck drivers responsible in lane departure crashes as compared to non-responsible drivers. Results of the simple odds ratio indicated that large truck drivers responsible in a single-vehicle lane departure crash were more likely to be in a crash in which a jackknife occurred (OR = 2.9), be fatigued (OR = 9.5), be upset (OR = 13.0), be unfamiliar with the roadway (OR = 2.1), be distracted (OR = 2.9), have a horizontal curve present (OR = 6.4), and have an up- or downgrade present (OR = 1.59). Large truck drivers responsible in a multi-vehicle lane departure crash were more likely to have a jackknife occur (OR = 3.1), be fatigued (OR = 4.6), be distracted (OR = 3.7), be in a work zone (OR = 4.4), or have congestion present (OR = 2.9).

Odds ratios were also computed for large truck drivers responsible in single-vehicle lane departures as compared to large truck drivers responsible in multi-vehicle crashes. Single-vehicle responsible drivers were less likely to be in a crash where any drugs were involved (OR = 0.26), have flow restrictions due to a work zone (OR = 0.20), or have flow restrictions due to congestion (OR = 0.09) than large truck drivers responsible in multi-vehicle lane departure crashes. Single-vehicle responsible drivers were more likely to be fatigued (OR = 2.07); be upset (OR = 5.45); be driving at night, dawn, or dusk (OR = 2.97); have a curve present (OR = 5.43); or be on an up-grade or down-grade (OR = 1.65).

Results of the logistic regression indicated causal factors for large truck lane departure crashes that were similar to the factors indicated by the simple odds ratio. Results of the logistic regression indicated that large truck drivers responsible in a single-vehicle lane departure crash were less likely than large truck drivers in multi-vehicle crashes to be in a crash where any drugs were involved (OR = 0.41) and were more likely to have a cargo shift (OR = 10.0), experience a driver distraction (OR = 10.4), have a curve present (OR = 3.8), or be on a roadway with narrow shoulders. They were more likely to be on a freeway with four or fewer lanes than a two-lane roadway and were equally likely to be on a two-lane roadway, a freeway with more than four lanes, or a non-freeway multi-lane divided roadway. They were less likely to be on a non-freeway multi-lane undivided roadway than a two-lane roadway.

Results of the logistic regression indicated that large truck drivers responsible in a multi-vehicle lane departure crash were more likely than non-responsible large truck drivers to be distracted (OR= 5.4). They were more likely to be on a freeway with more than four lanes than on a two-lane roadway (OR = 3.2). They were as equally likely as other drivers to be on a two-lane roadway, a freeway with four or fewer lanes, a non-freeway multi-lane divided roadway, or a non-freeway multi-lane undivided roadway. They were less likely to be driving at nighttime, dawn, or dusk than during the daytime (OR = 0.28).

6.3. Potential Factors for Improvement

The results of this study indicated several driver, roadway, and vehicle factors that may contribute to the likelihood of a large truck lane departure crash. Traveling at speeds too fast for conditions, including while negotiating a curve or turn, was found to be one of the major critical reasons for large truck lane departure crashes. Inattention and distraction were categorized together and were a main factor that, the analysis indicated, increased the odds of a lane departure crash. Both speeding and inattention/distraction are driver-related factors that would need to be addressed through policy, enforcement, or other measures directed at drivers.

The only vehicle factor evaluated that was relevant was cargo shift, which increased the odds that a driver would be involved in a single-vehicle large truck lane departure crash. Cargo shift is also a human factor because failing to secure a load can be due to the inattention of the driver or handlers.

Roadway factors that were indicated as increasing the likelihood of a driver's involvement in a large truck lane departure crash are presence of a curve, up- or down-grade, and narrow shoulders. Strategies to reduce driver speeds on curves may be particularly promising. Other strategies may include better delineation of curves, addition of rumble strips, and addressing of design deficiencies.

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