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Commercial Motor Vehicle Crash Risk by Time of Day

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EXECUTIVE SUMMARY

Despite a plethora of research examining commercial motor vehicle (CMV) crash risk as a function of time of day, there are few studies that have included objective measures of exposure. This is problematic, as raw crash frequencies without normalized data may lead to biased results and associated conclusions. The purpose of this study was to use carrier-owned crash and electronic logging device (ELD) data to assess CMV crash rates and, as a function of time of day, using the amount of driving time in each hour as a measure of exposure. More specifically, this study used the Hours-of-Service Rules (HOS) Impact Analysis dataset (Hickman et al., under agency review) to evaluate crash risk as a function of time of day (in hour bins), daytime vs. nighttime, and morning rush hour vs. evening rushing hour.

METHODOLOGY

As noted, this study used the recently completed the Hour-of-Service (HOS) Rules Impact Analysis (Hickman et al., under agency review), which contained crash and driver duty status data from 11 carriers with 36,000 crashes and ELD data from over 134,000 drivers over 21,639,182 log-days. The dataset included carrier descriptive information, detailed crash variables, driver log variables, and driver information. As each carrier's crash dataset was unique, researchers standardized crash types and other variable formatting across all carriers so that all crashes could be merged into one master crash dataset. Researchers aligned the ELD and crash data using time zone locations based on crash location and drivers' home terminal location.

Calculation of Hours and Time of Day

Three analyses were performed: crash rate by hour of day, crash rate by daytime vs. nighttime period, and crash rate by morning rush hour, evening rush hour, and non-rush hour periods. In the first analysis, the ELD data was used to determine time spent driving in each hour of the day for each driver. The second analysis used daytime hours from 6:00 a.m. to 6:00 p.m. and nighttime hours from 6:00 p.m. to 6:00 a.m. Driving time was summed across each time period. Morning rush hour was from 6:00 a.m. to 8:59 a.m. and evening rush hour was from 4:00 p.m. to 6:59 p.m. in the third analysis. Non-rush hour was all other times outside of morning and evening rush hour. Driving time was calculated for each rush hour period.

Driving time was calculated by HOS shift, including only driving hours within the HOS regulation limits (i.e., a maximum of the first 11 driving hours within a 14-hour on-duty window per shift). Researchers then determined how many crashes occurred during each driving hour and time of day hour bin. The rate of crashes per 1 million driving hours was calculated for each driving hour and time of day hour period and was compared for a single driving hour across the entire day using the Poisson regression model described below. Researchers also used beta regression models to assess differences in proportions of crash types between time periods.

RESULTS

Crash Rate by Individual Hour of Day

Figure ES-1 shows the average crash rates per 1 million driving hours for all crashes, injury crashes, and fatal crashes. In general, all three crash severities peaked between 4:00 a.m. and

7:00 a.m., 7:00 p.m. and 9:00 p.m., and at 11:00 p.m. Similar trends were observed for preventable and non-property damage only crashes.

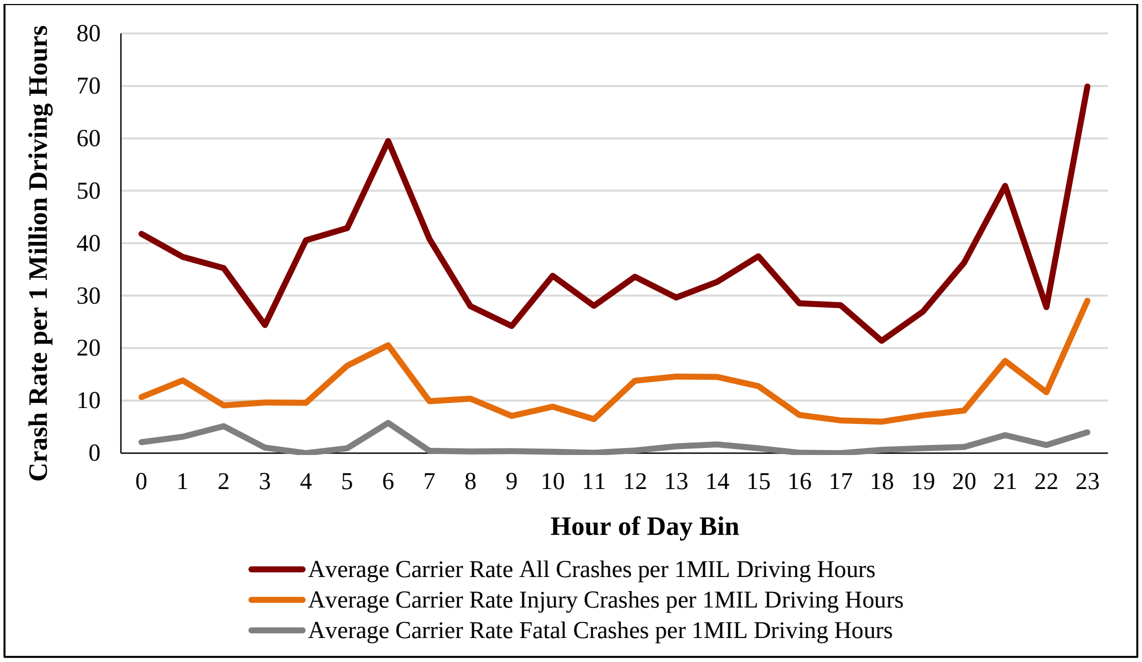

Figure ES-1. Graph. Average carrier crash rates per 1 million driving hours for all crashes, injury, and fatal crashes for each hour of the day.

Poisson regression results showed that the 6:00 a.m. and 11:00 p.m. hours had significantly higher overall crash rates compared to many other hours. In the analysis, hours with similar crash rate values were grouped in bins, to control the number of pairwise comparisons in the post hoc tests with adjusted alpha values. Specifically, the following hours showed statistically significant differences (across hour bin groupings):

- Hour 11:00 p.m. showed a significantly higher crash rate compared to hours 1:00 a.m., 2:00 a.m., 3:00 a.m., 8:00 a.m., 9:00 a.m., 10:00 a.m., 11:00 a.m., 12:00 p.m., 1:00 p.m., 2:00 p.m., 3:00 p.m., 4:00 p.m., 5:00 p.m., 6:00 p.m., 7:00 p.m., 8:00 p.m., and 10:00 p.m.
- Hour 6:00 a.m. showed a significantly higher crash rate compared to hours 3:00 a.m., 8:00 a.m., 9:00 a.m., 11:00 a.m., 1:00 p.m., 4:00 p.m., 5:00 p.m., 6:00 p.m., 7:00 p.m., and 10:00 p.m.
- Hours 12:00 a.m., 4:00 a.m., 5:00 a.m., and 7:00 a.m. showed significantly higher rates of crashes compared to hours 8:00 a.m., 11:00 a.m., 1:00 p.m., 4:00 p.m., 5:00 p.m., 7:00 p.m., and 10:00 p.m.

For each crash subgroup (all crashes, injury, fatal, preventable, non-claims only, run-off-road, rear end, and rollover), the proportion of those crashes over all crashes for each hour bin was compared using a beta regression model. Hours with similar proportion values were grouped into bins during analysis, to control the number of pairwise comparisons. Results showed the following hours had statistically significant differences (across hour bin groupings):

- The proportion of injury crashes was significantly higher in hours 8:00 a.m., 12:00 p.m., 1:00 p.m., 2:00 p.m., and 11:00 p.m. compared to hours 12:00 a.m., 2:00 a.m., 5:00 a.m., 10:00 a.m., 11:00 a.m., and 4:00 p.m.
- The proportion of fatal crashes was significantly higher in:
    - Hour 11:00 p.m. compared to hours 7:00 a.m., 8:00 a.m., 9:00 a.m., 10:00 a.m., 11:00 a.m., 12:00 p.m., 4:00 p.m., and 10:00 p.m.
    - Hour 2:00 a.m. compared to hours 7:00 a.m., 8:00 a.m., 9:00 a.m., 10:00 a.m., 11:00 a.m., 12:00 p.m., 4:00 p.m., and 10:00 p.m.
    - Hours 12:00 a.m., 1:00 a.m., 3:00 a.m., 5:00 a.m., 6:00 a.m., 1:00 p.m., 2:00 p.m., 3:00 p.m., 6:00 p.m., 7:00 p.m., 8:00 p.m., and 9:00 p.m. compared to hours 7:00 a.m., 8:00 a.m., 9:00 a.m., 10:00 a.m., 11:00 a.m., 12:00 p.m., 4:00 p.m., and 10:00 p.m.
- The proportion of preventable crashes was significantly higher at:
    - Hours 4:00 a.m. and 5:00 a.m. compared to hours 12:00 a.m., 1:00 a.m., 2:00 a.m., 3:00 a.m., 6:00 a.m., 8:00 a.m., 9:00 a.m., 10:00 a.m., 11:00 a.m., 1:00 p.m., 3:00 p.m., 4:00 p.m., 5:00 p.m., 6:00 p.m., 8:00 p.m., 9:00 p.m., and 11:00 p.m.
    - Hours 1:00 a.m., 2:00 a.m., 6:00 a.m., 7:00 a.m., 8:00 a.m., 10:00 a.m., 11:00 a.m., 12:00 p.m., 1:00 p.m., 2:00 p.m., 5:00 p.m., 7:00 p.m., 8:00 p.m., 9:00 p.m., and 11:00 p.m. compared to hours 3:00 a.m. and 10:00 p.m.
- The proportion of rollover crashes was significantly higher at:
    - Hour 7:00 p.m. compared to hours 12:00 a.m., 2:00 a.m., 3:00 a.m., 8:00 a.m., 9:00 a.m., 10:00 a.m., 11:00 a.m., 3:00 p.m., 4:00 p.m., 5:00 p.m., 6:00 p.m., 8:00 p.m., and 9:00 p.m.

Daytime and Nighttime Period

Figure ES-2 shows the average overall crash rates per 1 million driving hours during the daytime and nighttime periods by carrier. Results show that approximately half of the carriers had higher overall crash rates during daytime hours (carriers 1, 6, 9, and 11), and the other half of carriers had higher overall crash rates during nighttime hours (carriers 3, 4, 5, 7, and 10). No statistically significant differences in average overall crash rates between the daytime and nighttime periods were found across all the carriers in the Poisson regression model.

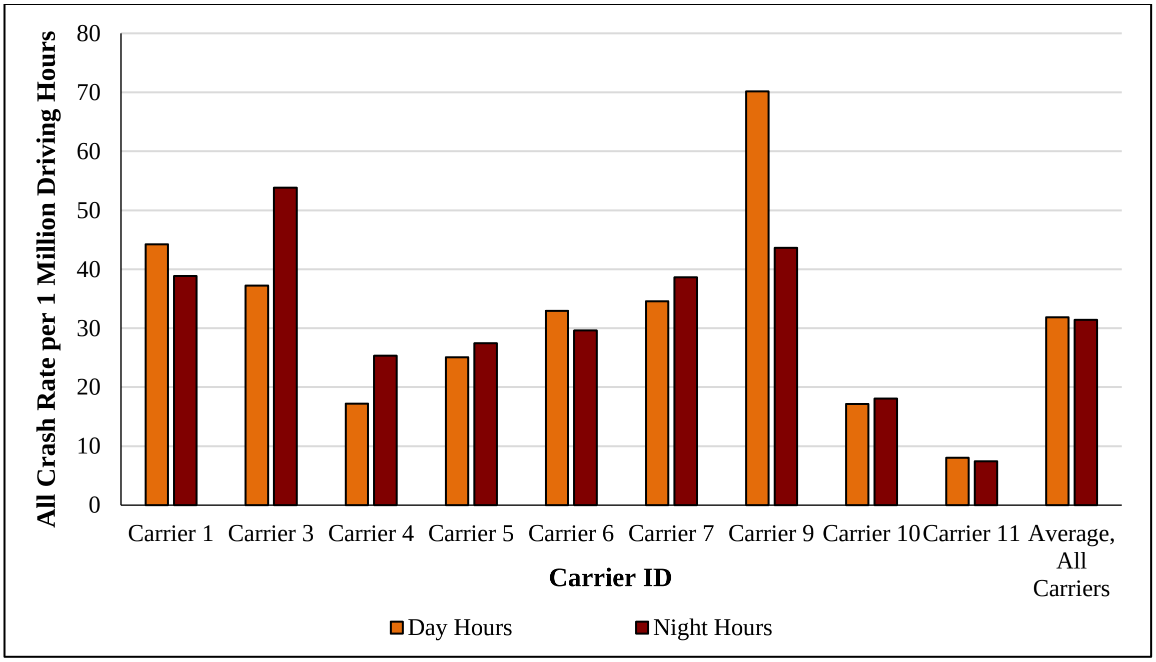

Figure ES-2. Graph. Crash rates of all crashes per 1 million driving hours in daytime and nighttime periods by carrier.

Beta regression analyses did find some statistically significant differences between daytime and nighttime crash rates for the proportion of run-off-road crashes—the proportion of run-off-road crashes was lower during daytime hours compared to nighttime hours. The crash rates for crash subgroups were not found to differ between daytime and nighttime periods.

Morning and Evening Rush Hour Period

Figure ES-3 shows the overall crash rates per 1 million driving hours for morning rush hour, evening rush hour, and non-rush hour periods by carrier. Results showed that across all carriers, the morning rush hour period had significantly higher overall crash rates per 1 million driving hours compared to the evening rush hour and non-rush hour periods. Beta regression analyses did not find statistically significant differences in the proportion of any crash subgroups between morning and evening rush hour periods.

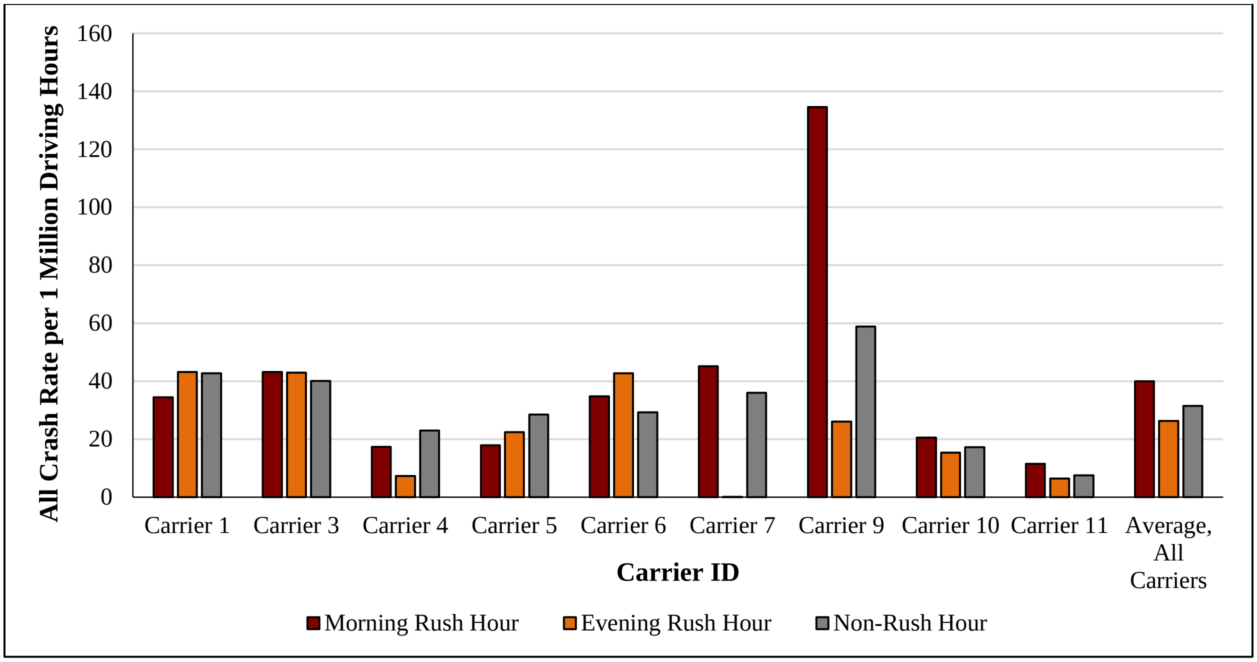

Figure ES-3. Graph. Overall crash rates per 1 million driving hours in morning rush hour, evening rush hour, and non-rush hour periods, by carrier.

DISCUSSION

Previous research is mixed on whether CMVs have a higher crash rate during daytime hours or nighttime hours. However, most previous studies indicated there was a greater risk of CMV crashes during daytime hours, possibly due to increased traffic density. Additionally, many previous studies did not have good measures of exposure to assess crash risk by time of day. Results from this study using driving hours per hour as a measure of exposure help to bridge the gap in previous research.

Using driving hours per hour of the day, results from this study showed that crash rates for overall, preventable, injury, and fatal crashes were highest in the early morning hours between 4:00 a.m. and 6:00 a.m. Additionally, overall crash rates were significantly higher at 6:00 a.m. and 11:00 p.m., compared to several other hours. In fact, the 11:00 p.m. hour had the highest crash rates per 1 million driving hours and was approximately twice as risky compared to many other hours. These results are consistent with some of the previous research examining time of day factors affecting CMV crash risk (Blower & Campbell, 1998; Knipling & Bocanegra, 2008; M. Islam & Hernandez, 2014; Panhukula et al., 2015; and Zheng et al., 2018). This study's results also partially support Barr et al. (2007), who found that many of the crash types related to driver fatigue occurred around the early morning circadian rhythm low point.

This study also provided some explanation for the inconsistencies in previous results regarding the effect of time of day on CMV crash risk. As this study collected carrier demographic data, researchers were able to glean some information regarding carrier operational differences. Results across carriers did not find statistically significant differences between the daytime and nighttime periods. However, a closer examination of the data showed that approximately half of the carriers had higher crash rates per 1 million driving hours during the daytime, and the other half of carriers had higher crash rates per 1 million driving hours during the nighttime. These differences were likely linked by the operational differences between each of the carriers, which supports results found in Blower and Campbell (1998). Operational differences between the carriers in the current study included regional versus long-haul operations and commodities delivered.

Finally, results from the regression models found that the proportion of preventable crashes was significantly higher between 4:00 a.m. and 5:00 a.m. than during many other hours of the day. These results suggest that the early morning hours are disproportionately risky for crashes caused by CMV drivers, possibly due to driver fatigue. Further, the proportion of run-off-road crashes was significantly higher during the nighttime hours compared to the daytime hours.

In summary, this study overcame a limitation in previous time of day research by collecting driving exposure via the ELD. The ELD data allowed researchers to calculate the number of driving hours for each hour of the day, thereby standardizing crash rates across hours of the day per 1 million driving hours. These results showed that CMV crash rates per 1 million driving hours were highest at nighttime in the 9:00 p.m. hour, 11:00 p.m. hour, and between 2:00 a.m. and 7:00 a.m.

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LIST OF ABBREVIATIONS AND SYMBOLS

CI	confidence interval
CMV	commercial motor vehicle
DF	degrees of freedom
ELD	electronic logging device
FARS	Fatality Analysis Reporting System
FMCSA	Federal Motor Carrier Safety Administration
GES	General Estimates Systems
HOS	hours-of-service
LTCCS	Large Truck Crash Causation Study
NTSCE	National Transportation Safety Center for Excellence
OR	odds ratio
SCE	safety-critical event
VMT	vehicle miles traveled

CHAPTER 1. INTRODUCTION

Prior research has examined the relationship between time of day and crashes involving commercial motor vehicles (CMVs), light vehicles, motorcycles, and/or bicycles. These studies evaluated the relationship between time of day and other factors, such as number of vehicles involved (single vs. multi-car crashes), crash location, sleep quantity and quality, and driver age and gender (details of these studies are described in Chapter 2). Despite a plethora of research examining CMV crash risk as a function of time of day, there are few studies that have included objective measures of exposure when assessing crash risk by time of day.

Exposure is important in this type of analysis, as it normalizes the data and allows quantitative analyses in which some driving epochs have a higher crash rate than others. Naturalistic driving research is one of the few methods that includes detailed data on exposure measures to analyze risk. However, while naturalistic research provides invaluable pre-crash behavior, there are few crashes present in most naturalist databases, making it is difficult to evaluate crash risk using these data. Conversely, CMV fleets often maintain detailed records of all crashes and incidents involving their vehicles as well as exposure data collected by onboard monitoring devices, such as electronic logging devices (ELDs).

The purpose of this study was to use carrier-owned crash and ELD data to assess CMV crash rates as a function of time of day using the amount of driving time in each hour as a measure of exposure. More specifically, this study uses the Hours-of-Service (HOS) Rules Impact Analysis dataset (Hickman et al., under agency review) to evaluate crash risk as a function of time of day (in hour bins), daytime vs. nighttime, and morning rush hour vs. evening rushing hour.

CHAPTER 2. LITERATURE REVIEW

This section of the report summarizes prior research that examined how time of day may influence CMV crashes. Most of these studies were retrospective, using data from police-reported crashes, insurance claims, hospital reports, etc. In general, most research found a higher frequency of CMV crashes during daytime hours. However, this was likely because the majority of CMV operations occur during daytime hours. The following are critical highlights of research examining the relationship between time of day and CMV crashes (see Appendix A for a high-level overview of findings across all CMV studies examining time of day factors).

TIME OF DAY AND CMV CRASHES

Zheng et al. (2018) mined the Federal Motor Carrier Safety Administration (FMCSA) datasets to understand what factors affected the frequency and severity of CMV crashes. This dataset included records from police reports (i.e., driver information, crash conditions, and environment), motor carrier operational factors, and CMV safety inspection records. The authors focused on CMV-related crashes that occurred in North Dakota and Colorado between 2010 and 2016. Results showed the early morning hours (between 3:00 a.m.–6:00 a.m.) were the most dangerous hours, as fatal crashes were more likely to occur during this time. Similarly, nighttime hours (between 9:00 p.m.–12:00 a.m.) were considered dangerous, as this time frame was also associated with many fatal crashes. Lastly, crashes on the weekend were more likely to be fatal; however, crashes on Fridays were more likely to be non-fatal.

Blower and Campbell (1998) analyzed the relationship between CMV crashes and time of day with data from the Fatality Analysis Reporting System (FARS) and the General Estimates System (GES) from 1993 to 1995. Although vehicle miles traveled (VMT) by hour of the day were not available, general VMT estimates per night (9:00 p.m.–6:00 a.m.) and day (6:00 a.m.–9:00 p.m.) were available. Overall, results showed that nighttime hours were approximately two times more risky than daytime hours. Additionally, 20% of all fatal crashes and their associated fatalities and 10% of all injuries involving a CMV occurred between 12:00 a.m. and 6:00 a.m. Crashes that occurred during these times also had a higher likelihood for severe injuries (Blower & Campbell, 1998).

In 2004, the Insurance Institute for Highway Safety analyzed FARS and GES to identify data trends in fatal and non-fatal car crashes. They found that almost 19% of fatal CMV crashes occurred between 12:00 p.m. and 3:00 p.m. Cerwick et al. (2014) conducted a study to understand the relationship between CMV crash severity and several causative factors. Data from CMV crashes between 2007 and 2012 in Iowa were collected, and results showed that crash severity involving a CMV differed by time of day and day of the week. There was a higher probability of a severe or fatal crash at the beginning of the week (Monday or Tuesday) and over the weekend (Saturday or Sunday). However, there was a lower probability of a serious injury or fatal crash towards the end of the week (Thursday or Friday). CMV crashes that occurred midday (i.e., from 11:00 a.m.–2:00 p.m.) were more likely to be severe or fatal, and crashes that occurred in the evening (i.e., from 3:00 p.m.–6:00 p.m.) were more likely to result in no injury.

M. Islam and Hernandez (2014) analyzed crash severity data from the GES (calendar years 2005 to 2008) and found that crashes between 3:00 p.m. and 7:00 p.m. had a smaller likelihood of resulting in injury compared to crashes that occurred between midnight and 6:00 a.m. Additionally, fewer injury crashes occurred in the fall (September to December) compared to the summer (June to August).

Data from the Texas Department of Public Safety between 1991 and 1999 showed that most CMV crashes transpired during the day (Ghariani, 2001). Offei & Young (2014) used data from rural freeways in Wyoming and Nebraska and found similar time of day crash trends. However, Duncan et al. (1998) found that the likelihood of a CMV crash in North Carolina resulting in a severe injury was higher during the nighttime. Curnow found the rate of CMV crashes was evenly distributed throughout a 24-hour period, but that the majority of severe crashes happened during the day (Curnow, 2002). Researchers from Australia conducted a study to look at what factors influenced CMV collisions at intersections and between blocks, including time of day, day of the week, and severity of a crash (Balakrishnan, Moridpour, & Tay, 2016). They collected data from VicRoads (the Victoria, Australia, driver licensing, vehicle registration, and towing authority) and police-reported collisions in Victoria, Australia, between 2003 and 2012. There were 556 single-vehicle crashes reported in the Melbourne metropolitan area that involved CMVs. The time of day variable was found to not be associated with CMV crashes at either the intersection or the midblock.

COMBINATION-UNIT VS. SINGLE-UNIT CMVS

An analysis of data from the Large Truck Crash Causation Study (LTCCS) was conducted to understand the frequency of crashes involving combination-unit CMVs and single-unit CMVs (Knipling & Bocanegra, 2008). Overall, most of the crashes occurred during the day and during rush hour. For combination-unit CMVs, there was a higher rate of crashes during nighttime conditions. They also found the probability of a crash occurring during dark conditions was three times higher for combination-unit CMVs versus single-unit CMVs. Lemp et al. (2011) sought to understand the crash performance of long-combination CMVs. They analyzed data collected from LTCCS, GES, and Vehicle Inventory and Use Survey datasets, which allowed them to analyze the impact of environmental, driver, occupant, and vehicle characteristics. The authors found the likelihood of a fatal crash increased during the nighttime on roads with no lighting (i.e., when visibility was compromised).

SINGLE-VEHICLE AND MULTI-VEHICLE CRASHES WITH A CMV

Wei et al. (2017) conducted a study to analyze factors affecting crash severity for both single- and multiple-vehicle CMV crashes. The study focused on CMV crashes that occurred between 2008 and 2012 in New York City, finding that most crashes occurred during the day (70% to 80%) and in dry road conditions (80%). Most single- and multiple-vehicle crashes occurred between 10:00 a.m. and 3:00 p.m.; however, single-vehicle crashes were less severe in the afternoon and nighttime compared to multiple-vehicle CMV crashes (Wei, Xiaokun, & Dapeng, 2017). S. Islam et al. (2014) analyzed factors that affected crash severity of at-fault single and multi-vehicle CMV crashes in rural and urban locations in Alabama. They found that dark conditions increased the probability of a fatal CMV crash. Multiple-vehicle collisions that occurred in dark conditions had a higher probability of resulting in minor injuries in urban areas compared to rural areas.

M. Islam & Hernandez (2014) found that single-vehicle crashes between 12:00 a.m. and 7:00 a.m. in rural areas were more likely to result in a major injury. Additionally, there was an increased probability of no injury in rural single-vehicle crashes during afternoon peak travel times. There was an increased probability of a major injury between 6:01 p.m. and 12:00 p.m. for multi-vehicle crashes in rural areas. There were no statistically significant effects for urban models. However, the authors found that congestion reduced the chance of crashes resulting in fatal, incapacitating, or any injuries during the afternoon time.

CMVs AND TRAFFIC DENSITY

Hanowski et al. (2008) conducted a naturalistic CMV driving study to evaluate the effects of cumulative driving time and time of day on involvement in a safety-critical event (SCE). Forty-six trucks were instrumented with sensors and video recorders to measure driver performance. Time of day was observed in 24 hourly bins. The analysis found that traffic density might explain the time of day effect, as SCE rates were highest during morning and evening rush hours. Additionally, the study found that a circadian effect was not associated with time of day. Thus, time of day effects seemed to be associated with traffic density rather than circadian rhythm.

Pahukula et al. (2015) conducted a study to identify contributing factors in urban freeway crashes that involved a CMV using 2006–2010 data from Texas' Crash Records Information System. The authors found an increased likelihood of crashes in the morning (between 5:00 a.m. and 9:00 a.m.) and evening (between 9:00 p.m. and 11:00 p.m.) when more CMVs were on the road. Further, results showed that different time periods had different influences on crash severity. Speeding and lane changes were factors that contributed to CMV crashes between 10:00 a.m. and 3:00 p.m. (usually an uncongested period). During summer months, traffic congestion impacted crash severity between 4:00 p.m. and 8:00 p.m. Finally, clear weather with dark lighting conditions was more likely to result in a severe injury or a no-injury crash between 4:00 p.m. and 8:00 p.m.

SLEEP, LOCATION, AND SHIFT CHANGE WITH CMV CRASHES

Marquis and Wang (2015) found that routes in areas with a large population and in areas with more businesses related to finance, insurance, and/or health care fields were less likely to have crashes at night. In comparison, routes that included areas with larger household sizes and in locations with more employment in the retail, professional services, education, and accommodation fields had an increase in nighttime crashes. There was an increase in crashes when CMV drivers altered their shifts from a morning peak workday to a nighttime peak workday. Also, when drivers changed their shifts from an afternoon peak shift to a nighttime shift, there was an increase in crashes, but these crashes were less likely to result in an injury or fatality. When the driver shifts changed from midday to nighttime, the rate of crashes was slightly reduced.

Park and Jovanis (2010) conducted a case-control study using data collected from three CMV companies in 2004 when new HOS regulations were implemented. The study included 231 CMV crashes. Results showed there was an increase in crash risk associated with driving hours after the first hour of driving. Additionally, CMV drivers had a higher crash risk when returning to work after an off-duty period of more than 46 hours.

Finally, Barr et al. (2007) found that CMV drivers were more likely to become fatigued or prone to drowsy events in the morning (7:00 a.m.–8:00 a.m.). This increased the drivers' likelihood of being in an SCE. Additionally, the results showed an increase in the frequency and severity of CMV SCEs during this time period.

LITERATURE REVIEW SUMMARY

Overall, the previous literature is inconclusive as to whether CMVs have a higher-crash rate during daytime or nighttime hours. However, most studies indicated there was a greater risk of CMV crashes during daytime hours due to increased traffic density. Although most CMV crashes occurred during the daytime hours, injury and fatal crashes were more likely to occur during the nighttime (9:00 p.m. to 12:00 a.m.). Early morning hours (3:00 a.m. to 6:00 a.m.) were reported as having the most dangerous crashes. However, there were differences regarding the number of vehicles involved in the crash, with single-vehicle crashes being less severe during the afternoon (1:00 p.m. to 4:00 p.m.) and multi-vehicle crashes being more severe during the nighttime (9:00 p.m. to 12:00 a.m.). Crashes that occurred on Monday, Tuesday, and the weekend were more likely to be fatal, whereas crashes on Thursday and Friday were less likely to result in severe injuries. Additionally, results indicated that traffic density, shift change, increased driving time, and drowsiness affected CMV crash occurrence.

CHAPTER 3. METHODS

The recently completed HOS Rules Impact Analysis (Hickman et al., under agency review) contained unparalleled data elements to assess CMV crash risk by time of day. This dataset contained crash and driver duty status data from 11 carriers with 36,000 crashes and ELD data from over 134,000 drivers over 21,639,182 log-days. The following variables were requested from each of the 11 carriers; however, carriers were only required to provide information on those variables in italics.

- Carrier descriptive variables
  - *Number of power units*
  - *Type of operations (i.e., long-haul, regional, and short-haul)*
  - *Typical commodities*
- Crash variables
  - *Anonymous driver identification*
  - *Crash date*
  - *Crash location (city, state)*
  - *Crash time of day*
  - Contributing factors (e.g., fatigue, aggressive driving, weather, etc.)
  - Narrative
  - *Crash type*
  - Was the crash an FMCSA-reportable?
  - Was the crash preventable?
  - How many injuries occurred?
  - How many fatalities occurred?
- Driver log variables
  - *Anonymous driver identification*
  - *Date*
  - *Duty status*
  - *Duty start time*
- Driver information
  - *Anonymous driver identification*
  - *Driver home terminal time zone*

CARRIER RECRUITMENT

Only carriers with more than 1,000 power units were targeted for recruitment. The only prerequisites for participation were the use of an ELD to record driver duty status and the ability and willingness to provide the necessary data. Researchers contacted 82 carriers via email and telephone. Of those 82 carriers, only 11 carriers ultimately agreed to participate.

CARRIER DATA COLLECTION

Carriers provided all the required data via a Microsoft Excel dataset or a comma separated value/XML/text file via email or flash drive through the U.S. Postal Service or an FTP transfer. Upon review, researchers worked with the carrier representatives to provide any missing data and/or codes for data included in each dataset.

Table 1 provides some demographic data on the participating fleets.

Table 1. Carrier demographics.

Carrier	Description	# of Power Units	Yearly Mileage	Commodities	Typical Haul
1	For Hire	3,000-4,000	300-400	General freight, paper products, construction, chemicals, beverages, farm supplies	Long, regional
2	For Hire	3,000-4,000	400-500	General freight, fresh produce, intermodal, paper products	Long, regional
3	For Hire	1,000-2,000	100-200	General fright, building materials, fresh produce, paper products, refrigerated food, metal, logs/lumber, machinery, meat	Long, regional
4	For Hire	1,000-2,000	100-200	General freight, building, paper products, refrigerated food, beverages	Long, regional
5	For Hire	2,000-3,000	200-300	General freight, building materials, fresh produce, paper products, refrigerated food, chemicals, beverages	Long, regional
6	For Hire	2,000-3,000	100-200	General freight, building materials, fresh produce, grain, dry bulk, paper products, construction, liquid/gas, refrigerated food, metal, logs/lumber, machinery, meat, chemicals, beverages, farm supplies, sand	Long, regional
7	For Hire	5,000+	500+	General freight, vehicles, building materials, fresh produce, grain, dry bulk, paper products, construction, liquid/gas, mail, metal, logs/lumber, machinery, chemicals, beverages, farm supplies	Long, regional
8	Private	1,000-2,000	10-20	Liquid/gas, intermodal, chemicals	Regional
9	Private	5,000+	200-300	Fresh produce, paper products, liquid/gas, refrigerated food, meat, chemicals, beverages	Regional
10	For Hire	5,000+	500+	General freight, building materials, grain, paper products, construction, liquid/gas, oil field equipment, mail, refrigerated food, metal, logs/lumber, intermodal, livestock, meat, chemicals, beverages, farm supplies	Long, regional
11	For Hire	4,000-5,000	500+	General freight, building materials, fresh produce, dry bulk, paper products, mail, refrigerated food, metal, logs/lumber, intermodal, meat, chemicals, beverages	Long, regional

Crash Data Coding and Standardization

As each carrier's crash dataset was unique, researchers were required to standardize variables and format across all carriers so that all crashes could be merged into one master crash dataset. Additionally, researchers standardized crash types across all carriers using information provided in the crash narrative (if available) and the carrier-provided crash type. The standardized crash types are shown in Table 2.

Table 2. Operational definitions for the uniform crash types.

Crash Type	Operational Definition
Run Off Road	The truck ran off the road and the surface caused the first damage to the truck.
Head On	The truck had a front-end collision with another vehicle on the roadway.
Rear-End	The truck rear-ended another vehicle on the roadway.
Rear-Ended	The truck was rear-ended by another vehicle on the roadway.
Sideswipe	The truck struck another vehicle/object traveling in the same direction on its side.
Opposite Sideswipe	The truck struck another vehicle traveling in the opposite direction on its side.
Backing	The truck backed up and struck another vehicle or object.
Parking Lot	The truck struck a fixed object or vehicle while maneuvering in a parking lot, dock, or truck stop.
Hit Object in Road	The truck hit an object in the roadway while driving.
Hit Animal	The truck struck an animal in the roadway.
Rollover	The truck rolled over, and the rollover was the first impact.
Jackknife	The truck jackknifed and the jackknife was the first impact (loss of control of the trailer).
Parked	Another vehicle, person, or object damaged the truck while it was parked.
Roll Back	The truck rolled back into another vehicle or object after releasing the brake.
Roll Away	The truck rolled forward into another vehicle or object after releasing the brake.
Hit Fixed Object	The truck struck a fixed object not on the roadway.
Hit Pedestrian	The truck struck a person.
Overhead	The truck struck an overhead object (e.g., an overpass).
Mechanical	The truck experienced some sort of mechanical failure causing the first impact.
Hit by Other Vehicle	Another vehicle struck the truck, but there was not enough information to classify a specific crash type.
Hit Other Vehicle	The truck struck another vehicle, but there was not enough information to classify a specific crash type.
Broadside	The truck had a driver/passenger side impact with another vehicle, or the other vehicle had a driver/passenger side impact with the truck.
Other	Miscellaneous crash circumstances that did not fit into other categories.
Non-Contact	Any instance where there was not contact with another vehicle, object, or pedestrian (e.g., tire blowout).

Additionally, some carriers provided data on all incidents involving their trucks (e.g., property claims, non-contact damage, etc.), while other carriers only provided data on actual vehicle collisions. Thus, researchers coded each incident as a crash or property-only claim using the crash narrative, carrier-provided crash type, and location. The following types of events were coded as property-only claims: curb strikes, mechanical failures with no other collisions, parking lot incidents not involving vehicle-to-vehicle contact, all non-contact incidents, incidents where the truck was struck while parked, and vandalism. All property-only claims were excluded from the study.

Aligning ELD and Crash Data

To overlay the ELD, driver, and crash datasets, carriers were required to use standard driver identification numbers across each of the datasets. Researchers reviewed each row of data to ensure driver identification was included. It was discovered that not all crashes were linked to a driver identification number in the crash data (i.e., driver duty status was not provided for that driver or the driver identification number was incorrect). Table 3 displays the percentage of matching driver identification numbers from the crash and ELD datasets. Due to low matching numbers (37.7%), Carrier 2 was removed from all analyses.

Table 3. Percentage of correct matching driver IDs in the crash and ELD datasets.

Carrier	Percentage of Matching Driver IDs
1	82.6%
2	37.7%
3	87.9%
4	91.0%
5	96.9%
6	64.9%
7	75.7%
8	76.4%
9	57.7%
10	99.4%
11	99.9%

As discussed above, the final dataset included detailed records of crashes and a measure of exposure (i.e., hours of driving within each hourly bin). Crash data included crash times reported in the time zone of crash occurrence. However, the ELD data was also reported in the drivers' home terminal time zone. Thus, the time zones for the crash times and ELD times often did not match. The crash locations were compared to the driver's home terminal to determine the crash time adjustment needed to align the crash time to the driver's reference time zone. For each driver, the number of crashes in each hour of the day was calculated. Only crashes from the same time periods as the driver logs were kept for analysis. Drivers without time zone data and those with unclear time zone data were excluded from the study.

CALCULATION OF HOURS AND TIME OF DAY

The exposure for the crash rate calculation was hours driving in the time period. For each driver, the ELD data was used to determine time spent driving in each hour of the day. For example, if the ELD data indicated the driver drove for 1 hour from 2:00 p.m. to 2:59 p.m., the driver would have 1 hour of driving time exposure added to the 2:00 p.m. hour bin. If a driver had 1 hour of driving from 2:30 p.m. to 3:30 p.m., the driver would have 30 minutes of driving time exposure added to the 2:00 p.m. hour bin and another 30 minutes of driving time exposure added to the

3:00 p.m. hour bin. These tabulations were performed for all drivers, for each carrier, using ELD data from the same years as the crash dataset.

For the analysis of crash rate by hour of the day, the driving time exposure was kept as it was tabulated above. In the analysis by daytime and nighttime bins, the exposure was summed across the hours included in each bin—6:00 a.m. to 6:00 p.m. for daytime and 6:00 p.m. to 6:00 a.m. for nighttime. In the analysis by rush hour periods, the same method was used, with periods defined as morning rush hour from 6:00 a.m. to 8:59 a.m. and evening rush hour from 4:00 p.m. to 6:59 p.m., and all other hours considered "non-rush hour."

The final analysis required exposure calculated by hour of the day and HOS shift driving hour. An algorithm developed to determine HOS shift behaviors was applied to the ELD data. The algorithm calculated the time driving and time on duty in each log entry. For this study, only driving hours within the HOS regulation limits were included (i.e., a maximum of the first 11 driving hours within a 14 hour on-duty window per shift). To determine driving exposure, the amount of driving time within driving hour by each hour of the day was calculated. For example, if a driver had 2 driving hours in their shift, starting at 7:30 a.m., the exposure in each driving hour and time of day hour would look like the example shown in Table 4.

Table 4. Example of exposure calculation by driving hour and time of day hour.

Driver ID	Start and End Time for Exposure Period	Driving Hour	Time of Day Hour	Total Minutes in Exposure Period	Cumulative Driving Minutes
0001	7:30 a.m.–8:00 a.m.	1	7:00 a.m. –8:00 a.m.	30 minutes	30 minutes
0001	8:00 a.m.–8:30 a.m.	1	8:00 a.m.–9:00 a.m.	30 minutes	60 minutes
0001	8:30 a.m.–9:00 a.m.	2	8:00 a.m.–9:00 a.m.	30 minutes	90 minutes
0001	9:00 a.m.–9:30 a.m.	2	9:00 a.m.–10:00 a.m.	30 minutes	120 minutes

The next step was to calculate how many crashes occurred in each driving hour and time of day hourly block. To do this, crashes with reported crash times were compared to the log data. Crashes were matched to the driving log entries by date and time, with an error buffer of 30 minutes to capture crashes with reported times after the truck came to a stop. The rate of crashes per 1 million driving hours was calculated for each driving hour and time of day hour period and compared for a single driving hour across the entire day using the Poisson regression model described below.

REGRESSION MODELS

To assess differences in driving safety between various time periods, researchers used Poisson regression models and beta regression models. The model details are explained further in this section. For all analyses in this study, alpha ("α") was held at 0.01. This value was chosen to be more conservative than the traditional alpha of 0.05, while also remaining appropriate for the exploratory nature of the study (Perneger, 1998; Rothman, 1990).

Poisson Regression Model

A mixed-effect Poisson regression model was used to assess differences in crash rates between time periods. Poisson regression models are commonly used in driving safety assessments, as the models quantify how the rate of an incident or behavior over time or distance changes with some explanatory variable (Guo, 2019). In this study, the model estimated how crashes over cumulative driving hours (the exposure value) changed for the time periods. The crash counts were modeled by time period, using the log of cumulative driving hours measured in 1 million hours as an offset. A carrier-level random effect was included in the model to account for correlations in the data from the same carrier. The model was structured as follows:

$$Y_{it} \sim Poisson(E_{it}\lambda_{it})$$

where Y_{it} was the number of crashes for carrier *i* in time period *t*; E_{it} was the total exposure in hours for carrier *i* and time period *t*; and λ_i was the expected safety outcome rate for carrier *i* and time period *t*.

$$\log(\lambda_i) = \alpha_i + \beta_t X_t$$

where β_t is the parameter for time period *t*, X_t is an indicator variable for time period *t*, and α_i was the carrier-specific random term. The λ_i is linked to the model explanatory variables by a logarithm link function.

A separate model was built for each time-period analysis (a model for hour of the day, daytime vs. nighttime, rush hour periods, and each shift driving hour). Results of the models are presented in this report as risk ratios (RRs) with adjusted confidence intervals (CIs) that describe differences in estimated involvement in a safety outcome for pairs of time periods. Due to the large number of time-period pairwise comparisons to be made, time periods with similar average crash rates were binned together in the analysis. The α value was adjusted using a Tukey adjustment to control the Type I error rate.

Beta Regression Model

Beta regression models were used to assess differences in crash type proportions between time periods. Beta regression models estimate the change in a variable with data that falls within a positive, bounded window by some other explanatory variable. In this study, the beta regression model was used to assess how proportions of crash types changed over time periods. The proportions for each crash type were calculated by taking the number of crashes of that type in the time period and dividing by the total number of crashes in the time period.

Data for beta regression models must be within a (0,1) bound, not inclusive of 0 or 1. The current dataset could include these bounds, as it was possible that an hour or time period may have had a crash type with 0% of all crashes (i.e., "0" crashes of a crash type observed in the time period). To prepare the data for analysis and to meet the bounds assumption, data calculations at these bounds were transformed using the method described by Smithson and Verkuilen (2006). The method for transforming requires that the following formula be applied to data calculations at the bounds 0 or 1:

$$Transformed\ value = \frac{[Original\ percent\ calculation * (n-1) + 0.5]}{n}$$

where the original percent calculation was the “0” or “1” value and *n* was the number of observations. In the following study, *n* was held at 240, which was the number of hourly calculations over all carriers. This *n* value was sufficient for transforming the “0” and “1” values for analysis and retaining the degree of difference from non-transformed values.

The model was structured as follows:

$$Y_{it} \sim Beta(\mu_{it} \phi_{it})$$

where Y_{it} was the proportion of all crashes that were the crash subtype of interest for carrier *i* in time period *t*; $\mu_{it}$was the mean proportion of crashes that were crash subtype of interest for carrier *i* and time period *t*;, and ϕ_{it} is a precision parameter carrier *i* and time period *t*.

$$\log\left(\frac{\mu_{it}}{1-\mu_{it}}\right) = \alpha_i + \beta_t X_t$$

where $\beta_t$is the parameter for time period *t*, X_t is an indicator variable for time period *t*, and α_i was the carrier specific random term. The μ_i is linked to the model explanatory variables by a logarithm link function. Individual models were used to test for differences in each time-period type and crash type. Significant results of the models are presented in this report with the *t*-value and corresponding *p*-value, for pairs of time periods with significant differences in estimated proportion of crash subtypes. As in the Poisson regression analysis, time periods with similar proportions of crash subtypes were binned together in the analysis. To further control the potential for inflated Type I error rates in the analysis, the α value was adjusted using a Tukey adjustment.

CHAPTER 4. RESULTS

The total driving time exposures in 1,000 driving hours and crash counts per carrier are listed in Table 5. Carrier 10 had the largest sample of driving hours and crashes of all the carriers in the study. Carrier 9 had the smallest sample of driving hours in the study, and Carrier 4 had the smallest number of crashes in the study.

Table 5. Exposure in driving hours and crash counts for each crash type by carrier.

Carrier ID	Exposure in 1,000 Driving Hours	All Incident Counts	Injury Crash Counts	Fatal Crash Counts	Non-preventable Crash Counts	Preventable Crash Counts	Non-property-only Crash Counts	Rollover Crash Counts	Run-off-road Crash Counts	Rear-end Type Crash Counts
1	4,654.41	195	63	4	148	45	179	9	5	43
3	5,652.57	232	76	8	162	69	214	15	10	69
4	2,593.06	51	10	4	26	10	33	2	2	10
5	4,093.01	107	27	4	67	40	103	0	1	34
6	2,882.20	92	29	3	45	42	91	4	11	14
7	8,435.31	304	99	11	171	133	290	16	5	71
9	2,002.47	121	48	3	0	0	77	5	2	14
10	37,228.52	649	215	22	425	224	642	24	19	25
11	29,613.27	231	62	6	130	101	217	22	7	54

CRASH RATES BY INDIVIDUAL HOUR OF DAY

The following analysis investigates how the crash rate changed over the individual hours of a day. The crash rate was calculated as the number of crashes in the hour over total driving time in the hour. For a list of crash counts by carrier in each hour, see Appendix B.

The average carrier crash rates across time of day are shown in Figure 1. The rate of all crashes per 1 million driving hours is shown as a maroon line. The average crash rate for all crashes rises in hours 4:00 a.m. to 6:00 a.m. and again from 7:00 p.m. to 9:00 p.m., with a steep increase observed at 11:00 p.m. The injury crash rate is shown in the plot as an orange line. The injury crash rate pattern closely follows the all crash rate pattern; however, the average injury crash rate is much lower (10 crashes per 1 million driving hours). The average carrier fatal crash rate is shown in grey in Figure 1. The average fatal crash rates were lower than 10 crashes per 1 million driving hours but did show rises at similar times seen for injury crashes and all crashes.

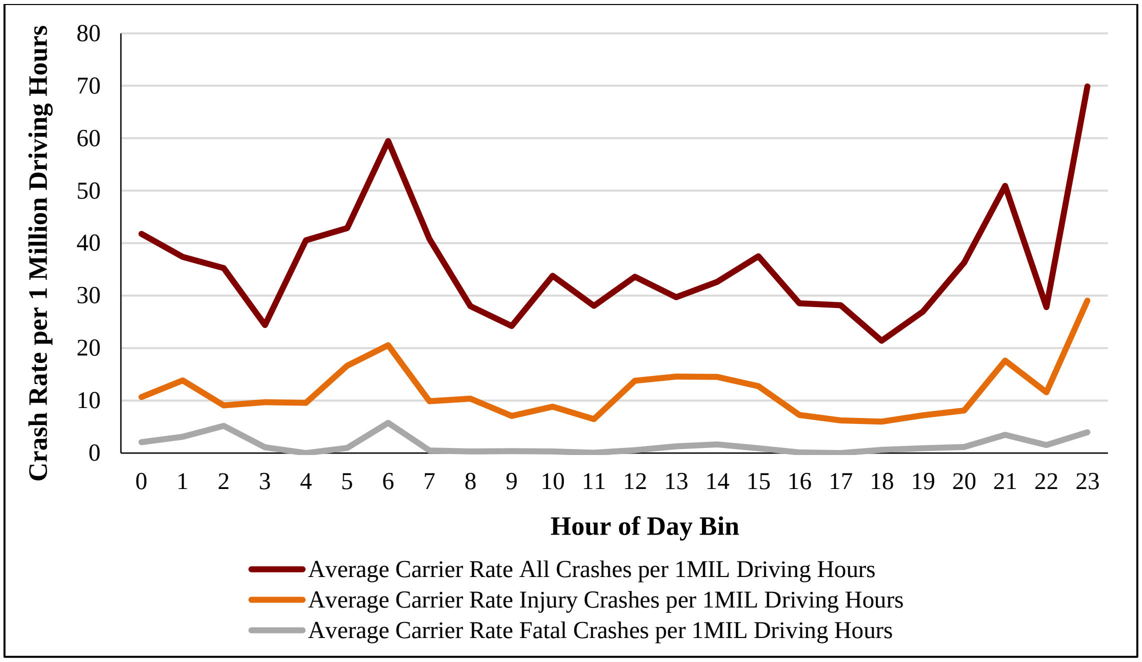

Figure 1. Graph. Average carrier crash rates per 1 million driving hours for all crashes, injury, and fatal crashes in each hour of the day.

In Figure 2, the average carrier crash rates per 1 million driving hours for preventable and non-property-only claims crashes are shown using orange and maroon lines, respectively. Average preventable crash rates hover around 10 crashes per 1 million driving hours, with a slight rise from 4:00 p.m. to 7:00 p.m., 7:00 p.m. to 8:00 p.m., and at 11:00 p.m. Average non-claims crash rates range from 21 to 57 per 1 million driving hours and are highest in hours 4:00 a.m. to 6:00 a.m., at 9:00 p.m., and at 11:00 p.m.

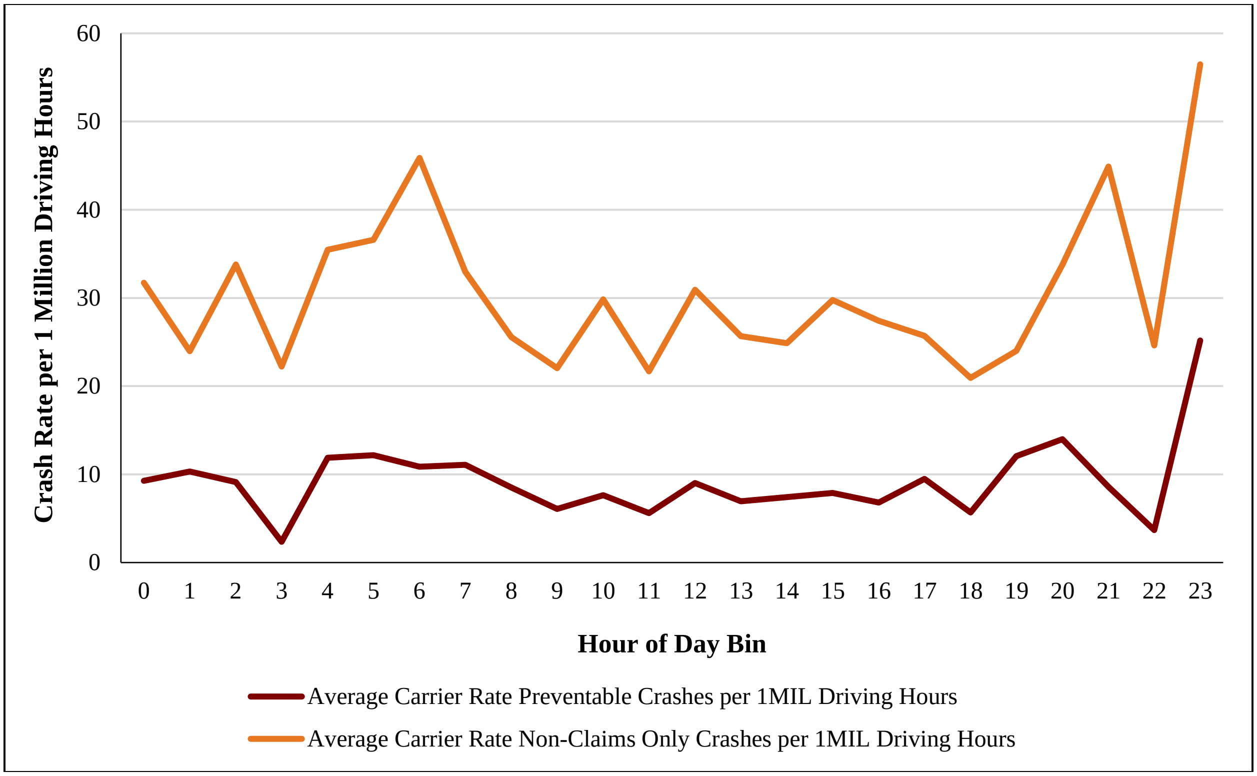

Figure 2. Graph. Average carrier crash rates per 1 million driving hours for preventable and non-property-only claims crashes in each hour of the day.

The average carrier crash rates per 1 million driving hours for rollover, run-off-road, and rear-end type crashes across time of day are shown in Figure 3 using maroon, orange, and grey lines, respectively.

- The average carrier rollover crash rate rises to 2 crashes per 1 million driving hours at 4:00 a.m. to a peak of 8 crashes at 5:00 a.m. and 4 crashes at 6:00 a.m.
- Run-off-road crashes showed rates elevated from late night hours through early morning hours, with a rise at 11:00 p.m. (rate = 8 crashes per 1 million driving hours) and another slight increase at 7:00 a.m. (rate = 4 crashes per 1 million driving hours).
- Rear-end type crashes showed a similar pattern of increased crash rates for night and early morning hours.
- Rates of rear-end type crashes were highest at 11:00 p.m. (rate = 20 crashes per 1 million driving hours), 2:00 a.m. (rate = 12 crashes per 1 million driving hours), and 6:00 a.m. (rate = 15 crashes per 1 million driving hours).

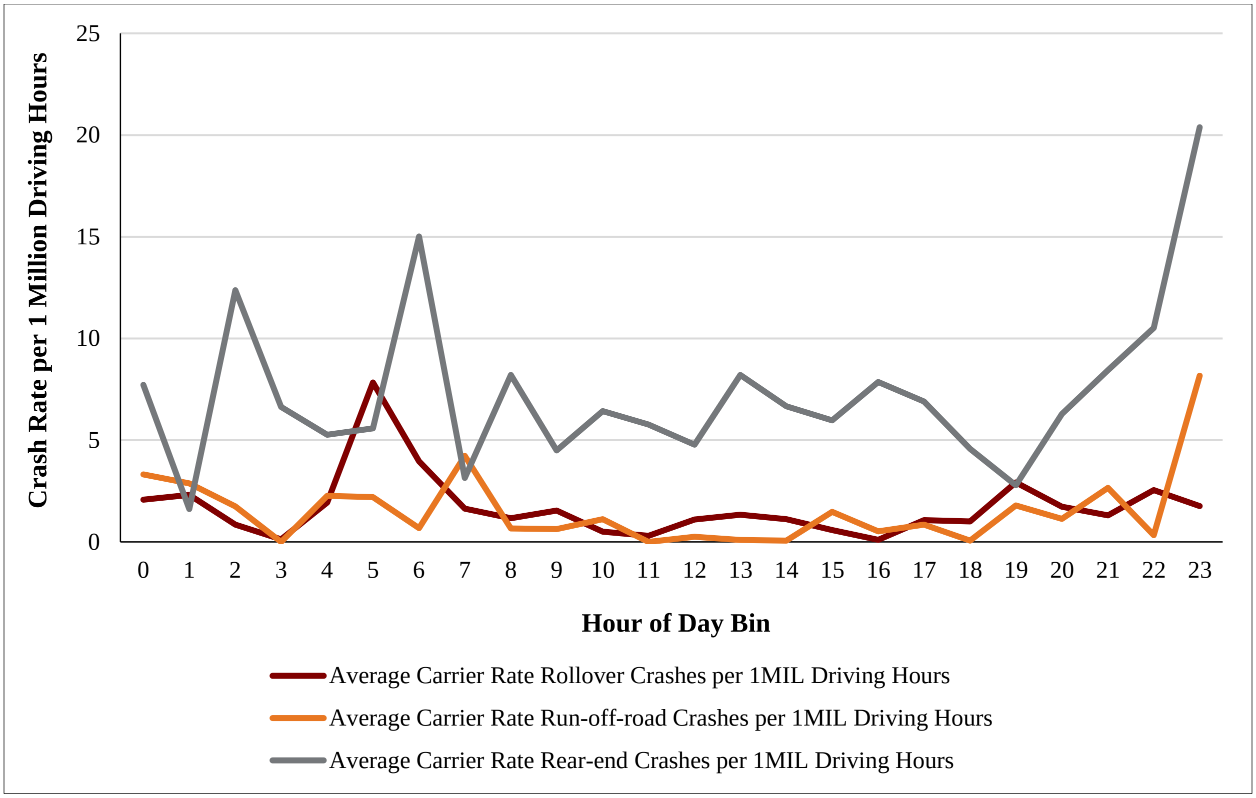

Figure 3. Graph. Average carrier crash rates per 1 million driving hours for rollover, run-off-road, and rear-end type crashes in each hour of the day.

Overall Crash Analysis

A Poisson regression model was used to evaluate how the rate of all crashes per 1 million driving hours changed over the hours of the day. To reduce the number of post hoc tests, hours with similar crash rates were grouped together and compared to other hour groups in the analysis. Driving time in the hour was used as an offset in the model. A Tukey adjustment was used to control the Type I error rate for multiple post hoc comparisons. In Table 6, the solutions for fixed effects from the model are listed with estimate calculation, *t*-value, and *p*-value.

Table 6. Solutions for fixed effects from Poisson regression model for all crashes by hour of day.

Effect	Time of Day Period	Estimate	Standard Error	DF	*t*-value	*p*-value
Intercept		-3.24	0.23	8	-14.38	<.0001
Time of Day	Hours 12:00 a.m., 4:00 a.m., 5:00 a.m., 7:00 a.m.	-0.23	0.11	200	-2.02	0.0442
Time of Day	Hours 1:00 a.m., 2:00 a.m., 10:00 a.m., 12:00 p.m., 2:00 p.m., 3:00 p.m., 8:00 p.m.	-0.35	0.10	200	-3.39	0.0009
Time of Day	Hour 6:00 p.m.	-0.62	0.15	200	-4.08	<.0001
Time of Day	Hour 9:00 p.m.	-0.13	0.16	200	-0.83	0.4047
Time of Day	Hour 11:00 p.m.	0.19	0.17	200	1.1	0.2732
Time of Day	Hours 8:00 a.m., 11:00 a.m., 1:00 p.m., 4:00 p.m., 5:00 p.m., 7:00 p.m., 10:00 p.m.	-0.50	0.10	200	-4.79	<.0001
Time of Day	Hours 3:00 a.m., 9:00 a.m.	-0.45	0.13	200	-3.57	0.0004
Time of Day	Hour 6:00 a.m.	0.00	.	.	.	.

The results of the Poisson regression model for hours with significant differences at $\alpha = 0.05$ are listed in Table 7. The following hours were found to have statistically significant differences in crash rates for the analysis of all crashes.

- The group with hours 12:00 a.m., 4:00 a.m., 5:00 a.m., and 7:00 a.m. showed significantly higher rates of crashes compared to the group with hours 8:00 a.m., 11:00 a.m., 1:00 p.m., 4:00 p.m., 5:00 p.m., 7:00 p.m., and 10:00 p.m.
- Hour 11:00 p.m. showed a significantly higher crash rate compared to:
    - the group with hours 1:00 a.m., 2:00 a.m., 10:00 a.m., 12:00 p.m., 2:00 p.m., 3:00 p.m., and 8:00 p.m.
    - hour 6:00 p.m.
    - the group with hours 8:00 a.m., 11:00 a.m., 1:00 p.m., 4:00 p.m., 5:00 p.m., 7:00 p.m., and 10:00 p.m.
    - the group with hours 3:00 a.m. and 9:00 a.m.
- Hour 6:00 a.m. showed a significantly higher crash rate compared to:
    - hour 6:00 p.m.
    - the group with hours 8:00 a.m., 11:00 a.m., 1:00 p.m., 4:00 p.m., 5:00 p.m., 7:00 p.m., and 10:00 p.m.
    - the group with hours 3:00 a.m. and 9:00 a.m.

Table 7. Poisson regression model results for all crashes by hour of day, with post-hoc analysis results comparing groups of hours for significant differences in crash rates.

Hour Group for Comparison	Hour Group for Comparison	Odds Ratio	Adjusted CI
Hours 12:00 a.m., 4:00 a.m., 5:00 a.m., 7:00 a.m.	Hours 8:00 a.m., 11:00 a.m., 1:00 p.m., 4:00 p.m., 5:00 p.m., 7:00 p.m., 10:00 p.m.	1.31	(1.05, 1.63)
Hour 11:00 p.m.	Hours 1:00 a.m., 2:00 a.m., 10:00 a.m., 12:00 p.m., 2:00 p.m., 3:00 p.m., 8:00 p.m.	1.72	(1.08, 2.72)
Hour 6:00 a.m.	Hours 1:00 a.m., 2:00 a.m., 10:00 a.m., 12:00 p.m., 2:00 p.m., 3:00 p.m., 8:00 p.m.	1.42	(1.03, 1.95)
Hour 11:00 p.m.	Hour 6:00 p.m.	2.25	(1.27, 4.00)
Hour 6:00 a.m.	Hour 6:00 p.m.	1.86	(1.17, 2.97)
Hour 11:00 p.m.	Hours 8:00 a.m., 11:00 a.m., 1:00 p.m., 4:00 p.m., 5:00 p.m., 7:00 p.m., 10:00 p.m.	1.99	(1.35, 3.16)
Hour 11:00 p.m.	Hours 3:00 a.m., 9:00 a.m.	1.90	(1.14, 3.16)
Hour 6:00 a.m.	Hours 8:00 a.m., 11:00 a.m., 1:00 p.m., 4:00 p.m., 5:00 p.m., 7:00 p.m., 10:00 p.m.	1.64	(1.20, 2.26)
Hour 6:00 a.m.	Hour 3:00 a.m., 9:00 a.m.	1.57	(1.07, 2.30)

Proportion of Crash Types by Hour of Day

In each crash type subgroup, the proportion of crashes over all crashes was calculated for each hour of the day. Figure 7 shows the proportion of injury and fatal crashes in orange and maroon lines, respectively, over the hours of the day.

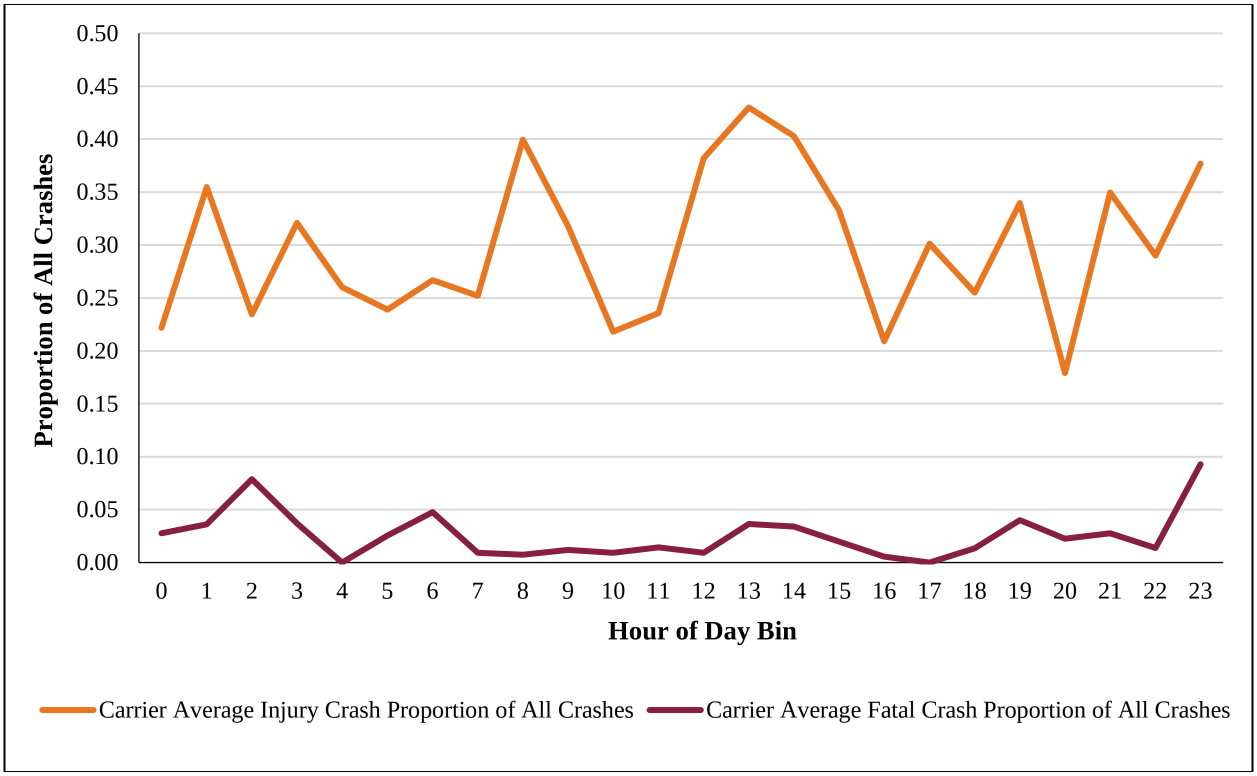

Figure 4. Graph. Carrier average proportions of all injury and fatal crashes in each hour of the day.

Individual beta regression models were used to assess whether the proportion of each crash subgroup changed significantly over the time of day. Hours with similar proportions of the crash type were grouped in the analysis to reduce the number of post hoc comparisons. To control the Type I error rate, post hoc tests compared groups of hours using an adjusted α value with a Tukey adjustment. Significant findings from the models for injury crashes and fatal crashes are listed in Table 8 and Table 9, respectively. The model for injury crash proportion found that the group with hours 8:00 a.m., 12:00 p.m., 1:00 p.m., 2:00 p.m., and 11:00 p.m. had significantly higher proportions of injury crashes compared to the group with hours 12:00 a.m., 2:00 a.m., 5:00 a.m., 10:00 a.m., 11:00 a.m., and 4:00 p.m.

Table 8. Significant post hoc test results from beta regression model for injury crash proportion of all crashes over time of day.

Hour Group 1 for Comparison	Hour Group 2 for Comparison	DF	*t*-value	*p*-value
Hours 8:00 a.m., 12:00 p.m., 1:00 p.m., 2:00 p.m., and 11:00 p.m.	Hours 12:00 a.m., 2:00 a.m., 5:00 a.m., 10:00 a.m., 11:00 a.m., and 4:00 p.m.	180	3.95	0.0015

In the model for fatal crash proportion, the group with hours 7:00 a.m., 8:00 a.m., 9:00 a.m., 10:00 a.m., 11:00 a.m., 12:00 p.m., 4:00 p.m., and 10:00 p.m. showed a significantly lower proportion of fatal crashes compared to 14 other hour bins (across three groups), shown in Table 9.

Table 9. Significant post hoc test results from beta regression model for fatal crash proportion of all crashes over time of day.

Hour Group 1 for Comparison	Hour Group 2 for Comparison	DF	*t*-value	*p*-value
Hours 12:00 a.m., 1:00 a.m., 3:00 a.m., 5:00 a.m., 6:00 a.m., 1:00 p.m., 2:00 p.m., 3:00 p.m., 6:00 p.m., 7:00 p.m., 8:00 p.m., 9:00 p.m.	Hours 7:00 a.m., 8:00 a.m., 9:00 a.m., 10:00 a.m., 11:00 a.m., 12:00 p.m., 4:00 p.m., 10:00 p.m.	199	2.81	0.0428
Hour 11:00 p.m.	Hours 7:00 a.m., 8:00 a.m., 9:00 a.m., 10:00 a.m., 11:00 a.m., 12:00 p.m., 4:00 p.m., 10:00 p.m.	199	3.41	0.0069
Hour 2:00 a.m.	Hours 7:00 a.m., 8:00 a.m., 9:00 a.m., 10:00 a.m., 11:00 a.m., 12:00 p.m., 4:00 p.m., 10:00 p.m.	199	4.04	0.0007

Figure 8 plots the proportion of all crashes that were preventable (in maroon) or non-property-only claims (in orange) over time of day. Overall, the average proportion of crashes marked as preventable was close to 30%, with an increase observed in hours 4:00 a.m. and 5:00 a.m. The non-property-only claims crash proportion had a similar pattern over time of day but vacillated around the 70% value.

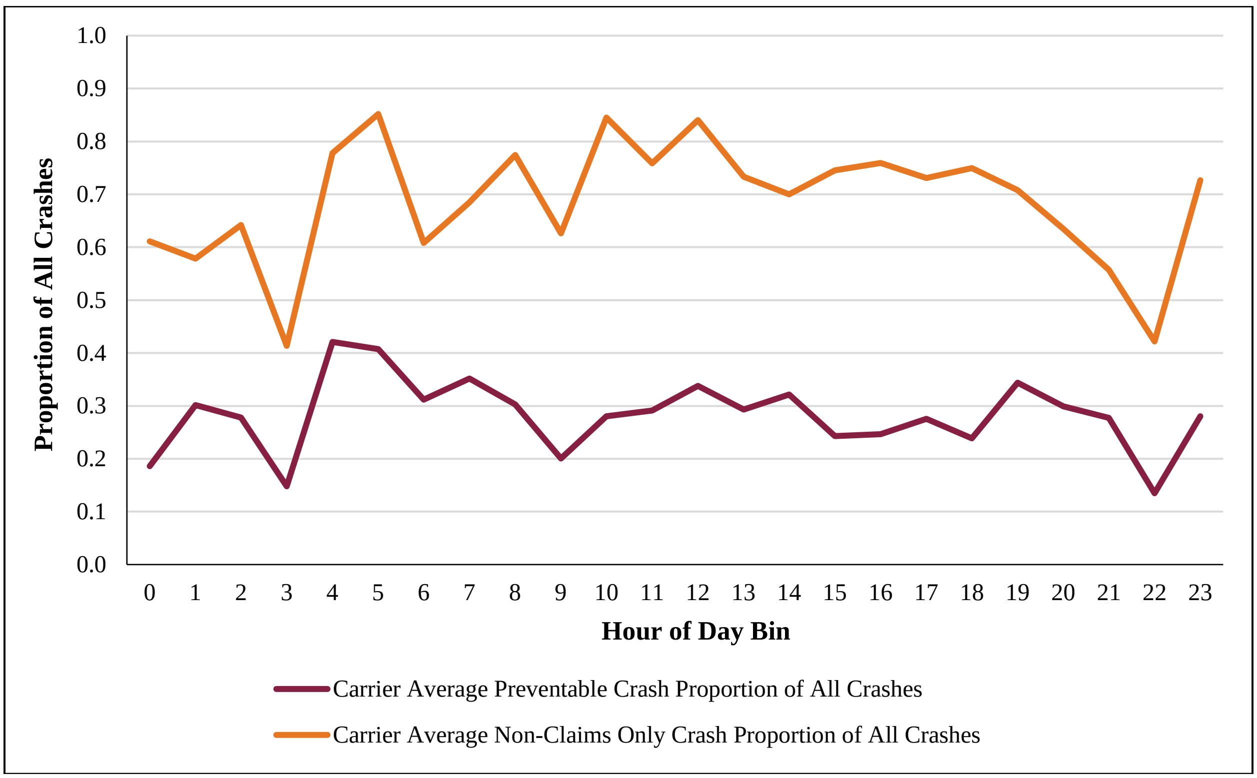

Figure 5. Graph. Carrier average proportions of all non-property-only claims and preventable crashes in each hour of the day.

The beta regression model results assessing the proportion of preventable crashes supports the plot. In Table 10, significant comparisons are listed, with the 4:00 a.m. and 5:00 a.m. hours being significantly higher than many other hours. Hours 3:00 a.m. and 10:00 p.m. showed significantly lower proportions of preventable crashes compared to multiple hour groups, shown in Table 10. Hours 4:00 a.m. and 5:00 a.m., analyzed as a group, had significantly higher proportions of preventable crashes compared to the groups of hours 12:00 a.m., 9:00 a.m., 3:00 p.m., 4:00 p.m., and 6:00 p.m.; hours 1:00 a.m., 2:00 a.m., 6:00 a.m., 8:00 a.m., 10:00 a.m., 11:00 a.m., 1:00 p.m., 5:00 p.m., 8:00 p.m., 9:00 p.m., and 11:00 p.m.; and hours 3:00 a.m. and 10:00 p.m. The model for proportion of non-property-only claims crashes did not identify any significant differences in paired comparisons of hour groups.

Table 10. Significant post hoc test results from beta regression model for preventable crash proportion of all crashes over time of day.

Hour Group 1 for Comparison	Hour Group 2 for Comparison	DF	*t*-value	*p*-value
Hours 4:00 a.m. and 5:00 a.m.	Hours 12:00 a.m., 9:00 a.m., 3:00 p.m., 4:00 p.m., and 6:00 p.m.	199	4.31	0.0003
Hours 1:00 a.m., 2:00 a.m., 6:00 a.m., 8:00 a.m., 10:00 a.m., 11:00 a.m., 1:00 p.m., 5:00 p.m., 8:00 p.m., 9:00 p.m., and 11:00 p.m.	Hours 3:00 a.m. and 10:00 p.m.	199	3.38	0.0077
Hours 4:00 a.m. and 5:00 a.m.	Hours 1:00 a.m., 2:00 a.m., 6:00 a.m., 8:00 a.m., 10:00 a.m., 11:00 a.m., 1:00 p.m., 5:00 p.m., 8:00 p.m., 9:00 p.m., and 11:00 p.m.	199	3.31	0.0095
Hours 4:00 a.m. and 5:00 a.m.	Hours 3:00 a.m. and 10:00 p.m.	199	5.02	<0.0001
Hours 7:00 a.m., 12:00 p.m., 2:00 p.m., and 7:00 p.m.	Hours 3:00 a.m. and 10:00 p.m.	199	3.60	0.0036

The average carrier proportions of crashes that were rollover, run-off-road, and rear-end type are shown over time of day in Figure 6. The rollover crash proportion, represented in maroon, had highs in hours 7:00 p.m. and 10:00 p.m., with lows at 3:00 p.m., 4:00 p.m., and 9:00 p.m. Significant differences in the proportion of rollover crashes by hour of the day are shown in Table 11. Hour 7:00 p.m. was significantly higher in the proportion of rollover crashes compared to many hours of the day. The group with hours 1:00 a.m., 5:00 a.m., and 10:00 p.m. had significantly higher proportions of rollover crashes compared to hours 3:00 p.m., 4:00 p.m., and 9:00 p.m. The proportion of run-off-road crashes, shown in orange in Figure 6, was low, with few hours showing averages above 2%. Proportions of run-off-road crashes were not significantly different across the day, with an adjusted alpha for pairwise comparisons of seven groups of hours. In Figure 6, rear-end crash proportions are shown in grey. This crash type showed a low in early afternoon, from 12:00 p.m. to 3:00 p.m. and from 11:00 p.m. to 3:00 a.m. The beta regression model did not find the proportion of rear-end type crashes to be significantly different across the day, with an adjusted alpha for pairwise comparisons of six groups of hours.

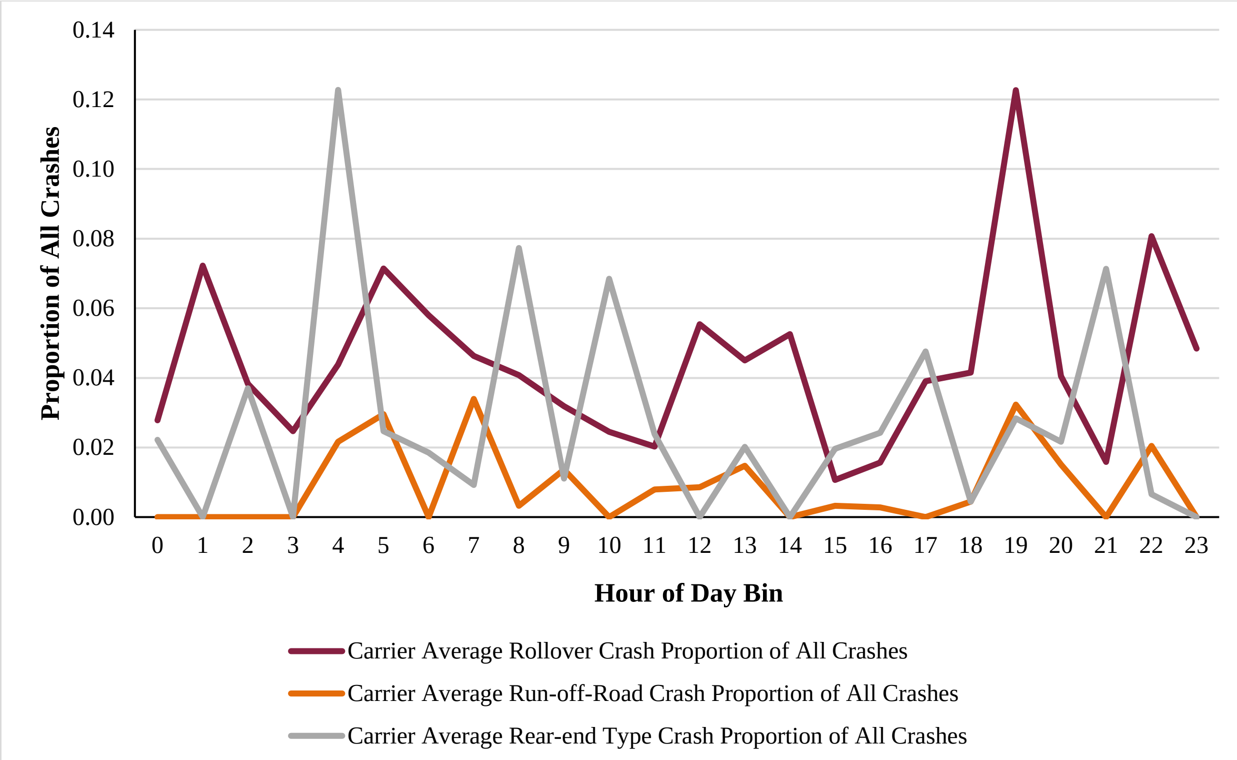

Figure 6. Graph. Carrier average proportions of rollover, run-off-road, and rear-end type crashes in each hour of the day.

Table 11. Significant post hoc test results from beta regression model for rollover crash proportion of all crashes over time of day.

Hour Group 1 for Comparison	Hour Group 2 for Comparison	DF	*t*-value	*p*-value
Hour 7:00 p.m.	Hours 12:00 a.m., 3:00 a.m., 10:00 a.m., and 11:00 a.m.	198	3.50	0.0075
Hours 1:00 a.m., 5:00 a.m., and 10:00 p.m.	Hours 3:00 p.m., 4:00 p.m., and 9:00 p.m.	198	2.97	0.0384
Hour 7:00 p.m.	Hours 3:00 p.m., 4:00 p.m., and 9:00 p.m.	198	3.61	0.0052
Hour 7:00 p.m.	Hours 2:00 a.m., 8:00 a.m., 9:00 a.m., 5:00 p.m., 6:00 p.m., and 8:00 p.m.	198	2.96	0.0403

DAYTIME AND NIGHTTIME PERIODS

To compare safety driving performance in daytime and nighttime periods, the crash and exposure data were summarized in bins of 6:00 a.m. to 6:00 p.m. for "Daytime" and 6:00 p.m. to 6:00 a.m. for "Nighttime." Figure 7 shows the rate of all crashes per 1 million driving hours for the daytime and nighttime periods for each carrier, as well as an average calculation over all carriers. The values are listed in Table 12. Carriers 1, 6, 9, and 11 show higher crash rates in the daytime period, and carriers 3, 4, 5, 7, and 10 show higher crash rates in the nighttime period. The average over all carriers shows nearly equivalent values in the daytime and nighttime periods.

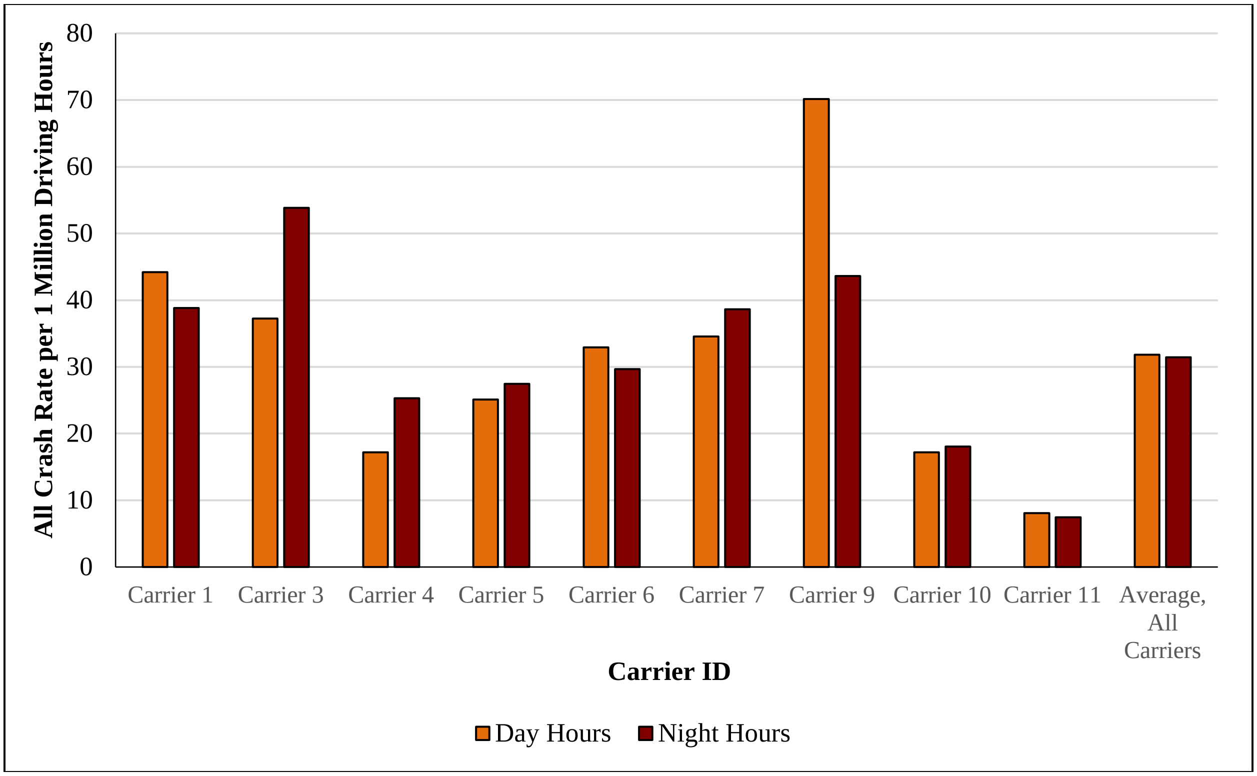

Figure 7. Graph. Comparison of crash rates for all crashes per 1 million driving hours in daytime and nighttime periods by carrier.

Table 12. Comparison of carrier rate of all crashes per 1 million driving hours in daytime and nighttime periods for all carriers.

Carrier ID	Daytime Hours All Crash Rate per 1 Million Driving Hours	Nighttime Hours All Crash Rate per 1 Million Driving Hours
Carrier 1	44	39
Carrier 3	37	54
Carrier 4	17	25
Carrier 5	25	27
Carrier 6	33	30
Carrier 7	35	39
Carrier 9	70	44
Carrier 10	17	18
Carrier 11	8	7
Average, All Carriers	32	31

A Poisson regression model, testing for differences between the rate of all crashes during the daytime and the rate of all crashes during the nighttime, controlling for carrier ID, found no significant difference in crash rate per 1 million driving hours, OR = 1.03, 95% CI = (0.92, 1.15). In Table 13, the solutions for fixed effects from the model are listed with the estimate value, *t*-value, and *p*-value.

Table 13. Solutions for fixed effects from Poisson regression model for all crashes by day and night hours of the day.

Effect	Time of Day Period	Estimate	Standard Error	DF	*t*-value	*p*-value
Intercept		-3.58	0.21	8	-17.37	<.0001
Time of Day	**Day Hour Period**	-0.03	0.05	8	-0.64	0.5420
Time of Day	**Night Hour Period**	0	.	.	.	.

Proportion of Crash Types by Daytime or Nighttime Periods

Proportions of all crashes for each crash type in daytime and nighttime periods are compared below. For individual carrier calculations, see Appendix B. The maroon bars in Figure 8show the average carrier proportions of all crashes for injury, fatal, preventable, non-property-only claims, rollover, run-off-road, and rear-end type crash types for the daytime period, while the orange bars display averages for the nighttime period. Beta regression models were used to compare the proportion of all crashes for each crash type of interest. The model controlled for carrier ID. Models with significant differences observed between daytime and nighttime hours included run-off-road crashes (t = 4.13, p = 0.0033; lower in daytime hours). The remaining crash types were not significantly different at α = 0.05, including injury (t = 0.41, p = 0.6917), fatal crashes (t = 2.16, p = 0.0631), preventable crashes (t = 0.20, p = 0.8469), non-property-only claims (t = 0.36, p = 0.7302), rollover crashes (t = 1.58, p = 0.1517), and rear-end type crashes (t = 1.76, p = 0.1161).

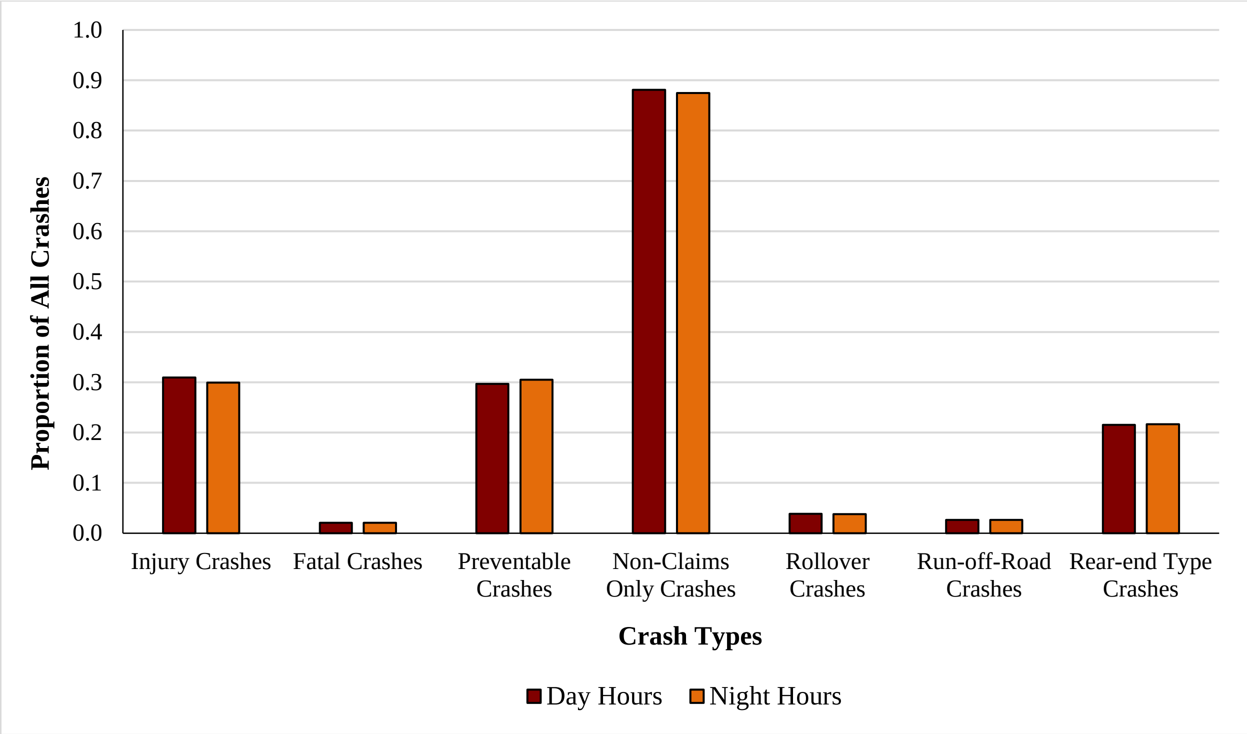

Figure 8. Graph. Average carrier proportions of all crashes by crash type for daytime and nighttime periods.

MORNING AND EVENING RUSH HOUR PERIODS

To compare driving safety performance in rush hour periods, the crash and exposure data were summarized for morning rush hour, defined as 6:00 a.m. to 8:59 a.m., and evening rush hour, defined as 4:00 p.m. to 6:59 p.m. All other hours were considered "non-rush hour." Figure 9 shows the rates of all crashes per 1 million driving hours by carrier for morning, evening, and non-rush hour periods. The values are listed by carrier in Table 14.

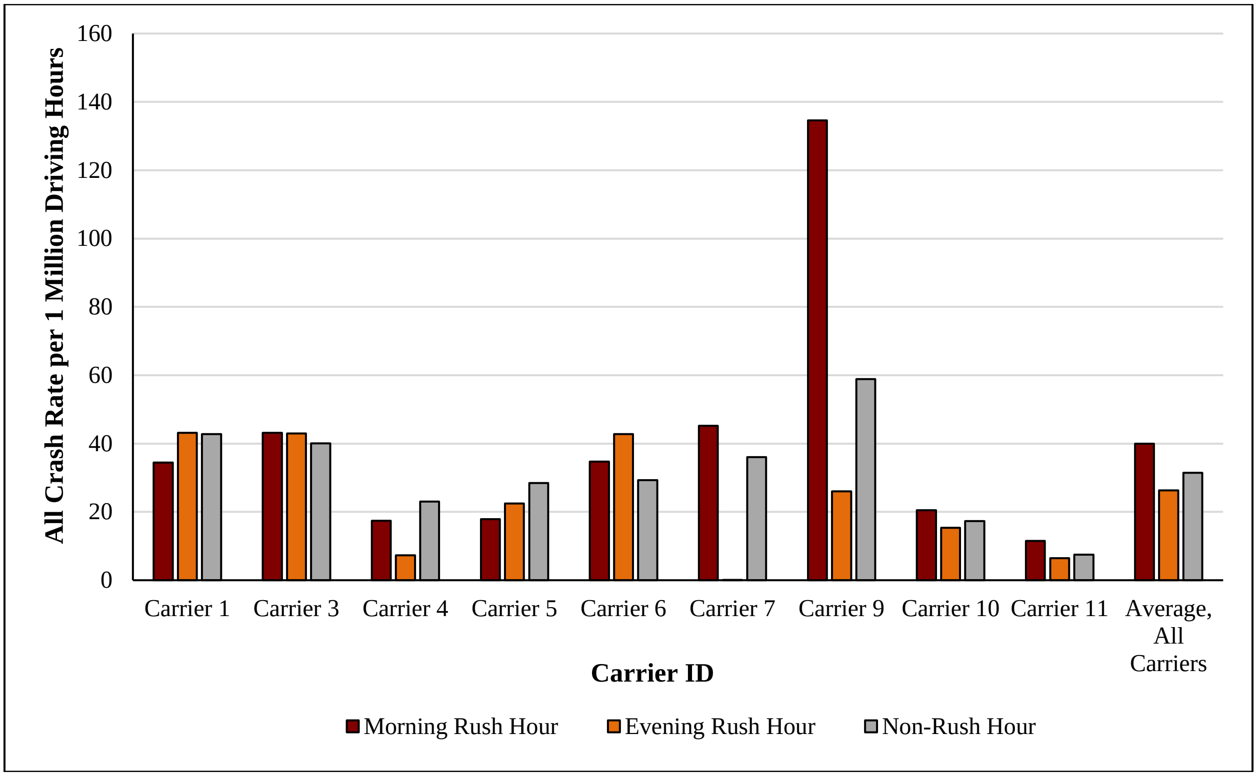

Figure 9. Graph. Comparison of carrier rate of all crashes per 1 million driving hours in morning rush hour, evening rush hour, and non-rush hour periods.

Table 14. Carrier rate of all crashes per 1 million driver hours in morning rush hour, evening rush hour, and non-rush hour periods.

Carrier ID	Morning Rush Hour All Crash Rate per 1 MIL Driving Hours	Evening Rush Hour All Crash Rate per 1 Million Driving Hours	Non-Rush Hour All Crash Rate per 1 Million Driving Hours
Carrier 1	34	43	43
Carrier 3	43	43	40
Carrier 4	17	7	23
Carrier 5	18	22	28
Carrier 6	35	43	29
Carrier 7	45	30	36
Carrier 9	135	26	59
Carrier 10	21	15	17
Carrier 11	11	6	7
Average, All Carriers	40	26	31

A Poisson regression model, testing for differences in the rate of all crashes during rush hour periods and controlling for carrier ID, found that morning rush hour was associated with a higher crash rate than evening rush hour, OR = 1.35, Adj 95% CI = (1.09, 1.68). Morning rush hour was also associated with a significantly higher crash rate than non-rush hour periods, OR = 1.18, Adj 95% CI = (1.01, 1.39). No difference was found between evening rush hour and non-rush hour, OR = 1.15, Adj 95% CI = (0.96, 1.36). In Table 15, the solutions for fixed effects from the model are listed with their estimate value, *t*-value, and *p*-value.

Table 15. Solutions for fixed effects from Poisson regression model for all crashes by rush hour periods of the day.

Effect	Time of Day Period	Estimate	Standard Error	DF	*t*-value	*p*-value
Intercept		-3.61	0.20	8	-17.61	<.0001
Time of Day	**Evening Rush Hour Period**	-0.14	0.07	16	-2.03	0.0589
Time of Day	**Morning Rush Hour Period**	0.17	0.06	16	2.69	0.0160
Time of Day	**Non-Rush Hour Period**	0	.	.	.	.

Proportion of Crash Types by Rush Hour Periods

The proportions of all crashes for each crash type in morning, evening, and non-rush hour periods are compared in Figure 10. The proportions of all crashes by crash type for each carrier are included in the tables in Appendix B. Figure 10 shows the morning rush hour, evening rush hour, and non-rush hour average proportions of all crashes that were injury, fatal, preventable, non-property-only claims, rollover, run-off-road, and rear-end type crashes. Beta regression models were used to compare the proportion of all crashes for each crash type of interest. The model controlled for carrier ID. The post hoc pairwise tests comparing evening, morning, and non-rush hour periods were adjusted for multiple comparisons. None of the crash types showed significant differences in the evening and morning rush hours: evening versus morning model results for injury ($t = -1.03$, $p = 0.5707$), fatal ($t = -1.37$, $p = 0.3771$), preventable crashes ($t =$

−1.46, p = 0.3338), non-property-only claims crashes (t = 2.54, p = 0.0539), rollover crashes (t = −1.33, p = 0.3992), run-off-road crashes (t = −1.99, p = 0.1468), and rear-end type crashes (evening vs. morning (t = 1.61, p = 0.2714).

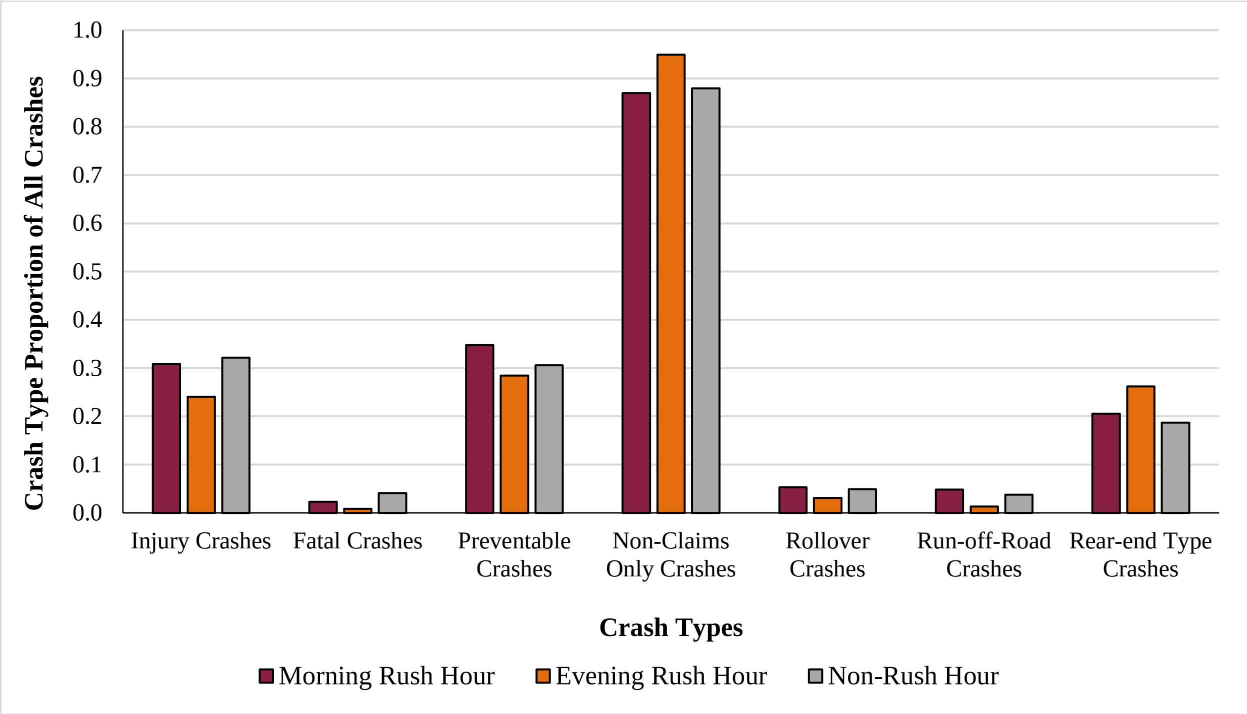

Figure 10. Graph. Average carrier proportions of all crashes by crash type in morning rush hour, evening rush hour, and non-rush hour periods.

CHAPTER 5. DISCUSSION

Although much research has examined how time-of-day factors influence CMV crashes, surprisingly few studies have included an objective measure of exposure to accurately assess crash risk. The adoption of onboard technologies provides an excellent opportunity to collect objective, reliable exposure data. The purpose of this project was to use previously collected carrier crash and ELD data to assess CMV crash risk by time of day, daytime vs. nighttime, and morning rush hour vs. evening rushing hour.

Overall, the results were consistent across all analyses. Injury, fatal, preventable, and non-preventable crash rates per 1 million driving hours were highest in the early morning circadian low period between 4:00 a.m. and 6:00 a.m. Additionally, the average crash rate per 1 million driving hours started to increase between 7:00 p.m. and 9:00 p.m. and was highest at 11:00 p.m. Further analysis using Poisson regression models showed that 6:00 a.m. and 11:00 p.m. generally had statistically significant higher crash rates compared to several other hours of the day. In fact, the hour between 11:00 p.m. and 12:00 a.m. was approximately twice as risky as many other hours in the day. The 6:00 a.m. hour had OR estimates around 1.5 for the majority of the statistically significant comparisons. In addition, the group with hours 12:00 a.m., 4:00 a.m., 5:00 a.m., and 7:00 a.m. showed significantly higher rates of crashes compared to the group with hours 8:00 a.m., 11:00 a.m., 1:00 p.m., 4:00 p.m., 5:00 p.m., 7:00 p.m., and 10:00 p.m.

These results support a number of previous studies that found that early morning (and 6:00 a.m.) and nighttime hours had higher CMV crash rates. Specifically, in the current study, the hours with significantly higher crash rates align almost exactly with the results from Zheng et al. (2018), Knipling and Bocanegra (2008), M. Islam and Hernandez (2014), and Pahukula et al. (2015). Furthermore, the ORs for the 11:00 p.m. hour in the current study align closely with results from Blower and Campbell (1998) and Knipling and Bocanegra (2008).

Barr et al. (2007) postulated that driver fatigue would increase during the natural circadian lows and found that SCEs related to drowsiness occurred most often between 7:00 a.m. and 8:00 a.m. Results from the current effort partially support Barr et al. (2007), who found that rollovers, run-off-road, and rear-end crashes were more likely to occur in the morning window in the hours surrounding 7:00 a.m. Results from this study showed that the proportion of rollover crashes were significantly higher in hours 1:00 a.m., 5:00 a.m., and 10:00 p.m. compared to 3:00 p.m., 4:00 p.m., and 9:00 p.m. The 1:00 a.m. and 5:00 a.m. hours are within the natural circadian low period. These results likely indicate that drivers may be prone to experiencing symptoms associated with driver fatigue towards the end of the early morning circadian low.

These results contradicted several other studies that found CMV crashes were more likely in the daytime hours (Cerwick et al. 2014; Curnow, 2002; Ghariani, 2001; Offei & Young, 2014; Wei et al. 2017). However, there are several factors that may explain this disprecancy in findings with daytime crashes. First, many of these studies did not have strong measures of exposure. Thus, it is possible some of these results were simply due to most of the driving taking place during the day. Blower and Campbell (1998) found that carrier operational characteristics impacted crash rates. This study did not find a statistically significant difference in crash rates between daytime hours and nighttime time hours, which may be explained by differences in operational characteristics. Approximately half of the carriers had higher crash rates during the day and the other half had higher crash rates during the nighttime. Moreover, recent research by Camden et al. (2019) documented the importance of carrier safety culture and operating factors in determining safety performance. Lastly, traffic density may account for much of these differences. Hanowski et al. (2008) also found a strong time-of-day effect where most SCEs occurred during daytime hours; however, the researchers also analyzed these data based on traffic density. This analysis showed that SCE involvement was highly correlated with traffic density. Thus, when controlling for traffic density, Hanowski et al.'s (2008) results seem to support the results in the current study.

In an effort to confirm Hanowski et al.'s (2008) conclusion that traffic density may significantly influence time-of-day effects, this study analyzed crash rates during morning and afternoon rush hour periods. Morning rush hours had significantly higher crash rates compared to evening rush hours. Thus, results from the current study do show that traffic density plays a role (at least in the morning rush hours) in increased crash risk. This result also supports M. Islam and Hernandez (2014), who found that multi-vehicle CMV crashes were more likely to occur in morning rush hours. Additionally, Pahukula et al. (2018) found that CMV crashes were more likely to occur between 5:00 a.m. and 9:00 a.m., which covers the morning rush hour period.

Another way to examine crash risk by time of day is to compare how the proportions of different crash types change over the hours of the day. These analyses showed that the proportion of crashes that were preventable was significantly higher between 4:00 a.m. and 5:00 a.m. than all but four other hours of the day. These results suggest that the early morning hours are disproportionately risky for crashes caused by CMV drivers, possibly due to driver fatigue. The finding that the proportion of run-off-road crashes was significantly higher at nighttime compared to during daytime hours supports this hypothesis, possibly helping to establish the critical link between fatigue and run-off-road crashes.

SUMMARY

Research on CMV crash risk by time of day is split on which parts of the day are associated with the highest crash risk. Some studies support daytime hours as presenting the highest risk, whereas other research indicates nighttime hours are the riskiest time of day. Results from the current study provide insight and help bridge the gap between the two groups of results. Using carrier-provided crash and ELD data, results showed that crash rates per 1 million driving hours are highest during early morning hours (4:00 a.m. to 8:00 a.m.) and late night hours (11:00 p.m. to 12:00 a.m.). Additionally, results showed the early morning hours are disproportionately more likely to result in a preventable crash. Finally, although some of the findings in the current study were similar to other research that did not use exposure data, the current study was able to eliminate this source of noise as a possible explanation for the findings.

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APPENDIX A. LITERATURE REVIEW KEY FINDINGS

The following table highlights all key findings from each source of literature as an easy way to understand and compare and contrast findings across all sources of research.

Authors	Findings
Zheng, Lu, & Lantz, 2018	1. Nighttime was considered dangerous because it is a high contributor to the number of fatal crashes. 2. Time of day and the day of the week can identify the likelihood of when a fatal and non-fatal crash will occur. 3. Crashes on the weekend are more prone to be fatal 4. Crashes on Fridays are more likely to be non-fatal.
Blower, D.F., Campbell, K., 1998	1. Higher rate of fatal crashes during daylight hours. 2. Higher probability of a fatal crash occurring during nighttime hours. 3. Even though there were fewer crashes between the hours of 12:00 a.m. and 7:00 a.m., the potential of a crash resulting in severe injuries was higher.
Pahukula, Hernandez, & Unnikrishnan, 2015	1. Speeding and lane changes were factors that contributed to heavy vehicle involved crashes between 10:00 a.m. and 3:00 p.m. 2. Summer months and the afternoon time segment suggest that traffic congestion can impact the severity of the injury sustained. 3. Evening segment and clear weather with dark lighting conditions results in either a severe injury or a no-injury crash. 4. More heavy motor vehicles are on the road; this increased the likelihood of a crash occurring in the morning and evening.
Chang & Mannering, 1999	1. When a heavy vehicle is involved in a crash, the probability of injury or a fatality increases by 50%.
Cerwick, Gkritza, Shaheed, & Hans, 2014	1. Higher probability of a severe or fatal crash at the beginning of the week (i.e., Monday, Tuesday) and over the weekend (i.e., Saturday, Sunday). 2. Lower probability of a severe or fatal crash towards the end of the week (i.e., Thursday, Friday). 3. Heavy motor vehicle crashes that occurred during the afternoon (i.e., between 11:00 a.m. and 2:00 p.m.) were more likely to be severe or fatal. 4. If a crash occurred in the evening (i.e., between 3:00 p.m. and 6:00 p.m.), the crash was more likely to result in no injury.
M. Islam & Hernandez, 2013	1. Crashes that occurred in rural areas were more likely to have severe or fatal injuries. 2. People involved in crashes located in urban areas were less likely to sustain any severe injuries. 3. Crashes that happened between 3:00 p.m. and 7:00 p.m. had a smaller chance of resulting in injury. 4. Crashes that happened in the fall tended to be less likely to have severe injuries.
Ghariani, 2001	1. Most heavy vehicle crashes transpired during the day.
Offei & Young, 2014	1. Most heavy vehicle crashes transpired during the day.
Duncan, C.S., Khattak, A.J., Council, 1998	1. The potential of a crash resulting in a severe injury was higher during the nighttime.

Authors	Findings
Curnow, 2002	1. Rate of heavy vehicle crashes was evenly distributed throughout a 24-hour period. 2. The majority of rigid crashes happened during the day.
Balakrishnan, Moridpour, & Tay, 2016	1. In rural areas, collisions are more likely to occur between 12:00 a.m. and 6:00 a.m. 2. Intersection collisions are more likely to occur on main roads and highways. 3. Midblock collisions were more likely to occur on divided 2-way roads.
Knipling, R.R., Bocanegra, J., 2008	1. Most of the crashes occurred during the day and predominantly during rush hour. 2. For unit trucks, a higher rate of crashes occurred during nighttime conditions. 3. The probability of a crash occurring during dark conditions was three times higher for unit trucks versus single-unit trucks.
Lemp, Kockelman, & Unnikrishnan, 2011	1. Likelihood of sustaining a severe or fatal injury in a crash was higher with the number of trailers. 2. Likelihood of a fatal crash increases during the night with no lighting conditions (when visibility is compromised).
Wei, Xiaokun, & Dapeng, 2017	1. Most crashes occurred during the day (between 70% and 80%), with dry road conditions (80%). 2. Most crashes happened during the mid-day segment for both single and multi-vehicle. 3. Fewer crashes occurred during the P.M. and night segments. 4. Change in the time of day effects between P.M. and nighttime segments. 5. Single vehicle crashes were not as severe in the afternoon and night. 6. However, the severity of injuries for a multi-vehicle truck crash during those times was more dangerous. 7. Note: four time blocks were (1) A.M., from 6:00–10:00 a.m., (2) Midday (MD), from 10:00 a.m. to 3:00 p.m., (3) P.M., from 3:00–7:00 p.m., and (4) Night (NT), from 7:00 p.m. to 6:00 a.m.
S. Islam, Jones, & Dye, 2014	1. Dark conditions also increase the probability of a fatal injury in a heavy motor vehicle crash. 2. For a multi-vehicle collision, crashes that occurred in dark conditions had a higher probability of experiencing minor injuries in urban areas.
M. Bin Islam & Hernandez, 2014	1. Congestion effects reduced the chance of crashes resulting in fatal, incapacitating, or any injuries during the afternoon time. 2. However, the likelihood of severe or fatal injuries increased during nighttime (dark) conditions.
Marquis & Wang, 2015	1. Routes that include areas with a large population, more employment in finance, insurance, or health care fields tend to have less crashes at night. 2. Larger household sizes and locations with more employment in the retail, professional services, education, and accommodation fields had an increase in nighttime crashes. 3. When trucks changed from a morning peak time to a nighttime slot, an increase of truck crashes occurred. 4. A shift from afternoon peak to nighttime slots also increased truck crashes, but the increase was less substantial. 5. When trucks changed from midday to nighttime driving, the rate of crash slightly reduced.

Authors	Findings
Park, S., Jovanis, 2010	1. If the truck operator took a duty time of more than 46 hours, they were at higher risk of being involved in a vehicle crash when they returned to work.
Barr, David Yang, Hanowski, & Olson, 2007	1. Drivers were more likely to become fatigued or prone to drowsy events in the morning. 2. This increases the drivers’ likelihood of being in a crash. 3. The frequency of heavy motor vehicle crashes and the severity of the crash increases during this time of day.

APPENDIX B. ADDITIONAL ANLAYSIS RESULTS

DAY AND NIGHT BIN DATA

Included below are reference tables listing the exposure hours and crash counts for individual crash types by carrier ID and day/night bin.

Table 16. Total exposure in 1,000 driving hours and counts of individual crash types for day period of day/night breakdown.

Carrier ID	Total Daytime Driving Time in 1,000 Hours	All Crash Counts	Injury Crash Counts	Fatal Crash Counts	Non-preventable Crash Counts	Preventable Crash Counts	Non-claims only Crash Counts	Rollover Crash Counts	Run-off-road Crash Counts	Rear-end Type Crash Counts
Carrier 1	2,646.69	117	46	2	89	27	109	5	3	24
Carrier 3	4,352.40	162	57	5	118	44	152	8	3	55
Carrier 4	1,803.09	31	7	0	16	6	19	1	1	7
Carrier 5	2,271.68	57	14	0	38	19	53	0	0	16
Carrier 6	2,005.25	66	21	2	32	31	65	4	7	12
Carrier 7	5,355.22	185	53	5	107	78	178	5	1	49
Carrier 9	295.32	89	33	3	0	0	56	1	1	10
Carrier 10	1,268.99	453	148	11	302	151	449	17	11	19
Carrier 11	26,380.43	139	37	3	81	58	132	12	2	40
Average, All Carriers	6,361.85	144.33	46.22	3.44	87.00	46.00	134.78	5.89	3.22	25.78

Table 17. Total exposure in 1,000 driving hours and counts of individual crash types during night period of day/night breakdown.

Carrier ID	Total Nighttime Driving Time in 1,000 Hours	All Crash Counts	Injury Crash Counts	Fatal Crash Counts	Non-preventable Crash Counts	Preventable Crash Counts	Non-claims-only Crash Counts	Rollover Crash Counts	Run-off-road Crash Counts	Rear-end Type Crash Counts
Carrier 1	2,007.71	78	17	2	59	18	70	4	2	19
Carrier 3	1,300.17	70	19	3	44	25	62	7	7	14
Carrier 4	789.97	20	3	4	10	4	14	1	1	3
Carrier 5	1,821.33	50	13	4	29	21	50	0	1	18
Carrier 6	876.95	26	8	1	13	11	26	0	4	2
Carrier 7	3,080.09	119	46	6	64	55	112	11	4	22
Carrier 9	253.82	32	15	0	0	0	21	4	1	4
Carrier 10	733.48	196	67	11	123	73	193	7	8	6
Carrier 11	10,848.09	92	25	3	49	43	85	10	5	14
Average, All Carriers	3,408.54	75.89	23.67	3.78	43.44	27.78	70.33	4.89	3.67	11.33

Included below are reference tables listing the carrier proportions of all crashes by individual crash types of interest by day and night periods.

Table 18. Proportion of all crashes by individual crash types injury and fatal crashes, during day and night periods.

Carrier ID	Day/Night Period	Injury Crash Proportion of All Crashes	Fatal Crash Proportion of All Crashes
1	Day	0.3932	0.0171
1	Night	0.2179	0.0256
3	Day	0.3519	0.0309
3	Night	0.2714	0.0429
4	Day	0.2258	0.0000
4	Night	0.1500	0.2000
5	Day	0.2456	0.0000
5	Night	0.2600	0.0800
6	Day	0.3182	0.0303
6	Night	0.3077	0.0385
7	Day	0.2865	0.0270
7	Night	0.3866	0.0504
9	Day	0.3708	0.0337
9	Night	0.4688	0.0000
10	Day	0.3267	0.0243
10	Night	0.3418	0.0561
11	Day	0.2662	0.0216
11	Night	0.2717	0.0326

Table 19. Proportion of all crashes by individual crash types preventable and non-property-only claims crashes, during day and night periods.

Carrier ID	Day/Night Period	Preventable Crash Proportion of All Crashes	Non-claims-only Crash Proportion of All Crashes
1	Day	0.2308	0.9316
1	Night	0.2308	0.8974
3	Day	0.2716	0.9383
3	Night	0.3571	0.8857
4	Day	0.1935	0.6129
4	Night	0.2000	0.7000
5	Day	0.3333	0.9298
5	Night	0.4200	1.0000
6	Day	0.4697	0.9848
6	Night	0.4231	1.0000
7	Day	0.4216	0.9622
7	Night	0.4622	0.9412
9	Day	0.0000	0.6292
9	Night	0.0000	0.6563
10	Day	0.3333	0.9912
10	Night	0.3724	0.9847
11	Day	0.4173	0.9496
11	Night	0.4674	0.9239

Table 20. Proportion of all crashes by individual crash types rollover, run-off-road, and rear-end type crashes, during day and night periods.

Carrier ID	Day/Night Period	Rollover Crash Proportion of All Crashes	Run-off-road Crash Proportion of All Crashes	Rear-end Type Crash Proportion of All Crashes
1	Day	0.0427	0.0256	0.2051
1	Night	0.0513	0.0256	0.2436
3	Day	0.0494	0.0185	0.3395
3	Night	0.1000	0.1000	0.2000
4	Day	0.0323	0.0323	0.2258
4	Night	0.0500	0.0500	0.1500
5	Day	0.0000	0.0000	0.2807
5	Night	0.0000	0.0200	0.3600
6	Day	0.0606	0.1061	0.1818
6	Night	0.0000	0.1538	0.0769
7	Day	0.0270	0.0054	0.2649
7	Night	0.0924	0.0336	0.1849
9	Day	0.0112	0.0112	0.1124
9	Night	0.1250	0.0313	0.1250
10	Day	0.0375	0.0243	0.0419
10	Night	0.0357	0.0408	0.0306
11	Day	0.0863	0.0144	0.2878
11	Night	0.1087	0.0543	0.1522

RUSH HOUR BIN DATA

Included below are reference tables listing the exposure hours and crash counts for individual crash types, by carrier ID and rush hour bin.

Table 21. Total exposure in 1,000 driving hours and counts of individual crash types for morning rush hour period of rush hour breakdown.

Carrier ID	Total Morning Rush Hour Driving Time in 1,000 Hours	All Crash Counts	Injury Crash Counts	Fatal Crash Counts	Non-preventable Crash Counts	Preventable Crash Counts	Non-claims-only Crash Counts	Rollover Crash Counts	Run-off-road Crash Counts	Rear-end Type Crash Counts
Carrier 1	522.30	18	9	0	12	6	17	2	0	4
Carrier 3	903.29	39	12	2	28	11	38	3	1	14
Carrier 4	402.40	7	2	0	4	1	4	0	1	1
Carrier 5	614.94	11	4	0	6	5	9	0	0	2
Carrier 6	518.03	18	4	0	6	12	17	1	4	3
Carrier 7	952.17	43	14	2	23	20	41	2	0	11
Carrier 9	207.99	28	8	2	0	0	19	1	1	5
Carrier 10	5,410.70	111	35	2	78	33	110	3	1	3
Carrier 11	3,576.62	41	7	1	21	20	39	5	0	13
Average, All Carriers	1,456.49	35.11	10.56	1	19.78	12	32.67	1.89	0.89	6.22

Table 22. Total exposure in 1,000 driving hours and counts of individual crash types during evening rush hour period of rush hour breakdown.

Carrier ID	Total Evening Rush Hour Driving Time in 1,000 Hours	All Crash Counts	Injury Crash Counts	Fatal Crash Counts	Non-preventable Crash Counts	Preventable Crash Counts	Non-claims-only Crash Counts	Rollover Crash Counts	Run-off-road Crash Counts	Rear-end Type Crash Counts
Carrier 1	625.80	27	7	0	18	9	25	0	2	4
Carrier 3	978.34	42	11	1	34	8	38	0	1	14
Carrier 4	409.45	3	0	0	2	1	3	0	0	1
Carrier 5	490.39	11	0	0	9	2	10	0	0	6
Carrier 6	350.82	15	1	0	9	6	15	1	0	4
Carrier 7	1,431.64	43	13	0	26	17	43	0	0	9
Carrier 9	383.92	10	7	0	0	0	9	1	0	1
Carrier 10	5,816.62	89	23	5	53	36	87	4	2	6
Carrier 11	4,340.63	28	9	0	19	9	26	2	0	10
Average, All Carriers	1,647.51	29.78	7.89	0.67	18.89	9.78	28.44	0.89	0.56	6.11

Table 23. Total exposure in 1,000 driving hours and counts of individual crash types during non-rush hour period of rush hour breakdown.

Carrier ID	Total Non-rush Hour Driving Time in 1,000 Hours	All Crash Counts	Injury Crash Counts	Fatal Crash Counts	Non-Preventable Crash Counts	Preventable Crash Counts	Non-claims-only Crash Counts	Rollover Crash Counts	Run-off-road Crash Counts	Rear-end Type Crash Counts
Carrier 1	3,506.31	150	47	4	118	30	137	7	3	35
Carrier 3	3,770.94	151	53	5	100	50	138	12	8	41
Carrier 4	1,781.21	41	8	4	20	8	26	2	1	8
Carrier 5	2,987.68	85	23	4	52	33	84	0	1	26
Carrier 6	2,013.35	59	24	3	30	24	59	2	7	7
Carrier 7	6,051.50	218	72	9	122	96	206	14	5	51
Carrier 9	1,410.56	83	33	1	0	0	49	3	1	8
Carrier 10	26,001.21	449	157	15	294	155	445	17	16	16
Carrier 11	21,696.01	162	46	5	90	72	152	15	7	31
Average, All Carriers	7,690.97	155.33	51.44	5.56	91.78	52.00	144.00	8.00	5.44	24.78

Included below are reference tables listing the carrier proportions of all crashes by individual crash types of interest by day and night periods.

Table 24. Proportion of all crashes by individual crash types injury and fatal crashes, during morning rush hour, evening rush hour, and non-rush hour periods.

Carrier ID	Rush Hour Period	Injury Crash Proportion of All Crashes	Fatal Crash Proportion of All Crashes
1	Morning Rush Hour	0.5000	0.0000
1	Evening Rush Hour	0.2593	0.0000
1	Non-Rush Hour	0.3133	0.0267
3	Morning Rush Hour	0.3077	0.0513
3	Evening Rush Hour	0.2619	0.0238
3	Non-Rush Hour	0.3510	0.0331
4	Morning Rush Hour	0.2857	0.0000
4	Evening Rush Hour	0.0000	0.0000
4	Non-Rush Hour	0.1951	0.0976
5	Morning Rush Hour	0.3636	0.0000
5	Evening Rush Hour	0.0000	0.0000
5	Non-Rush Hour	0.2706	0.0471
6	Morning Rush Hour	0.2222	0.0000
6	Evening Rush Hour	0.0667	0.0000
6	Non-Rush Hour	0.4068	0.0508
7	Morning Rush Hour	0.3256	0.0465
7	Evening Rush Hour	0.3023	0.0000
7	Non-Rush Hour	0.3303	0.0413
9	Morning Rush Hour	0.2857	0.0714
9	Evening Rush Hour	0.7000	0.0000
9	Non-Rush Hour	0.3976	0.0120
10	Morning Rush Hour	0.3153	0.0180
10	Evening Rush Hour	0.2584	0.0562
10	Non-Rush Hour	0.3497	0.0334
11	Morning Rush Hour	0.1707	0.0244
11	Evening Rush Hour	0.3214	0.0000
11	Non-Rush Hour	0.2840	0.0309

Table 25. Proportion of all crashes by individual crash types preventable and non-property-only claims crashes, during rush hour periods.

Carrier ID	Rush Hour Period	Preventable Crash Proportion of All Crashes	Non-claims-only Crash Proportion of All Crashes
1	Morning Rush Hour	0.3333	0.9444
1	Evening Rush Hour	0.3333	0.9259
1	Non-Rush Hour	0.2000	0.9133
3	Morning Rush Hour	0.2821	0.9744
3	Evening Rush Hour	0.1905	0.9048
3	Non-Rush Hour	0.3311	0.9139
4	Morning Rush Hour	0.1429	0.5714
4	Evening Rush Hour	0.3333	1.0000
4	Non-Rush Hour	0.1951	0.6341
5	Morning Rush Hour	0.4545	0.8182
5	Evening Rush Hour	0.1818	0.9091
5	Non-Rush Hour	0.3882	0.9882
6	Morning Rush Hour	0.6667	0.9444
6	Evening Rush Hour	0.4000	1.0000
6	Non-Rush Hour	0.4068	1.0000
7	Morning Rush Hour	0.4651	0.9535
7	Evening Rush Hour	0.3953	1.0000
7	Non-Rush Hour	0.4404	0.9450
9	Morning Rush Hour	0.0000	0.6786
9	Evening Rush Hour	0.0000	0.9000
9	Non-Rush Hour	0.0000	0.5904
10	Morning Rush Hour	0.2973	0.9910
10	Evening Rush Hour	0.4045	0.9775
10	Non-Rush Hour	0.3452	0.9911
11	Morning Rush Hour	0.4878	0.9512
11	Evening Rush Hour	0.3214	0.9286
11	Non-Rush Hour	0.4444	0.9383

Table 26. Proportion of all crashes by individual crash types rollover, run-off-road, and rear-end type crashes, during rush hour periods.

Carrier ID	Rush Hour Period	Rollover Crash Proportion of All Crashes	Run-off-road Crash Proportion of All Crashes	Rear-end Type Crash Proportion of All Crashes
1	Morning Rush Hour	0.1111	0.0000	0.2222
1	Evening Rush Hour	0.0000	0.0741	0.1481
1	Non-Rush Hour	0.0467	0.0200	0.2333
3	Morning Rush Hour	0.0769	0.0256	0.3590
3	Evening Rush Hour	0.0000	0.0238	0.3333
3	Non-Rush Hour	0.0795	0.0530	0.2715
4	Morning Rush Hour	0.0000	0.1429	0.1429
4	Evening Rush Hour	0.0000	0.0000	0.3333
4	Non-Rush Hour	0.0488	0.0244	0.1951
5	Morning Rush Hour	0.0000	0.0000	0.1818
5	Evening Rush Hour	0.0000	0.0000	0.5455
5	Non-Rush Hour	0.0000	0.0118	0.3059
6	Morning Rush Hour	0.0556	0.2222	0.1667
6	Evening Rush Hour	0.0667	0.0000	0.2667
6	Non-Rush Hour	0.0339	0.1186	0.1186
7	Morning Rush Hour	0.0465	0.0000	0.2558
7	Evening Rush Hour	0.0000	0.0000	0.2093
7	Non-Rush Hour	0.0642	0.0229	0.2339
9	Morning Rush Hour	0.0357	0.0357	0.1786
9	Evening Rush Hour	0.1000	0.0000	0.1000
9	Non-Rush Hour	0.0361	0.0120	0.0964
10	Morning Rush Hour	0.0270	0.0090	0.0270
10	Evening Rush Hour	0.0449	0.0225	0.0674
10	Non-Rush Hour	0.0379	0.0356	0.0356
11	Morning Rush Hour	0.1220	0.0000	0.3171
11	Evening Rush Hour	0.0714	0.0000	0.3571
11	Non-Rush Hour	0.0926	0.0432	0.1914

DRIVING HOUR AND HOUR OF DAY

In the following section, the analysis of the driving hour by hour of the day is presented. Included are tables listing the driving time exposure and crash counts for each carrier in the driving hour, followed by plots showing the crash rate over the day hours for the driving hour specified. Presented first is the analysis of driving hour 1. Table 26 lists the total driving time and crash counts for driving hour 1.

Table 27. Exposure in driving hours and total crash counts for driving hour 1 for each carrier.

Carrier ID	Total Driving Hour 1 Driving Time in 1,000 Hours	All Crash Counts
Carrier 1	674.06	9
Carrier 3	763.42	8
Carrier 4	318.84	4
Carrier 5	405.76	6
Carrier 6	238.25	6
Carrier 7	1,212.08	14
Carrier 9	433.31	6
Carrier 10	5,380.06	69
Carrier 11	3,954.22	19
Average, All Carriers	1,486.50	15.67

The crash rate for driving hour 1 across time of day is shown in Figure 11. For the first driving hour, the highest average crash rate (96 crashes per 1 million driving hours) occurred in the 1:00 p.m. hour. This rate is at least three times higher than the average crash rates in all other hours; however, this was driven by the observed crash rates of two carriers. The model did not identify any statistically significant differences in driving hour 1 crash rates over time of day at $\alpha = 0.01$.

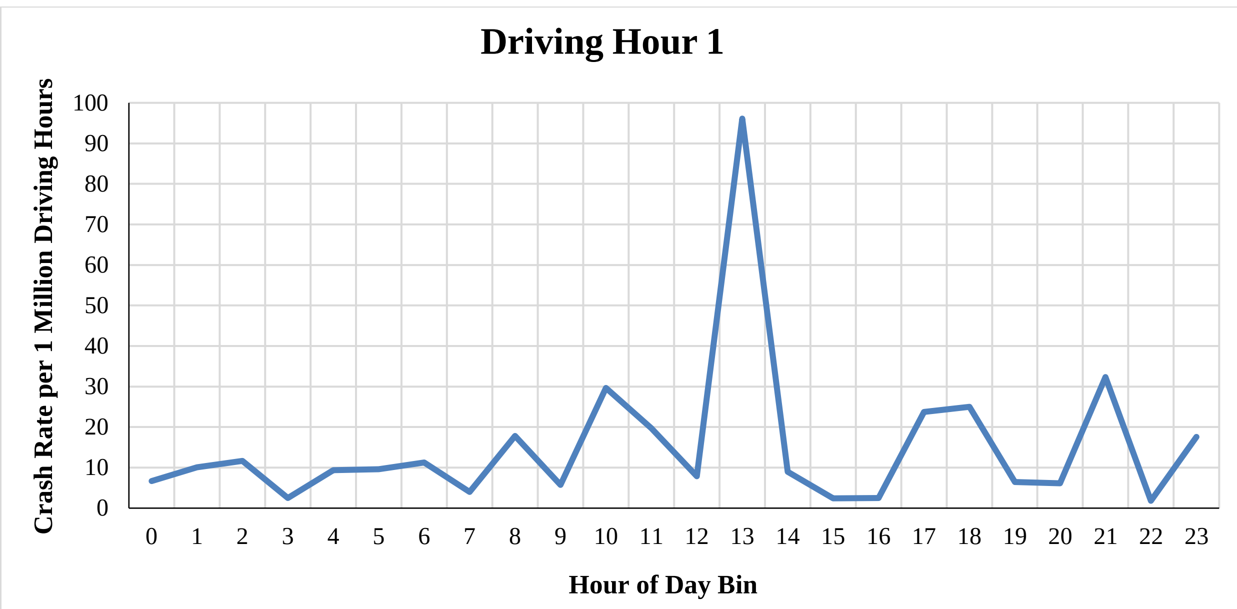

Figure 11. Graph. Driving hour 1 average carrier crash rate per 1 million driving hours in each hour of the day.

Following is the analysis for driving hour 2. The exposure and crash counts by carrier for driving hour 2 are included in Table 27.

Table 28. Exposure in driving hours and total crash counts for driving hour 2 for each carrier.

Carrier ID	Total Driving Hour 2 Driving Time in 1,000 Hours	All Crash Counts
Carrier 1	652.00	8
Carrier 3	740.23	19
Carrier 4	307.93	1
Carrier 5	395.06	6
Carrier 6	228.07	4
Carrier 7	1,165.68	20
Carrier 9	381.16	4
Carrier 10	5,264.67	70
Carrier 11	3,809.68	19
Average, All Carriers	1,438.28	16.78

The average carrier crash rate for driving hour 2 is plotted in Figure 12. Driving hour 2 shows more peaks at similar values through the day, with peaks at time of day hours 6:00–7:00 a.m. (average crash rate of 25 crashes per 1 million driving hours), 3:00–4:00 p.m. (average crash rate of 35 crashes per 1 million driving hours), and 10:00–11:00 p.m. (average crash rate of 26 crashes per 1 million driving hours). No significant differences were identified from the model of crash rates for driving hour 2 over the day.

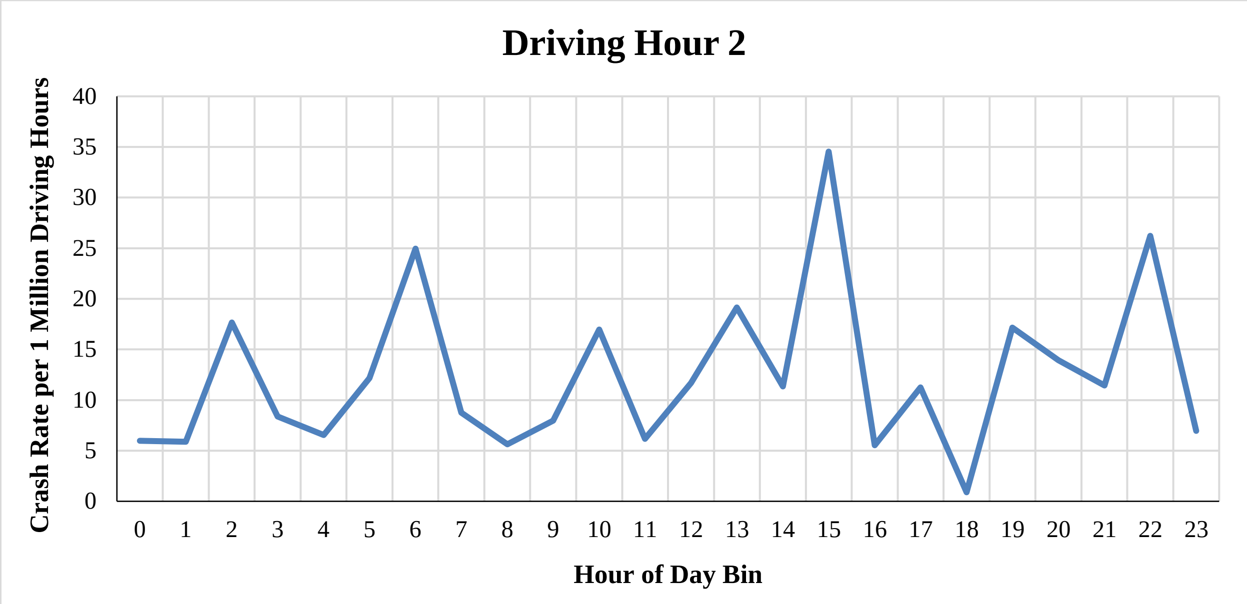

Figure 12. Graph. Driving hour 2 average carrier crash rate per 1 million driving hours in each hour of the day.

The following section includes analysis of driving hour 3, with the total exposure value and crash count for each carrier listed in Table 28.

Table 29. Exposure in driving hours and total crash counts for driving hour 3 for each carrier.

Carrier ID	Total Driving Hour 3 Driving Time in 1,000 Hours	All Crash Counts
Carrier 1	604.32	3
Carrier 3	708.78	15
Carrier 4	294.60	1
Carrier 5	377.69	3
Carrier 6	217.85	3
Carrier 7	1,110.46	20
Carrier 9	257.70	1
Carrier 10	5,079.53	58
Carrier 11	3,639.16	14
Average, All Carriers	1,365.57	13.11

In driving hour 3, shown in Figure 13 below, the average carrier crash rate peaked in hours 9:00 –10:00 p.m. (average crash rates of 68 and 28 crashes per 1 million driving hours). A slightly elevated crash rate was observed in hour 2:00 p.m. (average crash rate of 25 crashes per 1 million driving hours). The remaining hours hovered around an average crash rate of 10 crashes per 1 million driving hours. The model did not identify any statistically significant differences in crash rate between hours of the day for driving hour 3.

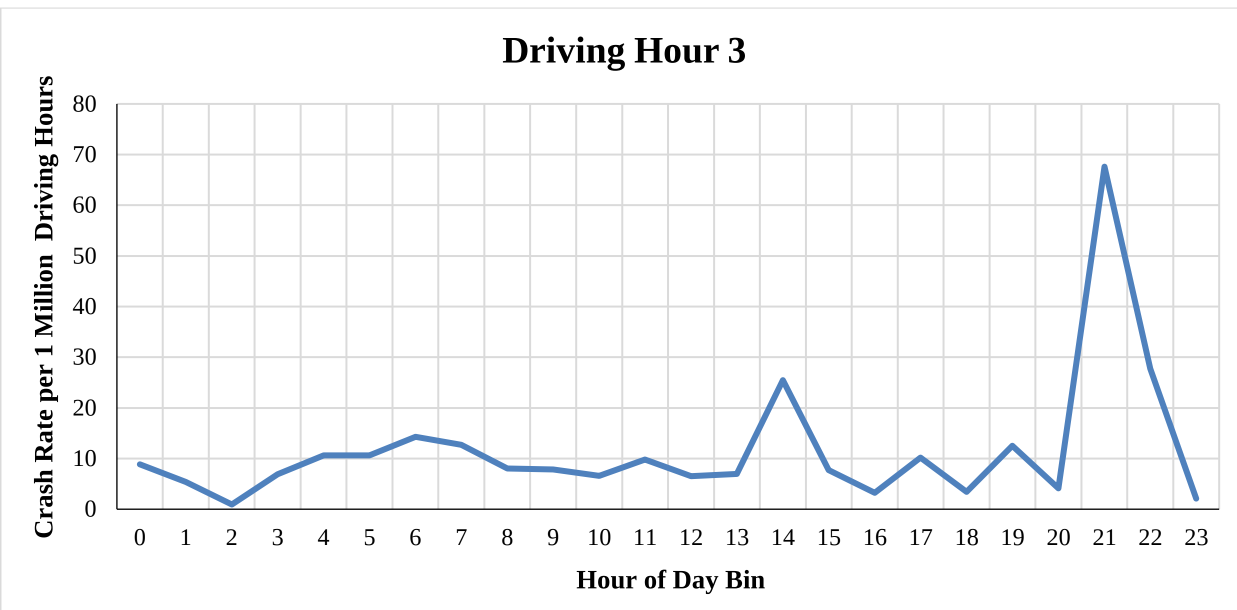

Figure 13. Graph. Driving hour 3 average carrier crash rate per 1 million driving hours in each hour of the day.

The following section includes analysis of driving hour 4, with the total exposure value and crash count for each carrier listed in Table 29.

Table 30. Exposure in driving hours and total crash counts for driving hour 4 for each carrier.

Carrier ID	Total Driving Hour 4 Driving Time in 1,000 Hours	All Crash Counts
Carrier 1	540.66	4
Carrier 3	665.08	14
Carrier 4	277.44	3
Carrier 5	353.73	7
Carrier 6	205.17	2
Carrier 7	1,042.02	33
Carrier 9	149.36	3
Carrier 10	4,774.37	63
Carrier 11	3,414.07	20
Average, All Carriers	1,269.10	16.56

The average carrier crash rate for driving hour 4 is plotted in Figure 14. The average crash rate for driving hour 4 showed a strong rise in hours 11:00 p.m.–1:00 a.m. (average crash rates of 116 and 43 crashes per 1 million driving hours) with additional average crash rate highs in hours 11:00 a.m.–1:00 p.m. (average crash rates of 45, 21, and 31 crashes per 1 million driving hours, respectively) and 5:00 p.m. (average crash rate of 33 crashes per 1 million driving hours). The model did not identify any statistically significant differences in crash rate between hours of the day for driving hour 4.

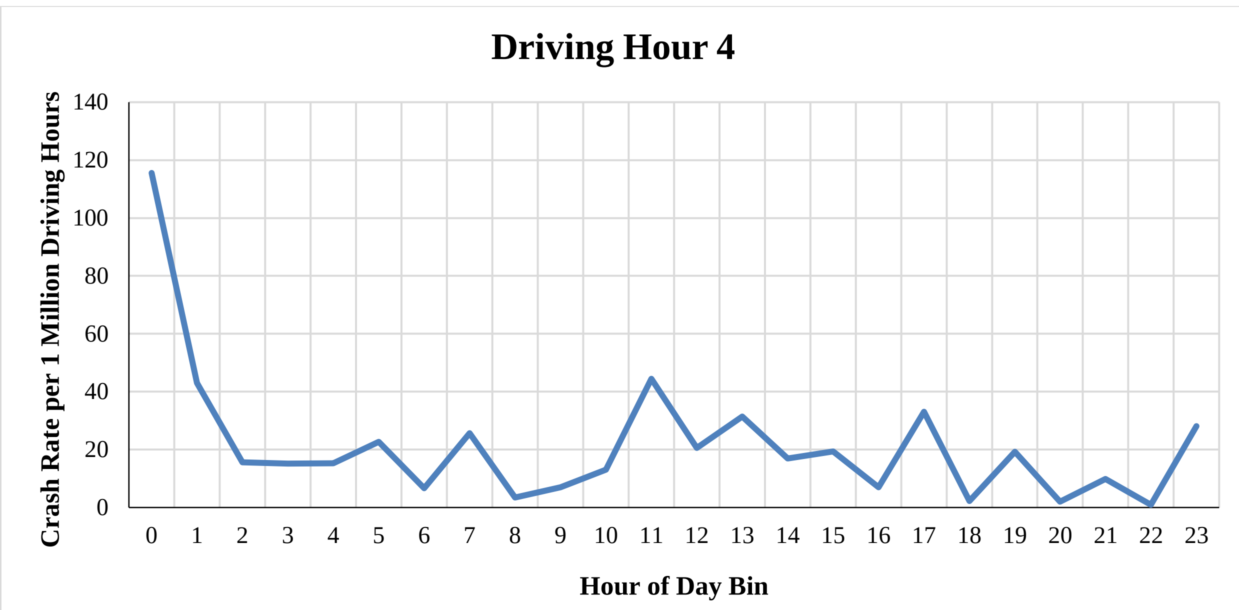

Figure 14. Graph. Driving hour 4 average carrier crash rate per 1 million driving hours in each hour of the day.

In the following section, the analysis of driving hour 5 is presented. Table 30 lists the total exposure value and crash count for each carrier.

Table 31. Exposure in driving hours and total crash counts for driving hour 5 for each carrier.

Carrier ID	Total Driving Hour 5 Driving Time in 1,000 Hours	All Crash Counts
Carrier 1	472.67	6
Carrier 3	609.81	21
Carrier 4	254.15	1
Carrier 5	322.63	4
Carrier 6	189.40	4
Carrier 7	956.39	20
Carrier 9	88.46	0
Carrier 10	4,304.76	78
Carrier 11	3,123.55	15
Average, All Carriers	1,146.87	16.56

Figure 15 shows the average carrier crash rate for driving hour 5 across time of day. Average crash rates were highest from 5:00 a.m.–7:00 a.m. (average crash rates of 31, 21, and 20 crashes per 1 million driving hours, respectively) and at 3:00 p.m. (average crash rate of 24 crashes per 1 million driving hours). The lowest average crash rates occurred at 2:00 p.m. (3 crashes per 1 million driving hours) and 10:00 p.m. (2 crashes per 1 million driving hours). The Poisson regression model identified significant differences in hour 12:00 a.m. and hour 2:00 p.m., OR = 4.82, CI = (1.04, 22.23). Hour 6:00 a.m. also was associated with a higher crash rate than hour 2:00 p.m., OR = 4.77, CI = (1.18, 19.23). Finally, hour 11:00 p.m. was associated with significantly higher crash rates than 2:00 p.m., OR = 4.81, CI = (1.05, 22.16).

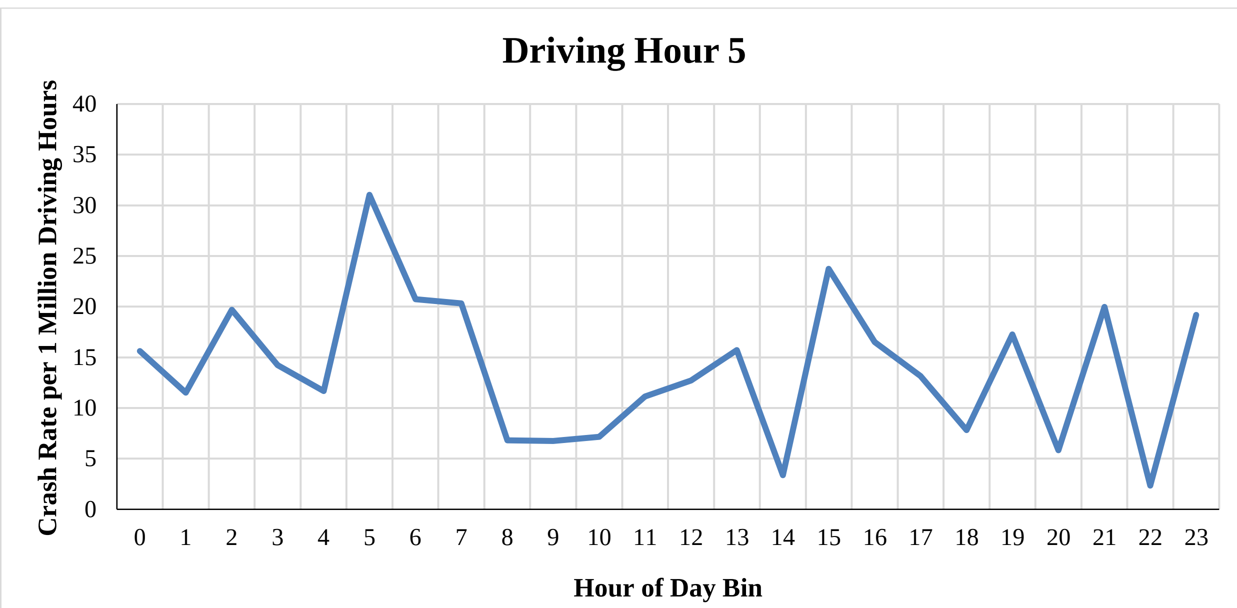

Figure 15. Graph. Driving hour 5 average carrier crash rate per 1 million driving hours in each hour of the day.

In the following section, the analysis of driving hour 6 is presented. Table 31 lists the total exposure value and crash count for each carrier.

Table 32. Exposure in driving hours and total crash counts for driving hour 6 for each carrier.

Carrier ID	Total Driving Hour 6 Driving Time in 1,000 Hours	All Crash Counts
Carrier 1	390.31	3
Carrier 3	538.47	13
Carrier 4	224.33	2
Carrier 5	283.22	8
Carrier 6	170.58	2
Carrier 7	848.31	14
Carrier 9	53.37	0
Carrier 10	3,652.69	42
Carrier 11	2,766.91	12
Average, All Carriers	992.02	10.67

The average carrier crash rate for driving hour 6 is plotted in Figure 16 across time of day. Driving hour showed several crash rate highs immediately adjacent to a single crash rate low. The peak average crash rates occurred in hour 12:00 a.m. (52 crashes per 1 million driving hours), hours 3:00 a.m.–4:00 a.m. (47 and 33 crashes per 1 million driving hours, respectively) and hour 8:00 a.m. (36 crashes per 1 million driving hours). The model did not identify any significant differences between day hours for driving hour 6. The model did not control for carrier due to convergence issues.

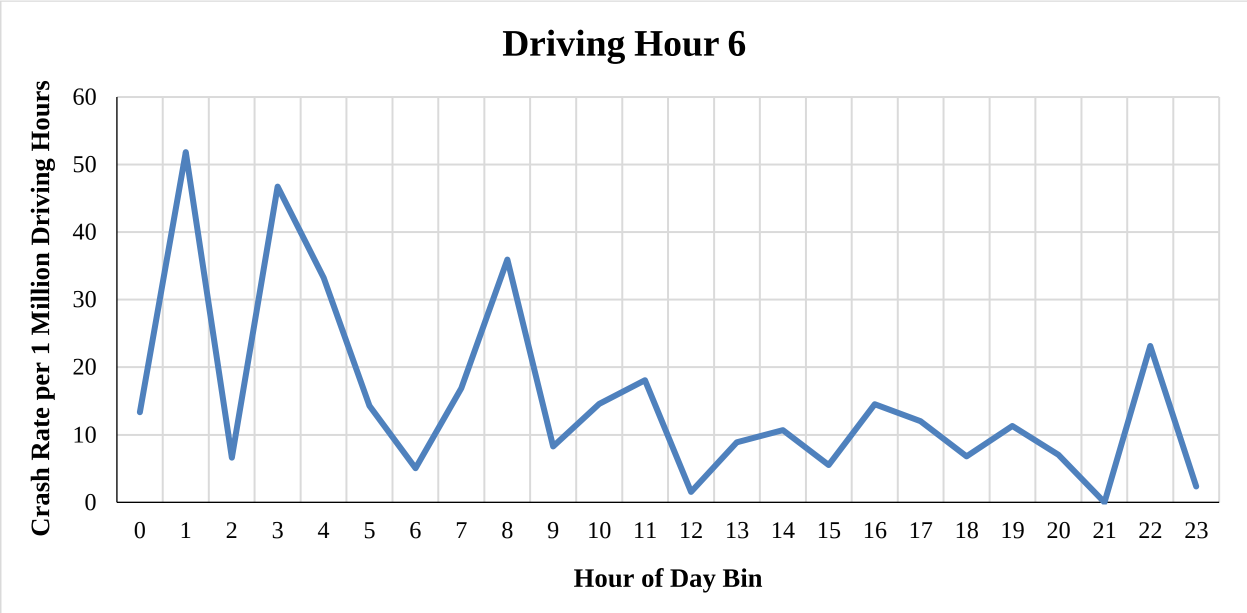

Figure 16. Graph. Driving hour 6 average carrier crash rate per 1 million driving hours in each hour of the day.

Analysis of driving hour 7 is included in the following section. Table 32 lists the total exposure value and crash count for each carrier.

Table 33. Exposure in driving hours and total crash counts for driving hour 7 for each carrier.

Carrier ID	Total Driving Hour 7 Driving Time in 1,000 Hours	All Crash Counts
Carrier 1	325.37	2
Carrier 3	446.88	11
Carrier 4	187.85	3
Carrier 5	241.30	3
Carrier 6	147.55	3
Carrier 7	712.70	10
Carrier 9	30.41	0
Carrier 10	2,875.28	49
Carrier 11	2,350.25	7
Average, All Carriers	813.06	9.78

In Figure 17, the average carrier crash rate for driving hour 7 is plotted by time of day. Higher crash rates were observed in hours 12:00 a.m., 6:00 a.m., 9:00 a.m., 5:00 p.m., and 7:00 p.m.–9:00 p.m. A single statistically significant difference was found with the model between 12:00 a.m. and 6:00 p.m., OR = 10.32, CI = (1.08, 98.20).

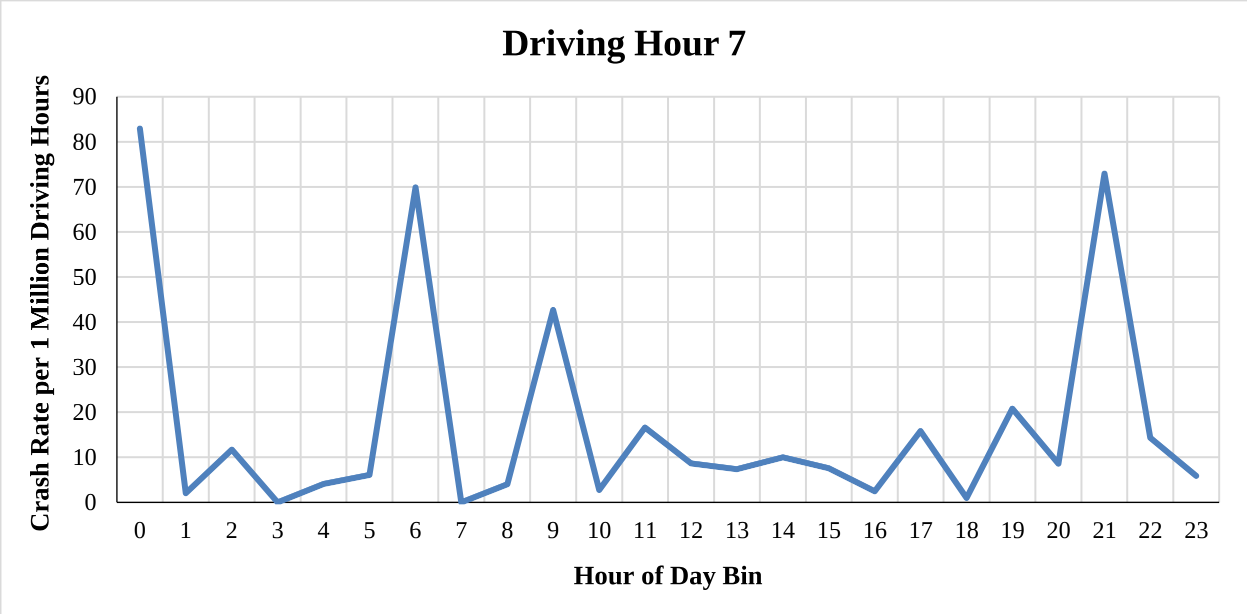

Figure 17. Graph. Driving hour 7 average carrier crash rate per 1 million driving hours in each hour of the day.

The analysis for driving hour 8 is included in the following section. Table 33 lists the total exposure value and crash count for each carrier.

Table 34. Exposure in driving hours and total crash counts for driving hour 8 for each carrier.

Carrier ID	Total Driving Hour 8 Driving Time in 1,000 Hours	All Crash Counts
Carrier 1	266.22	5
Carrier 3	336.30	9
Carrier 4	145.69	0
Carrier 5	188.94	4
Carrier 6	121.22	2
Carrier 7	549.50	13
Carrier 9	14.90	0
Carrier 10	2,076.83	30
Carrier 11	1,874.91	8
Average, All Carriers	619.39	7.89

Figure 18 shows the average carrier crash rate for driving hour 8 across time of day. The crash rate is below 25 crashes per 1 million driving hours for all but five hours. The average crash rate rises from 11:00 p.m.–12:00 a.m. (to 266 and 45 crashes per 1 million driving hours, respectively). Other peaks are observed at 7:00 a.m. (average crash rate of 80 crashes per 1 million driving hours) and 12:00 p.m. (average crash rate of 36 crashes per 1 million driving hours). Statistically significant differences were found between hour 12:00 a.m. and hour 7:00 p.m., OR = 19.89, CI = (1.08, 364.68).

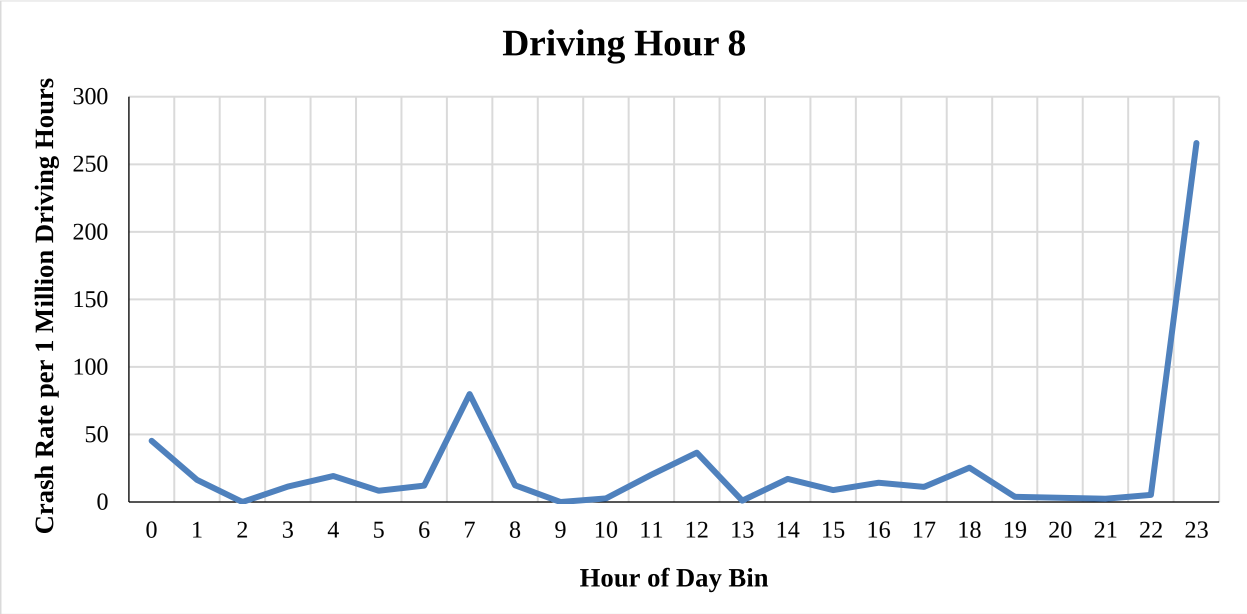

Figure 18. Graph. Driving hour 8 average carrier crash rate per 1 million driving hours in each hour of the day.

Analysis for driving hour 9 is presented in the following section. Table 34 lists the total exposure value and crash count for each carrier.

Table 35. Exposure in driving hours and total crash counts for driving hour 9 for each carrier.

Carrier ID	Total Driving Hour 9 Driving Time in 1,000 Hours	All Crash Counts
Carrier 1	191.36	2
Carrier 3	221.70	6
Carrier 4	101.65	0
Carrier 5	133.68	2
Carrier 6	93.06	1
Carrier 7	378.33	12
Carrier 9	6.57	0
Carrier 10	1,338.29	16
Carrier 11	1,368.20	4
Average, All Carriers	425.87	4.78

The average carrier crash rate for driving hour 9 is shown across time of day in Figure 19. Although the data were more limited, with fewer observations of these longer driving hours, peaks can be seen in the plot at hours 6:00 a.m. (average crash rate of 34 crashes per 1 million driving hours), 1:00 p.m. (average crash rate of 22 crashes per 1 million driving hours), and 8:00 p.m.–1:00 a.m. (range of crash rates from a low of 16 crashes per 1 million driving hours at 8:00 p.m. to a high of 43 at 12:00 a.m.). The model for driving hour 9 found no statistically significant differences in crash rates over the hours of the day.

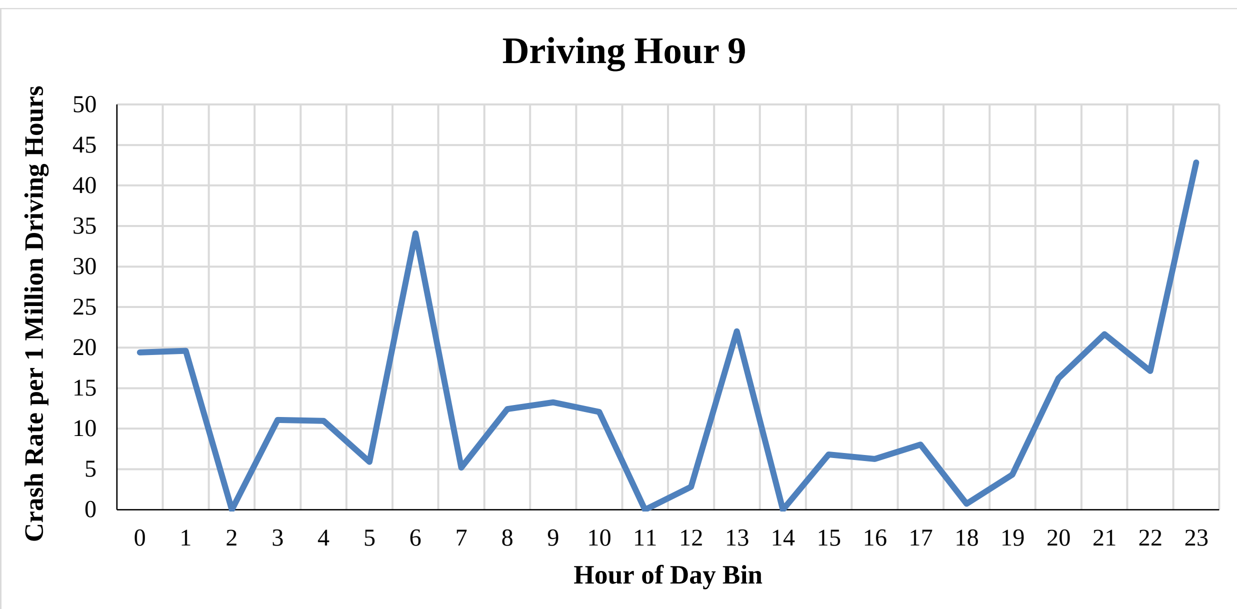

Figure 19. Graph. Driving hour 9 average carrier crash rate per 1 million driving hours in each hour of the day.

Analysis for driving hour 10 is presented in the following section, starting with a table for total exposure value and crash count by carrier (Table 35).

Table 36. Exposure in driving hours and total crash counts for driving hour 10 for each carrier.

Carrier ID	Total Driving Hour 10 Driving Time in 1,000 Hours	All Crash Counts
Carrier 1	94.21	3
Carrier 3	116.63	4
Carrier 4	59.09	1
Carrier 5	82.78	0
Carrier 6	63.68	1
Carrier 7	213.31	3
Carrier 9	3.08	0
Carrier 10	702.67	8
Carrier 11	828.46	2
Average, All Carriers	240.43	2.44

In Figure 20, the average carrier crash rate is shown for driving hour 10 across time of day. The observations in driving hour 10 were limited and the model resulted in no statistically significant comparisons. The plot shows the crash rate rising at several points before dropping back to zero or nearly zero, although the inconsistency could be an artifact of the smaller dataset.

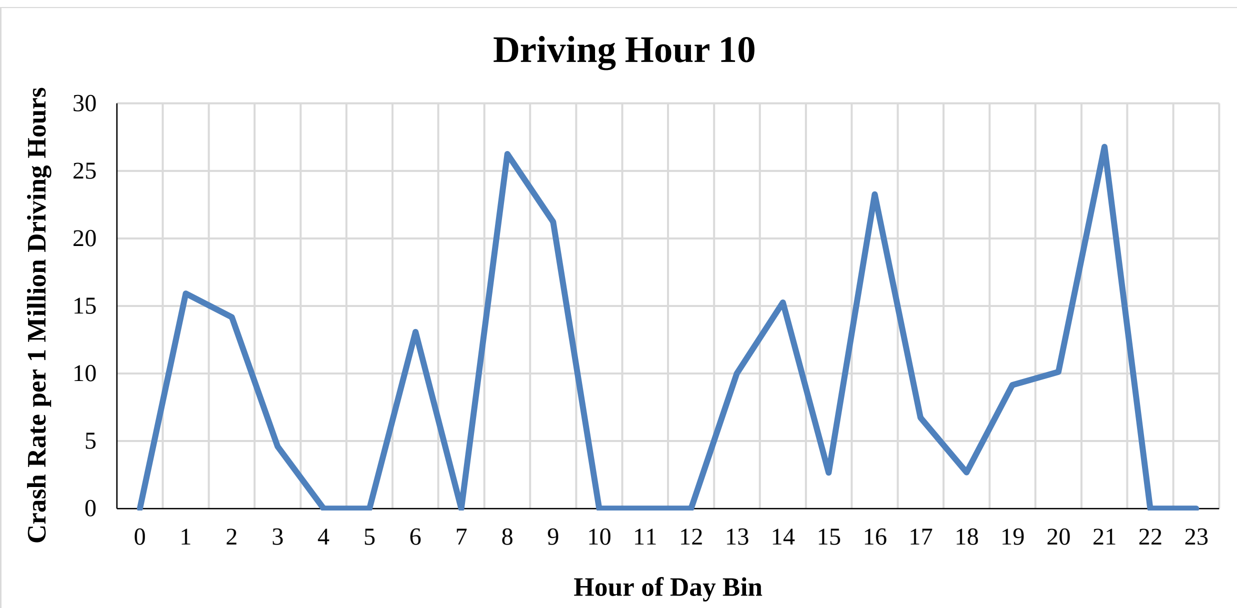

Figure 20. Graph. Driving hour 10 average carrier crash rate per 1 million driving hours in each hour of the day.

Analysis for driving hour 11 is presented below. Total exposure and crash count by carrier are included in Table 36.

Table 37. Exposure in driving hours and total crash counts for driving hour 11 for each carrier.

Carrier ID	Total Driving Hour 11 Driving Time in 1,000 Hours	All Crash Counts
Carrier 1	21.53	1
Carrier 3	34.20	1
Carrier 4	23.38	0
Carrier 5	43.08	0
Carrier 6	35.98	0
Carrier 7	70.92	3
Carrier 9	1.67	0
Carrier 10	238.16	3
Carrier 11	286.47	3
Average, All Carriers	83.93	1.22

The average carrier crash rate for driving hour 11 is shown by time of day in Figure 21. This driving hour also had limited observations in the dataset, and the model found no statistically significant differences by hour of the day. There is a rise in crash rate in hours 2:00–4:00 p.m. (average crash rates of 56 crashes per 1 million driving hours at 2:00 p.m., 186 crashes per 1 million driving hours at 3:00 p.m., and 31 crashes per 1 million driving hours at 4:00 p.m.).

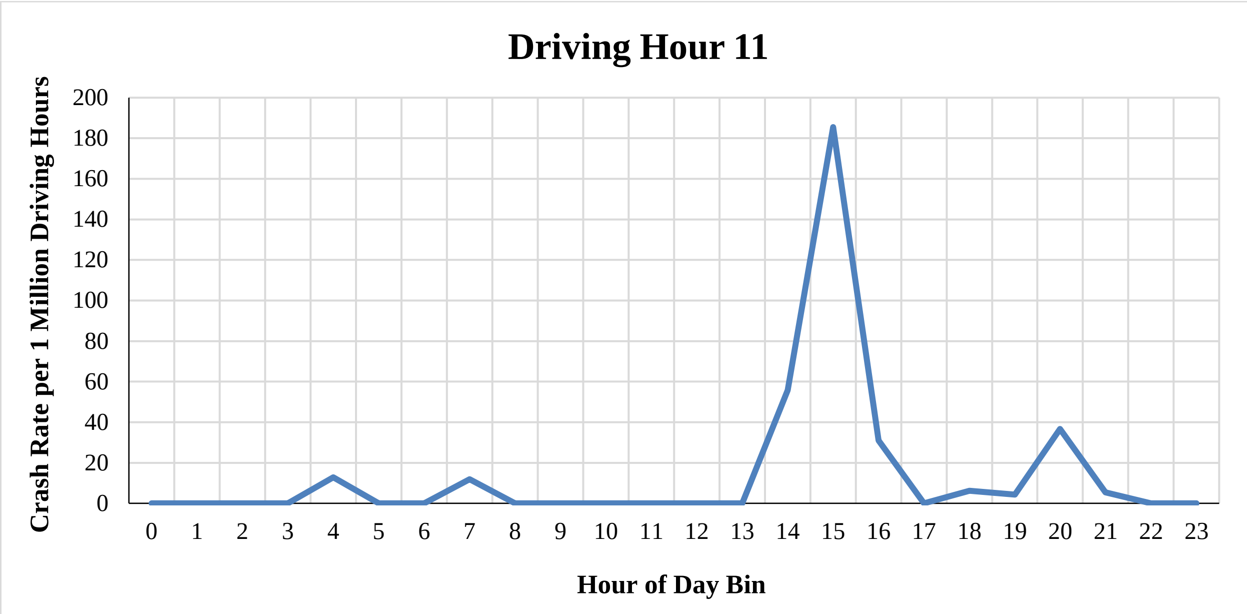

Figure 21. Graph. Driving hour 11 average carrier crash rate per 1 million driving hours in each hour of the day.

REFERENCES

Abdul Manan, M. M., Várhelyi, A., Çelik, A. K., & Hashim, H. H. (2018). Road characteristics and environmental factors associated with fatal motorcycle crash in Malaysia. *IATSS Research*. https://doi.org/10.1016/j.iatssr.2017.11.001

Adanu, E. K., Hainen, A., & Jones, S. (2018). Latent class analysis of factors that influence weekday and weekend single-vehicle crash severities. *Accident Analysis and Prevention, 113*(January), 187–192. https://doi.org/10.1016/j.aap.2018.01.035

Åkerstedt, T., & Kecklund, G. (2001). Age, gender, and early morning highway crashes. *Journal of Sleep Research*, *10*(2), 105–110. https://doi.org/10.1046/j.1365-2869.2001.00248.x

Asgarzadeh, M., Fischer, D., Verma, S. K., Courtney, T. K., & Christiani, D. C. (2018). The impact of weather, road surface, time of day, and light conditions on the severity of bicycle-motor vehicle crash injuries. *American Journal of Industrial Medicine*, *61*(7), 556–565. https://doi.org/10.1002/ajim.22849

Balakrishnan, S., Moridpour, S., & Tay, R. (2016). Differences in a single heavy vehicle crash at intersections and midblock. *Journal of Advanced Transportation*, *44*(March), 267–283. https://doi.org/10.1002/atr

Barr, L., David Yang, C., Hanowski, R., & Olson, R. (2007). Assessment of Driver Fatigue, Distraction, and Performance in a Naturalistic Setting. *Transportation Research Record: Journal of the Transportation Research Board*, *1937*(November), 51–60. https://doi.org/10.3141/1937-08

Blanco, M., Atwood, J., Vasquez, H. M., Trimble, T. E., Fitchett, V. L., Radlbeck, J., & Morgan, J. F. (2015). *Human factors evaluation of level 2 and level 3 automated driving concepts* (DOT HS 812 182). Washington, D.C.: National Highway Traffic Safety Administration.

Blower, D. F., Campbell, K. (1998). *Fatalities and injuries in a truck crash by the time of day*. (*UMTRI-98-48*). University of Michigan Transportation Research Institute.

Camden, M. C., Hickman, J. S., & Hanowski, R. J. (2019). *Effective strategies to improve safety: Case studies of commercial motor carrier safety advancement* (Report No. 19-UI-072). Blacksburg, VA: National Surface Transportation Safety Center for Excellence. https://vtechworks.lib.vt.edu/handle/10919/89323

Cerwick, D. M., Gkritza, K., Shaheed, M. S., & Hans, Z. (2014). A comparison of the mixed logit and latent class methods for crash severity analysis. *Analytic Methods in Accident Research*, *3–4*, 11–27. https://doi.org/10.1016/j.amar.2014.09.002

Chang, L. Y., & Chien, J. T. (2013). Analysis of driver injury severity in truck-involved crashes using a non-parametric classification tree model. *Safety Science*, *51*(1), 17–22. https://doi.org/10.1016/j.ssci.2012.06.017

Chang, L. Y., & Mannering, F. (1999). Analysis of injury severity and vehicle occupancy in a truck- and non-truck-involved crashes. *Accident Analysis and Prevention*, *31*(5), 579–592. https://doi.org/10.1016/S0001-4575(99)00014-7

Chen, I. G., Durbin, D. R., Elliott, M. R., Kallan, M. J., & Winston, F. K. (2005). Trip characteristics of vehicle crashes involving child passengers. *Injury Prevention*, *11*(4), 219–224. https://doi.org/10.1136/ip.2004.006767

Chen, Irene G., Durbin, D. R., Elliott, M. R., Senserrick, T., & Winston, F. K. (2006). Child passenger injury risk in motor vehicle crashes A comparison of nighttime and daytime driving by teenage and adult drivers. *Journal of Safety Research*. https://doi.org/10.1016/j.jsr.2006.01.005

Curnow, G. (2002). What do the statistics tell us? *Australian Transport Safety Bureau Heavy Truck Crash Databases*.

Doherty, S. T., Andrey, J. C., & MacGregor, C. (1998). The situational risks of young drivers: The influence of passengers, time of day, and day of the week on accident rates. *Accident Analysis and Prevention*, *30*(1), 45–52. https://doi.org/10.1016/S0001-4575(97)00060-2

Duncan, C. S., Khattak, A. J., & Council, F. M. (1998). Applying the ordered probit model to injury severity in a truck–passenger car rear-end collisions. *Transp. Res. Rec. J. Transp, Res. Board*(1635), 63–71.

Foss, R. D., Smith, R. L., & O'Brien, N. P. (2019). School start times and teenage driver motor vehicle crashes. *Accident Analysis and Prevention*, *126*(February 2018), 54–63. https://doi.org/10.1016/j.aap.2018.03.031

Ghariani, N. (2001). Measures to Improve Truck Traffic Safety in Texas Roadways. *ETD Collection for University of Texas, El Paso.*

Guo, F. (2019). Statistical methods for naturalistic driving studies. *Annual Review of Statistics and Its Application*, *6*(1), 309-328.

Gwynn, D. W. (1967). Relationship of accident rate and accident involvements with hourly volumes. *Traffic Quarterly, 21(3)*, 407–418.

Hanowski, R. J., Olsen, R. L., Bocanegra, J. L., & Hickman, J. S. (2008). *Analysis of risk as a function of driving-hour: Assessment of driving-hours 1 through 11*. Federal Motor Carrier Safety Administration.

Hickman, J. S., Scopatz, B., Lantz, B., Bergoffen, G., Wu, Y., Camden, M. C., Mao, H., Guo, F., & Hanowski, R. J. (under agency review). *Hours of service rules impact analysis.* Washington, D.C.: Federal Motor Carrier Safety Administration.

Herman, J., Ameratunga, S., Kafoa, B., Wainiqolo, I., Robinson, E., McCaig, E., … Jackson, R. (2012). Driver sleepiness and risk of motor vehicle crash injuries: A population-based case-control study in Fiji. *Injury Prevention*, *18*(Suppl 1), A74.2-A74. https://doi.org/10.1136/injuryprev-2012-040580g.7

Islam, M. Bin, & Hernandez, S. (2014). Modeling injury outcomes of crashes involving heavy vehicles on Texas highways. *Transportation Research Record: Journal of the Transportation Research Board*, *2388*(1), 28–36. https://doi.org/10.3141/2388-05

Islam, M., & Hernandez, S. (2013). Large truck–involved crashes: Exploratory injury severity analysis. *Journal of Transportation Engineering*, *139*(6), 596–604. https://doi.org/10.1061/(ASCE)te.1943-5436.0000539

Islam, S., Jones, S. L., & Dye, D. (2014). Comprehensive analysis of single- and multi-vehicle large truck-at-fault crashes on rural and urban roadways in Alabama. *Accident Analysis and Prevention, 67*, 148–158. https://doi.org/10.1016/j.aap.2014.02.014

Ivan, J. N., Wang, C., & Bernardo, N. R. (2000). Explaining two-lane highway crash rates using land use and hourly exposure. *Accident Analysis and Prevention*, *32*(6), 787–795. https://doi.org/10.1016/S0001-4575(99)00132-3

Jeong, H., Jang, Y., Bowman, P. J., & Masoud, N. (2018). Classification of motor vehicle crash injury severity: A hybrid approach for imbalanced data. *Accident Analysis and Prevention*, *120*(August), 250–261. https://doi.org/10.1016/j.aap.2018.08.025

Jermakian, J. S. (2011). Crash avoidance potential of four passenger vehicle technologies. *Accident Analysis and Prevention*. https://doi.org/10.1016/j.aap.2010.10.020

Knipling, R. R., Bocanegra, J., 2008. (n.d.). *Comparison of combination-unit truck and single-unit truck statistics from the LTCCS, FMCSA, and Volpe Center project report* (No. DTRS57-04-D-30043).

Livneh, M., & Ceder, A. (1982). Relationships between road crashes and hourly traffic flow-i analyses and interpretation. *Accident Analysis & Prevention*, *14*(1), 19–32.

Marquis, R., & Wang, X. (Cara). (2015). Investigating temporal effects on truck accident occurrences in Manhattan, New York City. *Transportation Research Record: Journal of the Transportation Research Board*, *2517*(1), 10–17. https://doi.org/10.3141/2517-02

Martensen, H., & Dupont, E. (2013). Comparing a single vehicle and multi-vehicle fatal road crashes: A joint analysis of road conditions, time variables, and driver characteristics. *Accident Analysis and Prevention*, *60*, 466–471. https://doi.org/10.1016/j.aap.2013.03.005

Monteiro, N. M., Balogun, S. K., Kote, M., & Tlhabano, K. (2015). Stationary tailgating in Gaborone, Botswana: The influence of gender, time of day, type of vehicle, and presence of traffic officer. *IATSS Research*, *38*(2), 157–163. https://doi.org/10.1016/j.iatssr.2014.05.003

National Highway Traffic Safety Administration. (2014). Restraint Use Among Fatally Injured Passenger Vehicle Occupants. *Www-Nrd.Nhtsa.Dot.Gov*, (May), Volume: 2001, Issue: June, Pages: 232.

Offei, E., & Young, R. (2014). *Quantifying the impact of large percent trucks proportion on rural freeways*. Mountain-Plains Consortium.

Pahukula, J., Hernandez, S., & Unnikrishnan, A. (2015). Time of day analysis of crashes involving large trucks in urban areas. *Accident Analysis and Prevention*, *75*, 155–163. https://doi.org/10.1016/j.aap.2014.11.021

Park, S., & Jovanis, P. (2010). Hours of service and truck crash risk. *Transportation Research Record: Journal of the Transportation Research Board*, (2194), 3–10.

Perneger, T. (1998). What's wrong with Bonferroni adjustments. *BMJ: British Medical Journal, 316*(7139), 1236-1238.

Qin, X., Ivan, J. N., Ravishanker, N., Liu, J., & Tepas, D. (2006). Bayesian estimation of hourly exposure functions by crash type and time of day. *Accident Analysis and Prevention*. https://doi.org/10.1016/j.aap.2006.04.012

Rothman, K. J. (1990). No adjustments are needed for multiple comparisons. *Epidemiology*, *1*(1), 43–46.

Sadeghniiat-Haghighi, K., Yazdi, Z., Moradinia, M., Aminian, O., & Esmaili, A. (2015). Traffic crash crashes in Tehran, Iran: Its relation with the circadian rhythm of sleepiness. *Chinese Journal of Traumatology - English Edition*, *18*(1), 13–17. https://doi.org/10.1016/j.cjtee.2014.09.001

Smith, A. C. (2016). Spring forward at your own risk: Daylight saving time and fatal vehicle crashes. *American Economic Journal: Applied Economics*, *8*(2), 65–91. https://doi.org/10.1257/app.20140100

Smithson, M., & Verkuilen, J. (2006). A better lemon squeezer? Maximum-likelihood regression with beta-distributed dependent variables. *Psychological Methods*, *11*(1), 54-71.

Soccolich, S. A., Blanco, M., Hanowski, R. J., Olson, R. L., Morgan, J. F., Guo, F., & Wu, S. C. (2013). An analysis of driving and working hour on commercial motor vehicle driver safety using naturalistic data collection. *Accident Analysis and Prevention*, *58*, 249–258. https://doi.org/10.1016/j.aap.2012.06.024

Wei, Z., Xiaokun, W., & Dapeng, Z. (2017). Truck crash severity in New York City: An investigation of the spatial and the time of day effects. *Accident Analysis and Prevention*, *99*(A), 249–261. https://doi.org/10.1016/j.aap.2016.11.024

Zhang, D., & Wang, X. C. (2014). Transit ridership estimation with network Kriging: A case study of Second Avenue Subway, NYC. *Journal of Transport Geography*, *41*, 107–115. https://doi.org/10.1016/j.jtrangeo.2014.08.021

Zheng, Z., Lu, P., & Lantz, B. (2018). Commercial truck crash injury severity analysis using gradient boosting data mining model. *Journal of Safety Research*, *65*(March), 115–124. https://doi.org/10.1016/j.jsr.2018.03.002