Analysis of Risk as a Function of Driving-Hour: Assessment of Driving-Hours 1 Through 11

Final Report

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

January 2008

FOREWORD

Crashes involving large trucks constitute a significant risk to the driving public and an occupational risk to truck drivers. In 2005, some 442,000 large trucks (weighing over 10,000 lbs each) were involved in vehicle crashes; 4,951 of these large-truck crashes resulted in fatalities. Driver impairment due to drowsiness is a known contributing factor in many crashes involving commercial motor vehicle (CMV) drivers (Maycock, 1997). The Large Truck Crash Causation Studies found that 13 percent of truck drivers were coded as having been fatigued at the time of the crash (Federal Motor Carrier Safety Administration [FMCSA], 2006).

On April 28, 2003, FMCSA published a revised set of regulations concerning the Hours-of-Service (HOS) of CMV drivers. These published regulations were amended on September 30, 2003 and implemented on January 4, 2004. One central component of the revisions was a two-hour extension of off-duty time from eight to 10 hours. One rationale given in an FMCSA posting in the *Federal Register* (2005) was that the additional two hours of off-duty time would provide drivers with "…substantially more opportunity to obtain restorative sleep" (p. 3342). The results from Hanowski, Dingus, Sudweeks, Olson, and Fumero (2005) indicated that this indeed may be the case; their research found that drivers may be getting more sleep under the revised 2003 HOS regulation (6.28 h per day) as compared to the old regulations (5.18 h per day; Mitler et al., 1997).

The current FMCSA-funded study examined some important issues pertaining to the HOS debate, particularly with regard to time-on-task or driving-hours. Hanowski et al. (2005) reported on an analysis that involved a comparison of critical incidents involving CMVs that occurred in the 10^{th} and 11^{th} driving-hours. This was a timely analysis effort as it provided insight into questions associated with the revised 2003 HOS regulations. Two limitations of the 2005 analysis of Hanowski et al. were that: (i) it included only a partial dataset and (ii) it compared only the frequency of critical incidents that occurred in the 10^{th} and 11^{th} driving-hours. Since that report was written, data collection for the naturalistic study on which the 2005 Hanowski et al. analysis was based has been completed (Hanowski et al., in press). As a result, the two limitations cited above as being associated with the initial analysis can be addressed in the current study. In addition, to provide a comprehensive and thorough examination of the topic, additional analyses were conducted to address how critical incidents may vary as a function of driving shift and time-of-day.

The current final report focused on the following research issues:

1. Critical incidents as a function of driving-hour for hours 1 through 11;
2. Critical incidents per driving-hour for hours 1 through 11, focusing on drivers that drove into the 11^{th} hour;
3. Modeling the data to look for significant differences in critical incidents across driving-hour;
4. Critical incidents as a function of shift within the driver's "work week" (i.e., "tour of duty") and;
5. Critical incidents as a function of time-of-day.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FMCSA-RRR-08-002		

4. Title and Subtitle
Analysis of Risk as a Function of Driving-Hour: Assessment of Driving-Hours 1 Through 11

5. Report Date
January 2008

6. Performing Organization Code:

7. Author(s)
Richard J. Hanowski, Rebecca L. Olson, Joseph Bocanegra, and Jeffrey S. Hickman

8. Performing Organization Report No.

9. Performing Organization Name and Address
Virginia Tech Transportation Institute
3500 Transportation Research Plaza (0536)
Blacksburg, VA 24061

10. Work Unit No.

11. Contract or Grant No.
DTMC75-07-D-00006

12. Sponsoring Agency Name and Address
Department of Transportation
Federal Motor Carrier Safety Administration
1200 New Jersey Ave., SE
Washington, DC 20590

13. Type of Report and Period Covered
Final Report
November 1, 2007–January 31, 2008

14. Sponsoring Agency Code
FMCSA

15. Supplementary Notes
This program was managed by the Federal Motor Carrier Safety Administration (FMCSA).

16. Abstract
The current FMCSA-funded study examined some important issues pertaining to the HOS debate, particularly with regard to time-on-task or driving-hours. Hanowski et al. (2005) reported on an analysis that involved a comparison of critical incidents involving CMVs that occurred in the 10th and 11th driving-hours. Two limitations of the Hanowski et al. (2005) analysis were that: (i) it included only a partial dataset and (ii) it compared only the frequency of critical incidents that occurred in the 10th and 11th driving-hours. Since that report was written, data collection for the naturalistic study on which the Hanowski et al. (2005) analysis was based has been completed (Hanowski et al., in press). These two limitations associated with the initial analysis were addressed in the current study. This study has resulted in a major finding that is relevant to the assessment of the 2003 HOS regulations. Specifically, the results from the analysis on critical-incident relative frequency, used as a surrogate for driver performance decrement, generally showed no statistical difference in the hours between the 2nd through 11th driving-hours (for almost all analyses); and the statistical difference between the 1st driving-hour and the 11th driving-hour is in the opposite direction of what would be expected had there been a time-on-task effect. That is, the results of this study do not support the hypothesis that there is an increased risk resulting from CMV drivers driving in the 11th driving-hour as compared to the 10th driving-hour, or any hour. These results from this research suggest time-on-task as being a poor predictor of crashes and safety-related traffic events. In fact, a significant spike in the rate of critical incidents was found during the 1st driving-hour. This spike was found across all possible trips and on only those trips in which the truck driver drove into the 11th driving-hour. The latter statement is noteworthy because it suggests that even on those trips in which the driver drove into the 11th driving-hour, the critical-incident relative frequency was highest in the 1st driving-hour (significantly more compared to driving-hours 2 though 11 for almost all analyses). Additional analyses found a strong time-of-day effect which, upon closer examination, appeared to have resulted from hour-by-hour traffic density variations. The authors hypothesized that exposure to heavy traffic conditions, and possibly sleep inertia and an increase in complex driving situations that may be typical in the 1st driving-hour, may be the key predictors of critical- incident occurrence.

17. Key Words	18. Distribution Statement
Hours-of-Service, HOS, Truck, Commercial Vehicle, Regulations, Fatigue, Drowsiness, Time-on-task	**No restrictions. This document is available through the National Technical Information Service; Springfield, VA 22161.**

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**98**	

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

SI* (Modern Metric) Conversion Factors									
APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					LENGTH		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					AREA		
in^2	square inches	645.2	square millimeters	mm^2	mm^2	square millimeters	0.0016	square inches	in^2
ft^2	square feet	0.093	square meters	m^2	m^2	square meters	10.764	square feet	ft^2
yd^2	square yards	0.836	square meters	m^2	m^2	square meters	1.195	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	square kilometers	km^2	km^2	square kilometers	0.386	square miles	mi^2
		VOLUME					VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml	ml	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	l	l	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	cubic meters	m^3	m^3	cubic meters	35.71	cubic feet	ft^3
yd^3	cubic yards	0.765	cubic meters	m^3	m^3	cubic meters	1.307	cubic yards	yd^3
		MASS					MASS		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.202	pounds	lb
T	short tons (2,000 lbs)	0.907	megagrams	Mg	Mg	megagrams	1.103	short tons (2,000 lbs)	T
		TEMPERATURE (exact)					TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	1.8 C + 32	Fahrenheit temperature	°F
		ILLUMINATION					ILLUMINATION		
fc	foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-lamberts	3.426	candela/m2	cd/m2	cd/m2	candela/m2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS					FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N	N	newtons	0.225	pound-force	lbf
psi	pound-force per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	pound-force per square inch	psi

*** SI is the symbol for the International System of Units. Appropriate rounding should be done to comply with Section 4 of ASTM E380.**

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

CMV	Commercial Motor Vehicle
DDWS	Drowsy Driver Warning System
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FOT	Field Operational Test
GEE	Generalized Estimating Equations
GPS	Global Positioning System
HOS	Hours of Service
ITS	Intelligent Transportation Systems
JPO	Joint Program Office
LCL	Lower Confidence Limit
LTCCS	Large Truck Crash Causation Study
NHTSA	National Highway Traffic Safety Administration
UCL	Upper Confidence Limit
VMT	Vehicle Miles Traveled

EXECUTIVE SUMMARY

2003 HOURS-OF-SERVICE

On April 28, 2003, FMCSA published a revised set of regulations concerning the Hours-of-Service (HOS) of commercial motor vehicle (CMV) drivers. These published regulations were amended on September 30, 2003 and implemented on January 4, 2004. One central component of the revisions was a two-hour extension of off-duty time from eight to 10 hours. One rationale given in an FMCSA posting in the *Federal Register* (2005) was that the additional 2 hours of off-duty time would provide drivers with "…substantially more opportunity to obtain restorative sleep" (p. 3342). The results from Hanowski, Dingus, Sudweeks, Olson, and Fumero (2005) indicated that this indeed may be the case; their research found that drivers may be getting more sleep under the revised 2003 HOS regulation (6.28 h per day) as compared to the old regulations (5.18 h per day; Mitler et al., 1997).

FMCSA believed the extra off-duty time, with better opportunities to obtain restorative sleep, would also reduce the incidence of crashes wholly or partially attributable to drowsiness or fatigue (*Federal Register*, 2005). Several groups (Public Citizen, Citizens for Reliable and Safe Highways, and Parents Against Tired Truckers) challenged the 2003 HOS regulations, indicating that FMCSA failed to show how additional off-duty time compensated for more driving time (from 10 to 11 hours of driving). A naturalistic driving study performed under the 2003 HOS regulations by Hanowski et al. (2005) found no significant difference in critical incidents (crashes and near-crashes) involving CMVs that occurred in the 10th and 11th driving-hours.

The current FMCSA-funded study examined some important issues pertaining to the HOS debate, particularly with regard to time-on-task or driving-hours. Hanowski et al. (2005) reported on an analysis that concerned a comparison of critical incidents involving CMVs that occurred in the 10th and 11th driving-hours. This was a timely analysis effort, as it provided insight into questions associated with the revised 2003 HOS regulations. Two limitations of the 2005 analysis of Hanowski et al. were that: (i) it included only a partial dataset and (ii) it compared only the frequency of critical incidents that occurred in the 10th and 11th driving-hours. Since that report was written, data collection for the naturalistic study on which the analysis of Hanowski et al. (2005) was based has been completed (Hanowski et al., in press). These two limitations associated with the initial analysis were addressed in the current study. In addition, to provide a comprehensive and thorough examination of the topic, additional analyses were conducted to address how critical incidents may vary as a function of driving shift and time-of-day.

OVERVIEW OF THE CURRENT STUDY

The current final report focused on the following five research issues: (1) critical incidents as a function of driving-hour for hours 1 through 11, (2) critical incidents per driving-hour for hours 1 through 11, focusing on drivers that drove into the 11th hour, (3) modeling the data to look for significant differences in critical incidents across driving-hour, (4) critical incidents as a function of shift within the driver's "work week" (i.e., "tour of duty"), and (5) critical incidents as a function of time-of-day.

METHODS

Data for these analyses were collected during a Field Operational Test (FOT) of a Drowsy Driver Warning System (DDWS). A description of the methodology used in the FOT can be found in Hanowski, Nakata, and Olson (2004) and the final data collection report is in press (Hanowski et al., in press). Data collection for the FOT began in May 2004 and ended in September 2005. A total of 103 drivers participated in the study (102 males, 1 female; mean age = 40.03 years; age range = 24 to 60 years). Five drivers could not be used for the driving-hour analyses because of unreliable driving-time histories. The gender and age distribution of the 98 drivers included in the driving-hour analyses were: 97 males, 1 female; mean age = 39.96 years; age range = 24 to 60 years.

A naturalistic-data-collection approach was used in which data were collected as study participants drove company trucks during their normal revenue-producing runs. Unobtrusive data collection equipment was installed in 46 trucks. The data collection equipment included sensors to measure driver performance and video that recorded the driver's face and three views outside of the truck. Driver participants were assigned to an instrumented truck to use on their normal delivery routes. The mean number of weeks that drivers participated in the study was 12.38 weeks, with a standard deviation of 4.17 weeks. The final project dataset consisted of 2.3 million miles of driving data and 11.8 TB of video and dynamic sensor data.

The data collection system, including the video cameras, became active when the ignition system of the vehicle was activated. The system was programmed to remain active and to gather data as long as the engine was on and the vehicle was in motion. The system was programmed to shut down when the ignition was turned off, and the system was programmed to pause if the vehicle ceased motion for a 10-minute period. Data collection resumed when the vehicle was again in motion. Driver performance was assessed through the occurrence of critical incidents (crashes, near-crashes, and crash-relevant conflicts). The critical incidents were identified using a software program to search through all data files for spikes in sensors that would indicate the possibility of a critical incident. For example, the program searched for all occurrences of longitudinal accelerations of $\geq \left| 0.35\ g \right|$ to locate instances of hard braking. Once potential critical incidents had been identified by the software program, researchers viewed the video and other corresponding data to determine if the event was a valid critical incident. To help ensure that all critical incidents included in the current dataset were valid (that is, that an actual conflict had occurred), assessment of an event's validity required the consensus of two researchers.

RESULT HIGHLIGHTS

The number of critical incidents varied on the analysis conducted. For example, Analysis 1 included 819 critical incidents (12 crashes, 12 tire-strike crashes, 85 near-crashes, and 710 crash-relevant conflicts). To fully investigate this issue, the data were parsed and analyzed in eight different ways. This thorough investigative approach was undertaken to help ensure that significant findings were not overlooked.

To adjust for the differences in opportunities across driving-hour, a rate was calculated which, in effect, normalized the data. That is, the frequency of critical incidents, in any given driving-hour, was divided by the total opportunities for that hour. This provided the relative frequency of having a critical incident in any given driving-hour. For example, there were 122 critical incidents and 4,748 total opportunities in Driving-Hour 1. Thus, the rate of critical incidents in Driving-Hour 1 was 0.026 (122 critical incidents / 4,748 total opportunities = 0.026).

Analysis 1 focused on critical incidents as a function of Driving-Hour for hours 1 through 11. Figure 1 shows the relative frequency of critical incidents as a function of driving-hour for Hours 1 through 11, in which the subject-vehicle driver (i.e., the study truck driver) was judged, based on video review, to have been at fault. A breakdown in the frequency for each type of critical incident is shown in Figure 1, including crashes (red), crashes: tire strikes (green), near-crashes (purple), and crash-relevant conflicts (blue). The top of each bar in Figure 1 represents the combined total of all types of critical incidents (crashes, tire strikes, near-crashes, and crash-relevant conflicts). As can be seen from the results of this analysis, there was a notable "spike" in the relative frequency of critical incidents in the 1st driving-hour. Odds ratios were evaluated and found that all comparisons with the 1st driving-hour were statistically significant. This was a consistent finding throughout the eight sub-analyses conducted and suggests a robust and meaningful effect. Analysis 2, which focused on critical incidents as a function of driving-hour for hours 1 through 11, for drivers who drove 11 hours, found similar findings.

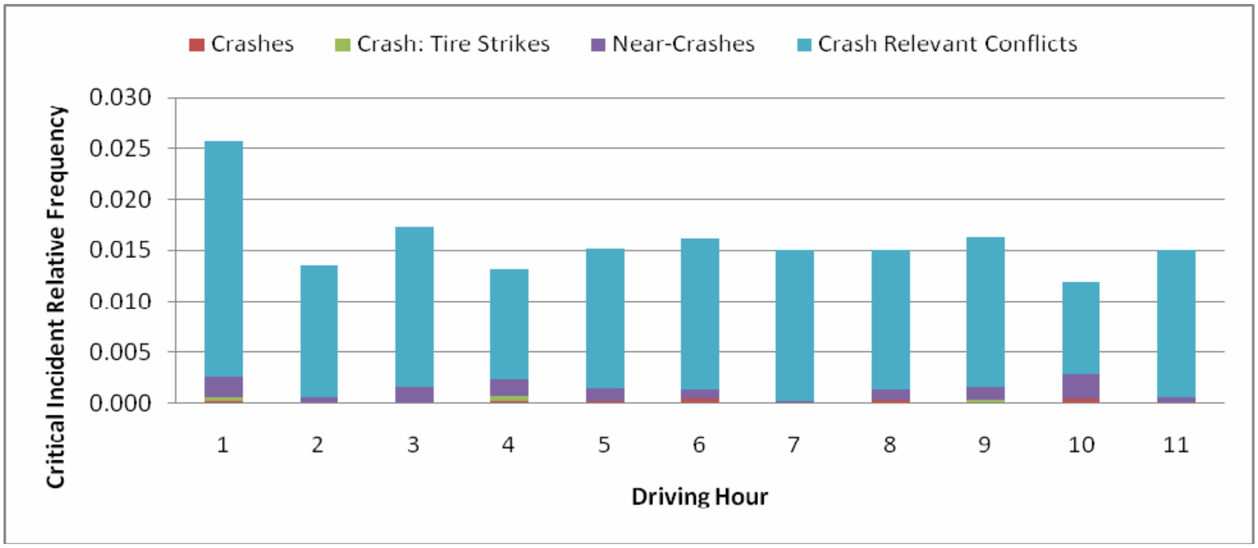

Figure 1. Critical-Incident Relative Frequency as a Function of Driving-Hour, in Which the Subject Driver was at Fault

As a follow-up to Analyses 1 and 2, Analysis 3 computed odds ratios using logistic regression modeling. One difference between this approach and the approach used in Analyses 1 and 2 is that an assumption of independence is not being made. That is, the approach used generalized estimating equations to account for correlations that might exist between drivers (i.e. the correlation between driver 1 and 2) and within drivers (i.e. the correlation between driver 1 across days) (with respect to critical-incident occurrence).

The logistic regression modeling approach was applied to two different datasets: (1) the entire dataset (Analysis 1), and (2) the subset of trips that went into the 11th driving-hour (Analysis 2). The output of the model is the odds ratios for each driving-hour, and not the critical-incident relative frequency, as in the previous analyses. Consistent with the general Analysis 1 results, there was a spike in the 1st driving-hour as compared to all other driving-hours. No other hour-by-hour comparisons were statistically significant. The second logistic regression analysis conducted was similar to Analysis 2, in that the focus was on trips that went into the 11th driving-hour.

Analysis 4 investigated critical incidents as a function of driving-shift. Once again, the critical-incident data were parsed and analyzed in eight different ways. To summarize the findings from Analysis 4, there were no results that were consistent across all of the different analyses conducted. When there was a significant finding, it often involved the 5th or 8th driving-shift. However, when multiple within-shift critical incidents were accounted for, such significant findings were not found. Because of the inconsistency of the findings across the different analyses, these results do not seem to provide strong, convincing support for a driving-shift effect

Analysis 5 assessed critical incidents as a function of time-of-day. As in Analyses 1, 2, and 4, Analysis 5 conducted eight separate analyses. At first, the time-of-day data plot and the results from the odds ratios did not seem to indicate any clear pattern; however there was obviously a strong time-of-day effect. Note that both a frequency odds ratio approach and a logistic regression modeling approach were used and similar results were found using both approaches.

In an attempt to interpret what might be going on, follow-up analyses were conducted, one of which considered traffic density as a function of driving-hour. Traffic-density data were plotted against the hour-by-hour critical-incident relative frequency plots shown in Figure 2. Note that the traffic-density overlay in Figure 2 is based on visual inspection of plots found in Festin (1996).

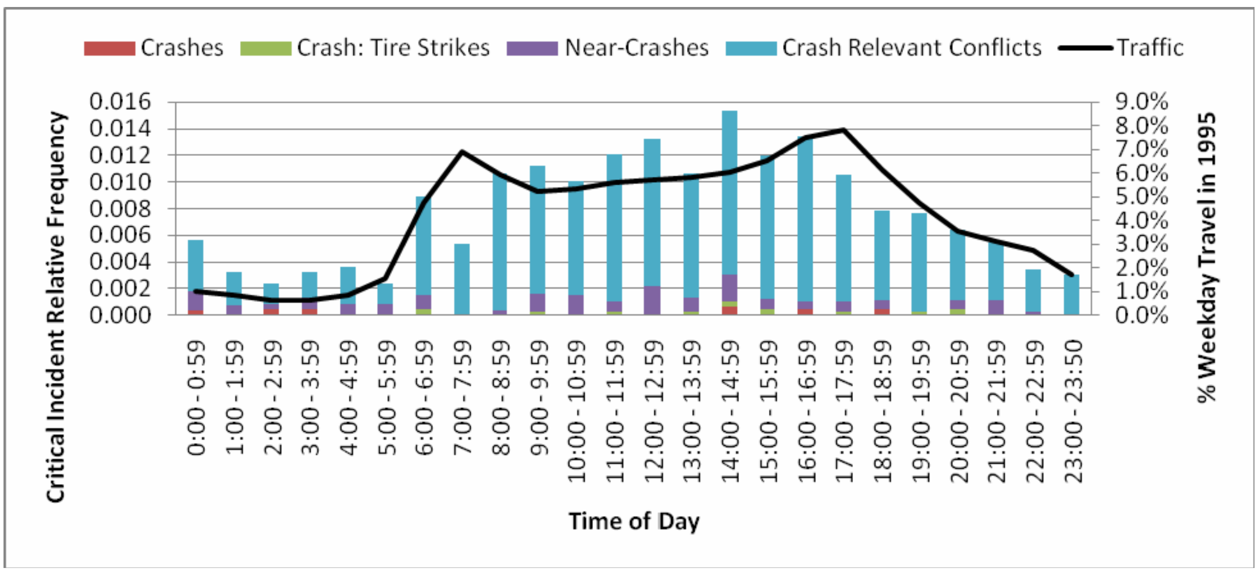

Figure 2. Critical-Incident Relative Frequency as a Function of Time-of-Day, with Traffic-Density Plot Superimposed

The black line in Figure 2 displays the U.S. distribution of daily weekday traffic across each hour of the day in 1995 (Festin, 1996). Festin (1996) used two primary data sources, highway statistics for annual vehicle miles traveled (VMT), and 5,000 automatic traffic recorder sites across the United States, to estimate annual travel trends in the United States. Note that these traffic data represent national weekday averages and are not location-specific. The distribution is likely to change based on region, setting (i.e., urban vs. rural), and day of week (i.e., weekday vs.

weekend). The traffic-density plot appears to follow the critical-incident relative frequency plot, particularly with regard to the sharp onset (around 6 a.m.) and slow decline after what presumably would be the evening rush period. As such, it is hypothesized that the hour-by-hour differences observed in the current study may be primarily a function of traffic density (i.e., increased exposure to other vehicles, leading to increased number of critical incidents). To investigate this hypothesis further, a Pearson correlation coefficient was calculated between the daily weekday traffic across each hour of the day and the relative frequency of safety-critical events across each hour of the day. As suggested by the plotted data, the results showed a strong positive linear relationship between the two variables with a correlation (r) of 0.83. With an R^2 of 0.69, there is a strong linear relationship between critical- incident relative frequency and traffic density (i.e., the two increase and decrease with similar patterns). With regard to a strong time-of-day effect, similar results were found for the seven other analyses in Analysis 5.

CONCLUSIONS

This study has resulted in a major finding that is relevant to the assessment of the 2003 HOS regulations. Specifically, the results from the analysis on critical-incident relative frequency, used as a surrogate for driver performance decrement, generally showed no statistical difference in the 2nd through 11th driving-hours (for almost all analyses); and the statistical difference between the 1st driving-hour and the 11th driving-hour lies in the direction opposite to what would be expected, had there been a time-on-task effect. That is, the results from this study do not support the hypothesis that there is an increased risk resulting from CMV drivers driving in the 11th driving-hour as compared to the 10th driving-hour, or any hour, although caution must be used in interpreting these results, due to the small sample of drivers represented in the study as compared to the larger CMV driver population.

These results from this research are consistent with Wylie et al. (1996) with regard to time-on-task being a poor predictor of crashes and safety-related traffic events. In fact, a significant spike in the rate of critical incidents was found during the 1st driving-hour. These results are not consistent with the contention that crash risk increases as hours of driving increase (see Kaneko and Jovanis, 1992; Lin, Jovanis, and Yang, 1993; Park et al., 2005). This spike was found across all possible trips and only those trips where the truck driver drove into the 11th driving-hour. The latter statement is noteworthy because it suggests that even on those trips in which the driver drove into the 11th driving-hour, the critical-incident relative frequency was highest in the 1st driving-hour (significantly more, as compared to driving-hours 2 though 11 for almost all analyses).

There are at least three possible explanations for the significant spike in the critical-incident relative frequency found in the 1st driving-hour. The first reason may be *sleep inertia*. Sleep inertia refers to the decrease or impairment of alertness and performance immediately upon waking from sleep. Sleep inertia refers to impairment in a variety of performance tasks, including short-term memory, vigilance, cognitive functioning, reaction time, and ability to resist sleep (Bonnet and Arand, 1995; Dinges, 1990; Mullington and Broughton, 1994). Obviously, personnel who are expected to perform work duties immediately on awaking, such as over-the-road drivers who sleep in sleeper berths in their trucks, may be most affected by sleep inertia.

Another possible reason for the spike found in the 1st driving-hour could be related to road type and/or traffic density. Drivers may start their trips on local and other undivided roads with higher traffic densities (as compared to what they might find on the open road). Similarly, for line-haul operations specifically, drivers may end their trips on local and other undivided roads, again experiencing higher traffic density than might occur on a highway. These can be conceived as "take-off" and "landing" effects. Hickman et al. (2005), using the same dataset as Hanowski et al. (2005), found that drivers were almost five times more likely to be involved in a critical incident on an undivided highway than on a divided highway. Additionally, the results from Analysis 5 in the current study on time-of-day indicated a potential explanation for the time-of-day effects as attributable to traffic density. These results suggest a possible "take-off" and "landing" effect.

The third possible explanation for the spike found in the 1st driving-hour could reflect time-of-day effects. The current study found a strong time-of-day effect, but it seemed that these effects were related to traffic density. Wylie et al. (1996) indicated time-of-day effects to be the strongest and most consistent factor influencing driver fatigue. The current analysis did not focus on driver fatigue events specifically, so the impact of time-of-day on driver fatigue is unknown with respect to the dataset used for this analysis effort. An analysis was conducted looking at all critical incidents that occurred in the circadian low and high periods (presumably including both fatigue and alert incidents), but the results did not point to a circadian effect.

Note that these three possible explanations for the spike in critical-incident relative frequency during the 1st driving-hour are not mutually exclusive. That is, it could very well be the case that a combination of these effects may be involved. For example, sleep inertia may be more attributable to the long-haul drivers who sleep in sleeper berths and who may go, in a relatively short period of time, from sleeping in the sleeper berth to driving. This may be exacerbated by complex driving environments (e.g., urban environments, loading areas, undivided highways, intersections) and higher traffic density levels that may occur in loading (i.e., "take-off") and drop-off (i.e., "landing") situations which occur at the beginning and, depending on the fleet operation, end of the shift. Time-of-day effects, which are influenced by internal factors (i.e., circadian rhythm) and external factors (e.g., rush hours, traffic density), also play a role. However, based on the current research and other findings in the literature, the impact of time-on-task, which is the basis for the 10th driving-hour vs. 11th driving-hour debate, does not seem to be an obvious or significant factor when considering increased critical-incident risk.

1. INTRODUCTION

Crashes involving large trucks constitute a significant risk to the driving public and occupational risk to truck drivers. In 2005, some 442,000 large trucks (weighing over 10,000 lbs each) were involved in vehicle crashes; 4,932 of these large-truck crashes resulted in fatalities. A total of 5,212 people died (12 percent of all traffic fatalities in 2005) and an additional 112,000 were injured (National Highway Traffic Safety Administration [NHTSA], 2007). Driver fatigue is a prominent factor in large-truck crashes. The Large Truck Crash Causation Study (LTCCS) found that 13 percent of truck drivers were coded as being fatigued at the time of the crash (Federal Motor Carrier Safety Administration [FMCSA], 2006).

1.1 2003 HOURS-OF-SERVICE

On April 28, 2003, FMCSA published a revised set of regulations concerning the Hours-of-Service (HOS) of commercial motor vehicle (CMV) drivers. These published regulations were amended on September 30, 2003 and implemented on January 4, 2004. One central component of the revisions was a two-hour extension of off-duty time from eight to 10 hours. One rationale given in an FMCSA posting in the *Federal Register* (2005) was that the additional 2 hours of off-duty time would provide drivers with "…substantially more opportunity to obtain restorative sleep" (p. 3342). The results from Hanowski, Dingus, Sudweeks, Olson, and Fumero (2005) indicated that this indeed may be the case; their research found that drivers may be getting more sleep under the revised 2003 HOS regulation (6.28 h per day) as compared to the old regulations (5.18 h per day; Mitler et al., 1997).

FMCSA believed the extra off-duty time, with better opportunities to obtain restorative sleep, would also reduce the incidence of crashes wholly or partially attributable to drowsiness or fatigue (*Federal Register*, 2005). Several groups (Public Citizen, Citizens for Reliable and Safe Highways, and Parents Against Tired Truckers) challenged the 2003 HOS regulations, indicating that FMCSA failed to show how additional off-duty time compensated for more driving time (from 10 to 11 hours of driving). A naturalistic driving study performed under the 2003 HOS regulations by Hanowski et al. (2005) found no significant difference in critical incidents (crashes and near-crashes) involving CMVs that occurred in the 10^{th} and 11^{th} driving-hours.

1.2 FATIGUE AND CRASH RISK

Driver impairment due to drowsiness is a known contributing factor in many crashes involving CMV drivers (Maycock, 1997). Fatigue affects mental alertness, thereby decreasing an individual's ability to operate a vehicle safely. Drowsiness slows reaction time, decreases awareness, and impairs judgment (Balkin et al., 2000; Von Dongen et al., 2003). Many factors may affect driver alertness and fatigue, including time-of-day, previous hours of sleep, hours awake, health and wellness, caffeine intake, over-the-counter and prescription drug use, individual differences, and time-on-task (Orris et al., 2005). While all these factors are important in determining driver fatigue and alertness, one of the concerns in the challenge of the 2003 HOS regulations was driving an extra hour, from 10 to 11 hours (within a 14-hour work window). For CMV drivers, time-on-task can be conceptualized as hours driving.

Mackie and Miller (1978) studied the relationship between HOS and truck-crash risk. They found a higher proportion of crashes in the second half of trips, a strong increase in crash risk as continuous hours of driving increased, and consistent evidence of reduced driving performance as the number of consecutive shifts increased. Mackie and Miller (1978) also found a circadian effect (i.e., time-of-day) with the highest crash risk occurring between the hours of 2 and 6 a.m. However, the schedules assigned to drivers exceeded the U.S. legal HOS at the time, and most of the performance decrements they found occurred during "illegal" (i.e., over 11 hours) HOS driving-hours.

Based on company-reported crash data, and within the parameters of U.S. legal HOS driving-hours, Jovanis and colleagues found that crash risk increased as driving-hours increased, most notably after the 4th driving-hour (see Kaneko and Jovanis, 1992; Lin, Jovanis, and Yang, 1993). Most recently, Park et al. (2005) used pre-existing crash data from the mid-1980s with 5,050 drivers (954 accident-involved drivers and 1,506 non-accident-involved drivers in 1984; 887 accident-involved drivers and 1,604 non-accident-involved drivers in 1985). As in prior research, Park et al. (2005) found an increase in crash risk associated with increasing driving-hours. Crash risk increased slightly between driving-hours 1 and 4, but increased significantly in the 5th hour and was sustained though the 10th driving-hour.

However, the Driver Fatigue and Alertness Study casts doubt on whether the number of driving-hours has any effect on increased crash risk (Wylie et al., 1996). The Driver Fatigue and Alertness Study was an on-road study with 80 drivers in the United States and Canada. Trucks were instrumented with video cameras and several driving measures were collected (e.g., driving task performance, driving speed and distance, physiological measures, and self-report questionnaires) over a period of 16 weeks. The strongest and most consistent factor influencing driver fatigue was time-of-day; hours driving were not a consistent predictor of fatigue (Wylie et al., 1996). In fact, Dingus et al. (2002) found, during a naturalistic driving study with sleeper-berth truck drivers, that the highest frequency of critical incidents occurred in the first driving-hour. While there was a "spike" in the frequency of critical incidents during the first driving-hour, when the data were normalized to account for exposure (i.e., dividing the frequency per hour by the number of times driving in each hour), statistical analyses found no significant difference between driving-hours.

Analogous to time-on-task performance decrements is the contention that crash risk increases as the number of consecutive driving-shifts increases (i.e., the cumulative effect of fatigue increases over consecutive shifts). Jovanis and Kaneko (1991) used retrospective crash reports and drive histories and found a consistent trend in crash risk over four successive driving-shifts. On average, compared to the first shift, crash risk was 6 percent higher on the second shift, 17 percent higher on the third shift, and 36 percent higher on the fourth shift. However, these effects were found only in drivers who drove during the night; there was no significant effect for drivers who drove during the day, suggesting time-of-day was a more likely explanation of the findings. The Driver Fatigue and Alertness Study found that the cumulative number of trips was not a strong or consistent predictor of fatigue (Wylie et al., 1996). Similarly, three different naturalistic driving studies with CMV drivers did not find an increase in critical-incident occurrence as the cumulative number of shifts increased (Dingus et al., 2002; Hanowski, Wierwille, Garness, and Dingus, 2000; Olson, 2006). These studies suggest that cumulative driving-shifts within the driver's work week have little effect on crash risk.

1.3 OVERVIEW OF THE CURRENT STUDY

The current study examines some important issues pertaining to the HOS debate, particularly with regard to time-on-task or driving-hours. Hanowski et al. (2005) reported on an analysis that concerned a comparison of critical incidents involving CMVs that occurred in the 10^{th} and 11^{th} driving-hours. This was a timely analysis effort, as it provided insight into questions associated with the revised 2003 HOS regulations. Two limitations of the 2005 analysis of Hanowski et al. were that: (i) it included only a partial dataset and (ii) it compared only the frequency of critical incidents that occurred in the 10^{th} and 11^{th} driving-hours. Since that report was written, data collection for the naturalistic study on which the analysis of Hanowski et al. (2005) was based has been completed (Hanowski et al., in press). These two limitations associated with the initial analysis can be addressed in the current study. In addition, to provide a comprehensive and thorough examination of the topic, additional analyses were conducted to address how critical incidents may vary as a function of driving-shift and time-of-day.

The current analysis focused on the following research issues:

1. Critical incidents as a function of driving-hour for hours 1 through 11
2. Critical incidents per driving-hour for hours 1 through 11, focusing on drivers that drove into the 11^{th} hour
3. Modeling the data to look for significant differences in critical incidents across driving-hour
4. Critical incidents as a function of shift within the driver's "work week" (i.e., "tour of duty")
5. Critical incidents as a function of time-of-day

2. METHOD

Data for these analyses were collected during a Field Operational Test (FOT) of a Drowsy Driver Warning System (DDWS). This FOT was co-sponsored by NHTSA, FMCSA, and the Federal Highway Administration's (FHWA) Intelligent Transportation System Joint Program Office (ITS JPO). A description of the methodology used in the FOT can be found in Hanowski, Nakata, and Olson (2004) and the final data collection report is in press (Hanowski et al., in press). Data collection for the FOT began in May 2004 and ended in September 2005. A total of 103 drivers participated in the study (102 males, 1 female; mean age = 40.03 years; age range = 24 to 60 years). As described below, data from five drivers could not be used for the driving-hour analyses (Analyses 1, 2, 3, and 4 described later) because of unreliable driving-time histories. The gender and age distribution of the 98 drivers included in the driving-hour analyses were: 97 males, 1 female; mean age = 39.96 years; age range = 24 to 60 years.

A naturalistic-data-collection approach was used where data were collected as study participants drove company trucks during their normal revenue-producing runs. Unobtrusive data- collection equipment was installed in 46 trucks. The data-collection equipment included sensors to measure driver performance and video that recorded the driver's face and three views outside of the truck (Figure 3). Driver participants were assigned to an instrumented truck to use on their normal delivery routes. Typically, once a driver had completed his or her participation in the study, a different driver would be assigned to the instrumented truck. The experimental design of the FOT called for drivers to operate an instrumented truck for up to 16 continuous weeks. However, for a variety of reasons, including attrition, truck downtime, and scheduling issues, some drivers drove more or less than this initially allotted time. The mean number of weeks that drivers participated in the study was 12.38 weeks, with a standard deviation of 4.17 weeks. The final project dataset consisted of 2.3 million miles of driving data and 11.8 TB of video and dynamic sensor data.

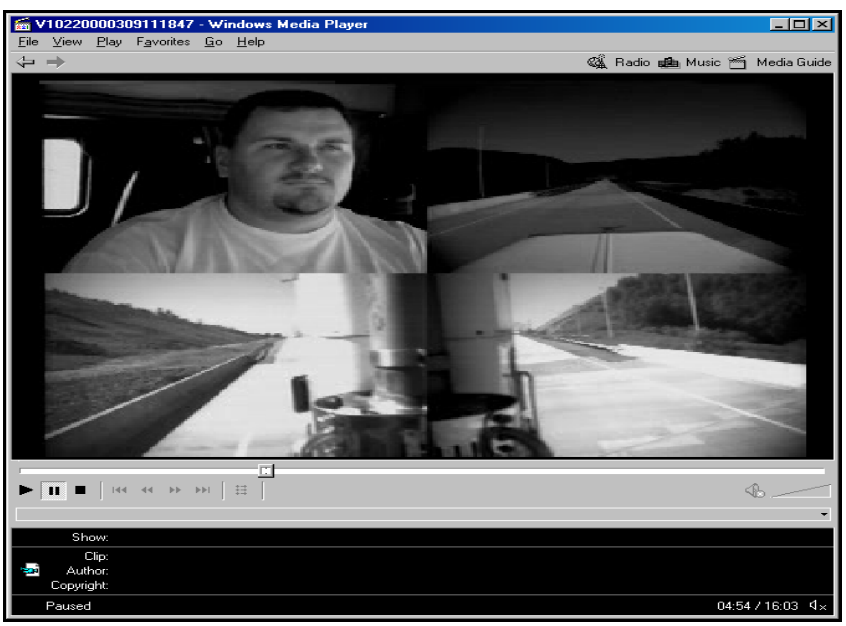

Figure 3. Split-Screen Presentation of the Four Camera Views

Clockwise from top left: driver's face, forward road, rearward left, rearward right.

The data collection system, including the video cameras, became active when the ignition system of the vehicle was activated. The system was programmed to remain active and to gather data as long as the engine was on and the vehicle was in motion. The system was programmed to shut down when the ignition was turned off, and the system was programmed to pause if the vehicle ceased motion for a 10-minute period. Data collection resumed when the vehicle was again in motion.

Driver performance was assessed through the occurrence of critical incidents (crashes, near-crashes, and crash-relevant conflicts). Briefly, a crash was defined as any contact with an object, either moving or fixed, at any speed. A near-crash was defined as any circumstance that required a rapid, evasive maneuver (e.g., hard braking) by the subject vehicle or any other vehicle, pedestrian, cyclist, or animal, in order to avoid a crash. A crash-relevant conflict was defined as any circumstance that required a crash-avoidance response on the part of the subject vehicle, any other vehicle, pedestrian, cyclist, or animal that was less severe than a rapid evasive maneuver (as defined above), but greater in severity than a normal maneuver. A crash-avoidance response can include braking, steering, accelerating, or any combination of control inputs. Examples of potential crash-relevant conflicts include hard braking by a driver because of a specific crash threat or proximity to other vehicles. Evasive maneuvers resulting in unsafe and/or illegal maneuvers or situations were included in this category (or as near-crashes, if more severe). All longitudinal accelerations of $\geq |0.35\ g|$ were reviewed to assess whether they qualified as crash-relevant conflicts (or near-crashes); those with longitudinal acceleration of $\geq |0.50\ g|$ were always coded as crash-relevant conflicts or near-crashes. Table 1 outlines all of the trigger types and thresholds used to identify critical incidents.

Table 1. Trigger Types Used to Flag Critical Incidents in the FOT Dataset

Trigger Type	Description
Longitudinal Acceleration	(1) Acceleration or deceleration greater than or equal to $|0.35\ g|$. Speed greater than or equal to 15 mph. (2) Acceleration or deceleration greater than or equal to $|0.5\ g|$. Speed less than or equal to 15 mph.
Time-to-Collision	(3) A forward time-to-collision [TTC] value of less than or equal to 1.85 s, coupled with a range of less than or equal to 150 ft, a target speed of greater than or equal to 5 mph, a yaw rate of less than or equal to $|4°/s|$, and an azimuth of less than or equal to $|0.8°|$. (4) A forward TTC value of less than or equal to 1.85 s, coupled with an acceleration or deceleration greater than or equal to $|0.35\ g|$, a forward range of less than or equal to 150 ft, a yaw rate of less than or equal to $|4°/s|$, and an azimuth of less than or equal to $|0.8°|$.
Swerve	(5) Swerve value of greater than or equal to 3. Speed greater than or equal to 15 mph.
Critical-Incident Button	(6) Activated by the driver upon pressing a button, located by the driver's visor, when an incident occurred that he/she deemed critical.
Analyst Identified	(7) Event that was identified by a data reductionist viewing video footage; no other trigger listed above identified the event (i.e., Longitudinal Acceleration, TTC, etc.).

The critical incidents were identified using a software program to search through all data files for spikes in sensors that would indicate the possibility of a critical incident. For example, the program searched for all occurrences of longitudinal accelerations of $\geq |0.35\ g|$ to locate instances of hard braking. Once potential critical incidents had been identified by the software program, researchers viewed the video and other corresponding data to determine whether the event were a valid critical incident. To help ensure that all critical incidents included in the current dataset were valid (that is, that an actual conflict occurred), assessment of an event's validity required the consensus of two researchers.

2.1 DRIVING HISTORY SOFTWARE AND DATA CAVEATS

Once critical incidents were identified, it was possible to obtain the driving-hour and time-of-day at the time of the critical incident. The full DDWS FOT dataset was processed through a software program which used the network speed on each truck to determine if the driver were driving. That is, the software program started with the first file for a given driver, and once the truck network speed moved above 0 mph, the software program assumed that the driver was driving and started counting driving time. The program then searched the data for ≥6-hour gaps in the driving files (where the network speed = 0) and assumed that the driver had taken a break. The next driving file, as long as it was not less than 14 h from the start of the previous driving shift, was considered the start of the next driving shift or "trip." The driving-hour and shift-hour data produced by this software were used in Analysis 1.4, described in the Results section.

It is important to point out a number of caveats with regard to the data and the approach used:

- There are only driving files; there was no record of non-driving work activity.
- Embedded in breaks were non-driving work; there was no way to separate non-driving work from rest breaks, as there was only a record of driving.
- A "break" (network speed = 0) of less than 10 min was ignored and counted as driving time. This was done to avoid considering time when the driver was stuck in traffic as a "break."
- In searching for the start of a "work week," the software program searched for non-driving segments of ≥34 h and assumed this was the restart break (it is unknown whether this non-driving break included non-driving work).
- For any shift, if the system did not collect data, that fact was unknown.
- Data from five drivers were not included because the driving-time history was unreliable. For four of these drivers, the vehicle network speed sensor malfunctioned such that a non-zero speed was recorded when the truck was not moving. Because driving time was assessed, in part, by the speed variable, the driving times in these cases were unreliable and not used. In one other case, an error with the file-naming convention affected the method used to sort the data and calculate driving-time history. As a result, the driving-time data for this driver were also unreliable and were not included in the analysis.
- Each critical incident was checked by two data analysts to help ensure that the driving-hour produced by the software program was valid. For example, all files prior to a critical incident were checked to make sure that there were not any files with bad network speed, or any files where the subject driver could not be verified, that may have affected the calculation of the driving-hour. If any such files were found, then the associated critical

incident was not included in the dataset for analysis. Although all critical incidents were checked for accuracy, it was not possible to check all trips used to determine exposure values. However, any potential errors with respect to the exposure data would be assumed to be unbiased across trips.

3. RESULTS

As noted previously, data analysis for this study focused on the following five areas:

1. Critical incidents as a function of driving-hour for hours 1 through 11
2. Critical incidents as a function of driving-hour for hours 1 through 11, for drivers that drove into the 11th hour
3. Modeling the data to look for significant differences in critical incidents across driving-hour
4. Critical incidents as a function of shift within the driver's "work week"
5. Critical incidents as a function of time-of-day
6 Below we consider each of these areas in turn.

3.1 CRITICAL INCIDENTS AS A FUNCTION OF DRIVING-HOUR FOR HOURS 1 THROUGH 11

The dataset used in this analysis included all data that occurred in driving-hours 1 through 11. This included 819 critical incidents: 12 crashes, 12 tire-strike crashes, 85 near-crashes, and 710 crash-relevant conflicts. For this analysis, critical incidents were assumed to be independent, although Analysis 3 used a logistic regression modeling approach that accounted for repeated measures to test this assumption.

To fully investigate this issue, the data were parsed and analyzed in eight different ways. This thorough investigative approach was to help ensure that significant findings were not overlooked. The eight different analyses used the following datasets:

- Analysis 1.1: All Data: This included the entire dataset, with the exception of information outlined in the Data Caveats section above. This provided the largest dataset available.
- Analysis 1.2: All Data, Truck Driver at Fault: Using the dataset noted above, this analysis included only those critical incidents that were judged to have been the fault of the subject driver (i.e., the study truck driver).
- Analysis 1.3: Baseline and Control Data: Only critical incidents that occurred in the control and baseline conditions (where no DDWS was used) were included. As the study for which these data were collected investigated a DDWS, it was possible that the presence of this in-vehicle technology may have affected the occurrence of critical incidents in an unknown manner.
- Analysis 1.4: Baseline and Control Data, Truck Driver at Fault: Using the baseline and control data noted above, this analysis included only critical incidents in which the truck driver was judged to have been at fault.
- Analysis 1.5: All Data, No Within-Hour Incidents: Although it was not a frequent occurrence, there were cases in which a given driving-hour had multiple critical incidents recorded. Using the dataset noted in Analysis 1.1, this analysis removed these multiples and treated critical incidents as a Bernoulli random variable (i.e., for each hour there are two possible outcomes—"yes, at least one incident occurred" or "no, an incident did not

occur"). The critical incident with the less severe classification was removed (e.g., a near-crash would be removed instead of a crash).

- Analysis 1.6: All Data, Truck Driver at Fault, No Within-Hour Incidents: Using the dataset noted in Analysis 1.1, this analysis considered only critical incidents in which the truck driver was at fault and removed multiple within-hour incidents.
- Analysis 1.7: Baseline and Control Data, No Within-Hour Incidents: This analysis used the baseline and control data and removed multiple within-hour incidents.
- Analysis 1.8: Baseline and Control Data, Truck Driver at Fault, No Within-Hour Incidents: Using the baseline and control data, this analysis considered only critical incidents in which the truck driver was at fault and removed muliple within-hour incidents.

The findings from these eight analyses are outlined below.

Analysis 1.1: All Data

Table 2 shows the dataset for the first analysis, which included all critical incidents, and all driving opportunities (i.e., trips), that occurred in the 1st through 11th driving-hours. As shown in Table 2, each driving-hour has a different number of opportunities to be involved in a critical incident. For example, a driver may have driven into the 10th hour but not into the 11th hour; as a result, there were fewer opportunities to be involved in a critical incident in the 11th hour. To adjust for the differences in opportunities across driving-hour, a rate was calculated which, in effect, normalized the data. That is, the frequency of critical incidents, in any given driving-hour, is divided by the total opportunities for that hour. This provides the relative frequency of having a critical incident in any given driving-hour. As noted previously, it is important to point out the data in Table 2 include cases where multiple critical incidents were recorded in the same driving-hour; a follow-up analysis, presented later, removed the multiple cases to set up a dichotomous variable.

Table 2. Critical Incidents and Total Opportunities by Driving-Hour for Hours 1 Through 11

Hour	Critical Incidents Per Driving-Hour	Total Opportunities Per Driving-Hour	Rate: Critical Incidents/ Total Opportunities
1	155	4,748	0.033
2	82	4,518	0.018
3	94	4,393	0.021
4	79	4,241	0.019
5	84	4,022	0.021
6	80	3,697	0.022
7	62	3,320	0.019
8	64	2,941	0.022
9	52	2,510	0.021
10	38	2,019	0.019
11	29	1,535	0.019

Figure 4 plots the number of opportunities (also considered "trips") for each driving-hour. Not surprisingly, the number of opportunities drops off as the number of driving-hours increases. Thus, by the time drivers reach the 11th hour, many of the trips had concluded. This suggests that drivers in the current study did not always drive 11 h, but rather stopped their trips short of the 11th hour. However, there were 1,535 trips that did include the 11th hour.

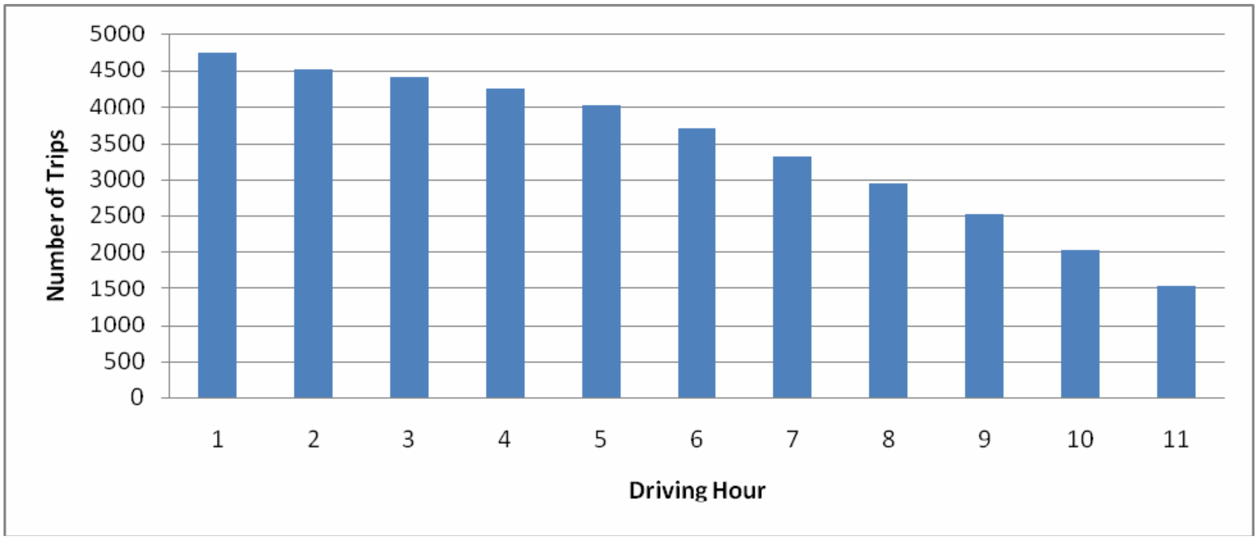

Figure 4. Total Opportunities (Trips) for Driving-Hours 1 Through 11

Figure 5 shows the relative frequency of critical incidents as a function of driving-hour for hours 1 through 11. A breakdown in the frequency for each type of critical incident is shown in Figure 5, including crashes (red), crashes: tire strikes (green), near-crashes (purple), and crash-relevant conflicts (blue). The top of each bar in Figure 5 represents the combined total of all types of critical incidents (crashes, tire strikes, near-crashes, and crash-relevant conflicts). This number was used for all further analyses. The frequencies of crashes, tire strikes, and near-crashes were too small to conduct any meaningful analyses independent of the crash-relevant conflict data. As can be seen from the results of this analysis, there was a notable "spike" in the relative frequency of critical incidents in the 1st driving-hour.

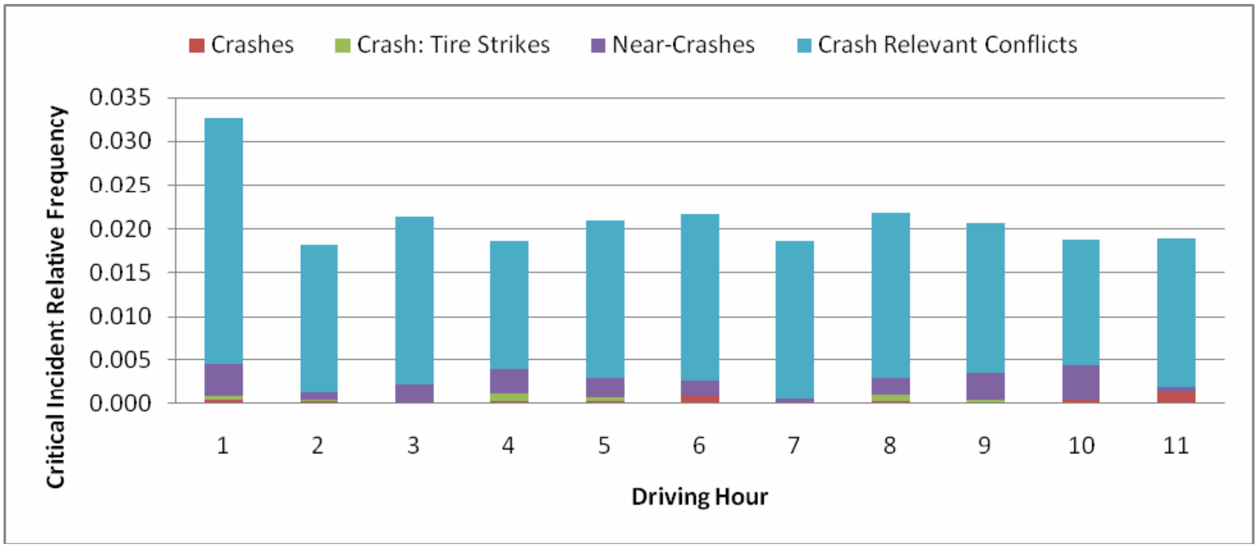

Figure 5. Critical Incident Relative Frequency as a Function of Driving-Hour

Odds ratios determined whether the critical-incident relative frequency was statistically different across driving-hours. Under the assumption that the occurrence of critical incidents was rare, the retrospective odds ratio provides an approximate estimate of the prospective relative risk; therefore, the relative risk of driving in the Ith hour vs. the Jth hour can be assessed with an odds ratio.

To provide some background on this statistical technique: An odds ratio is a measure of association commonly employed in the analysis of 2 × 2 contingency tables (Agresti, 1996). The data for this analysis can be displayed as a 2 × 2 contingency table, as shown in Table 3.

Table 3. 2 × 2 Contingency Table Used to Calculate Odds Ratio

	Incident Occurrence	No Incident Occurrence	Total Opportunity for Incident Occurrence
Ith hour of shift	n_{11}	n_{12}	$n_{1.}$
Jth hour of shift	n_{21}	n_{22}	$n_{2.}$
	$n_{.1}$	$n_{.2}$	$n_{..}$

Odds of occurrence were defined as the probability of event occurrence divided by the probability of non-occurrence. The following formula was used to perform the calculation to determine the odds ratio in order to assess the increase in probability of having a critical incident in the Ith hour vs. the Jth hour:

$$\textit{Odds Ratio} = (n_{11})(n_{22})/(n_{21})(n_{12})$$

Table 4 displays the results from the odds ratio analyses. The first two columns in Table 4 show the comparison hours (e.g., the first row compares the 1st and 2nd driving-hours). The third column shows the calculated odds ratio and the last two columns show the lower confidence limits (LCL) and upper confidence limits (UCL), respectively. Odds ratios with LCLs and UCLs that contain "1" are not statistically significant (note that 95 percent confidence level was used in these calculations). All significant odds ratios shown in Table 4 are highlighted and italicized.

Thus, the comparison of the 1st driving-hour to the 2nd indicates that drivers were 1.83 times more likely to be involved in a critical incident during the 1st hour than in the 2nd driving-hour. This was statistically significant as the LCL-UCL interval does not include “1.”

Note that all significant effects are included in the odds ratio tables along with selected other analyses that are not significant. For example, in Table 4, it can be seen that all comparisons with the 1st driving-hour were statistically significant. Once that was determined, the next step was to look for the hour with the next highest relative frequency (8th driving-hour) and the lowest relative frequency (2nd driving-hour). Since this comparison was not significant, we would expect that all other comparisons would not be significant. This approach was followed for all analyses. It should also be noted that the 10th vs. 11th driving-hour comparison is always provided because this is such a controversial change in the HOS regulations.

Table 4. Results from the Odds Ratio Analyses

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	1.83	1.39	2.39
1	3	1.54	1.19	2.00
1	4	1.78	1.35	2.34
1	5	1.58	1.21	2.07
1	6	1.53	1.16	2.01
1	7	1.77	1.32	2.39
1	8	1.52	1.13	2.04
1	9	1.60	1.16	2.19
1	10	1.76	1.23	2.52
1	11	1.75	1.39	2.39
8	2	1.20	0.86	1.67
8	11	1.16	0.74	1.80
10	11	1.00	0.61	1.62

Analysis 1.2: All Data, Truck Driver at Fault

Analysis 1.2 included only critical incidents in which the subject-vehicle driver (i.e., the study truck driver) was judged, based on video review, to have been at fault. Note that these data do include multiple critical incidents that may have occurred within the same hour. The resulting dataset is shown in Table 5 below and plotted in Figure 6.

Table 5. Critical Incidents and Total Opportunities by Driving-Hour for Hours 1 Through 11, in Which the Subject Driver was at Fault

Driving-Hour	Critical Incidents Per Driving-Hour	Total Opportunities Per Driving-Hour	Rate: Critical Incidents/ Total Opportunities
1	122	4,748	0.026
2	61	4,518	0.014
3	76	4,393	0.017
4	56	4,241	0.013
5	61	4,022	0.015
6	60	3,697	0.016
7	50	3,320	0.015
8	44	2,941	0.015
9	41	2,510	0.016
10	24	2,019	0.012
11	23	1,535	0.015

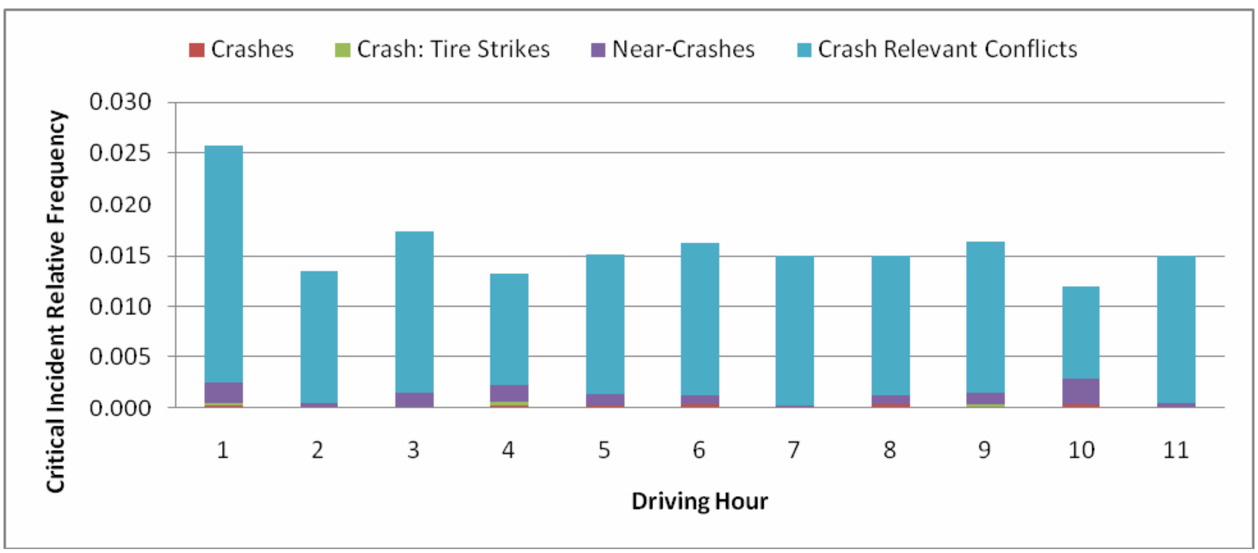

Figure 6. Critical-Incident Relative Frequency as a Function of Driving-Hour, in Which the Subject Driver was at Fault

Table 6 displays the results from the odds ratio analyses, including all trips in which the subject driver was at fault. Once again, the 1st driving-hour was found to be significantly greater in critical incidents than all other hours. No other significant differences were found between any other two hours.

Table 6. Results from the Odds Ratio Analyses, Including all Trips in Which the Subject Driver was at Fault

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	1.93	1.41	2.63
1	3	1.50	1.12	2.00
1	4	1.97	1.43	2.71
1	5	1.71	1.26	2.34
1	6	1.60	1.17	2.18
1	7	1.72	1.24	2.40
1	8	1.74	1.23	2.46
1	9	1.59	1.11	2.27
1	10	2.19	1.41	3.41
1	11	1.73	1.11	2.72
3	10	1.46	0.92	2.32
9	10	1.38	0.83	2.29
11	10	1.26	0.71	2.25

Analysis 1.3: Baseline and Control Data

Analysis 1.3 used only the data from the "control" and "baseline" conditions from the study. Recall that the study for which these data were collected investigated a DDWS; thus it was possible that the presence of this in-vehicle technology may have affected the occurrence of incidents in an unknown manner. To examine this possibility, only critical incidents that occurred in the control and baseline conditions (where no DDWS was used) were included, and the resulting dataset is shown in Table 7. Figure 7 plots the critical-incident relative frequency across driving-hours for the baseline and control conditions.

Table 7. Critical Incidents and Total Opportunities by Driving-Hour for Hours 1 Through 11 for Baseline and Control Conditions

Driving-Hour	Critical Incidents Per Driving-Hour	Total Opportunities Per Driving-Hour	Rate: Critical Incidents/ Total Opportunities
1	79	2,275	0.035
2	43	2,154	0.020
3	48	2,089	0.023
4	37	2,021	0.018
5	47	1,932	0.024
6	43	1,788	0.024
7	26	1,619	0.016
8	39	1,458	0.027
9	27	1,269	0.021
10	20	1,031	0.019
11	17	796	0.021

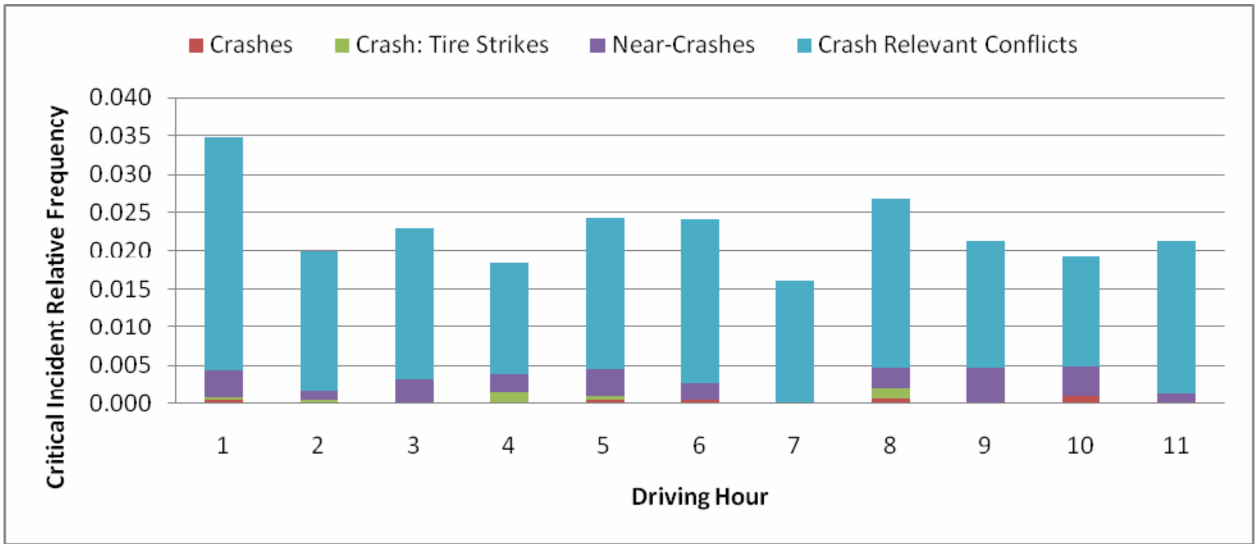

Figure 7. Critical-Incident Relative Frequency as a Function of Driving-Hour for Baseline and Control Conditions

Table 8 displays the results from the odds ratio analyses, including all trips during the baseline and control conditions. Statistically significant differences were found between the 1st driving-hour and all other driving-hours, with the exception of the 8th and 11th driving-hours. No other significant results were found.

Table 8. Results from the Odds Ratio Analysis Across all Trips for Baseline and Control Conditions

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	1.77	1.21	2.57
1	3	1.58	1.10	2.27
1	4	1.93	1.30	2.86
1	5	1.44	1.00	2.08
1	6	1.46	1.00	2.13
1	7	2.20	1.41	3.45
1	8	1.31	0.89	1.93
1	9	1.65	1.06	2.58
1	10	1.82	1.11	2.99
1	11	1.65	0.97	2.80
6	7	1.51	0.92	2.47
3	7	1.44	0.89	2.33
11	10	1.10	0.57	2.12

Analysis 1.4: Baseline and Control Data, Truck Driver at Fault

Analysis 1.4 used only the data from the control and baseline conditions in which the subject driver was judged at fault. Table 9 displays the dataset used and Figure 8 plots the critical-incident relative frequency across the driving-hours.

Table 9. Critical Incidents and Total Opportunities by Driving-Hour for Hours 1 Through 11, in Which the Subject Driver was at Fault, for Baseline and Control Conditions

Driving-Hour	Critical Incidents Per Driving-Hour	Total Opportunities Per Driving-Hour	Rate: Critical Incidents/ Total Opportunities
1	62	2,275	0.027
2	34	2,154	0.016
3	37	2,089	0.018
4	26	2,021	0.013
5	36	1,932	0.019
6	33	1,788	0.018
7	21	1,619	0.013
8	25	1,458	0.017
9	20	1,269	0.016
10	11	1,031	0.011
11	16	796	0.020

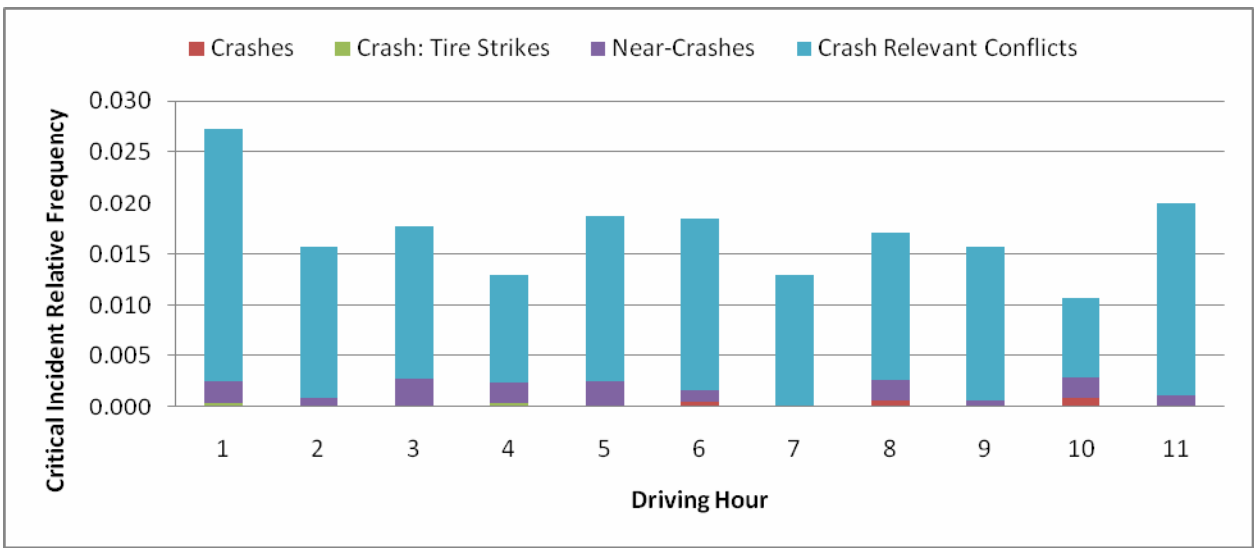

Figure 8. Critical-Incident Relative Frequency as a Function of Driving-Hour in Which the Subject Driver was at Fault, for Baseline and Control Conditions

Odds ratios were conducted on the critical-incident relative frequency data and the results are shown in Table 10. The 1st driving-hour was found to be statistically significant and greater in number of critical incidents than hours 2, 3, 4, 7, 8, 9, and 10. No other odds ratio comparisons were significant.

Table 10. Results from the Odds Ratio Analysis, Including All Trips in Which the Subject Driver was at Fault, for Baseline and Control Conditions

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	1.75	1.14	2.67
1	3	1.55	1.03	2.34
1	4	2.15	1.35	3.41
1	5	1.48	0.97	2.24
1	6	1.49	0.97	2.28
1	7	2.13	1.29	3.51
1	8	1.61	1.00	2.57
1	9	1.75	1.05	2.91
1	10	2.60	1.36	4.95
1	11	1.37	0.78	2.38
8	10	1.62	0.79	3.30
9	10	1.48	0.71	3.11
11	10	1.90	0.88	4.12

Analysis 1.5: All Data, No Within-Hour Incidents

As noted, the larger dataset included multiple critical incidents that may have been recorded in the same hour of the same trip.

Table 11 shows the dataset where these multiple critical incidents (same hour, during the same trip), were removed. This resulted in a dichomotous variable, either “yes, at least one critical incident occurred” or “no critical incident occurred.” It is important to indicate that the occurrence of multiple critical incidents per hour was rare. In addition, as will be shown from the analysis results, re-analyzing the data with multiple within-hour critical incidents removed did not significantly affect the results. Figure 9 shows the plot of the critical-incident relative frequencies for each driving-hour.

Table 11. Critical Incidents and Total Opportunities by Driving-Hour for Hours 1 Through 11, with Multiple Within-Hour Critical Incidents Removed

Driving-Hour	Critical Incidents Per Driving-Hour	Total Opportunities Per Driving-Hour	Rate: Critical Incidents/ Total Opportunities
1	145	4,748	0.031
2	78	4,518	0.017
3	89	4,393	0.020
4	74	4,241	0.017
5	79	4,022	0.020
6	74	3,697	0.020
7	58	3,320	0.017
8	53	2,941	0.018
9	49	2,510	0.020
10	38	2,019	0.019
11	27	1,535	0.018

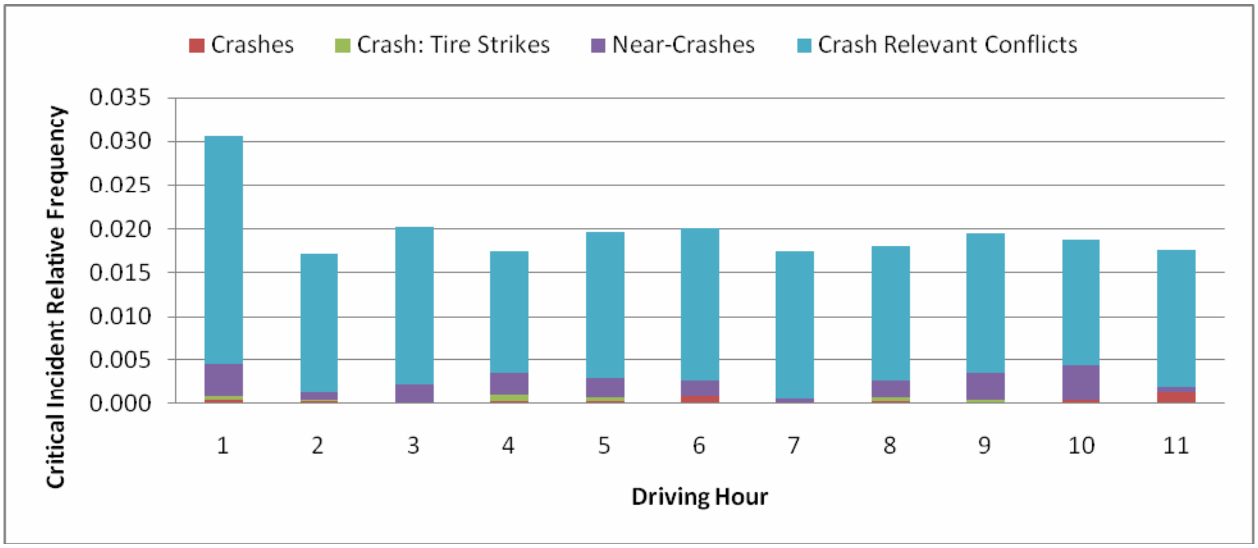

Figure 9. Critical-Incident Relative Frequency as a Function of Driving-Hour, with Multiple Within-Hour Critical Incidents Removed

As previously found, a spike of critical-incident relative frequency was seen in the 1st driving-hour. As shown in Table 12 below, odds ratios were analyzed and this spike was statistically significant across all other driving-hours. No other driving-hours differed with respect to critical-incident relative frequency.

Table 12. Results from the Odds Ratio Analysis with Multiple Within-Hour Critical Incidents Removed

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	1.79	1.36	2.37
1	3	1.52	1.17	1.99
1	4	1.77	1.34	2.35
1	5	1.57	1.19	2.07
1	6	1.54	1.16	2.05
1	7	1.77	1.30	2.41
1	8	1.72	1.25	2.36
1	9	1.58	1.14	2.20
1	10	1.64	1.14	2.36
1	11	1.76	1.16	2.66
3	2	1.18	0.87	1.60
9	11	1.11	0.69	1.79
10	11	1.07	0.65	1.76

Analysis 1.6: All Data, Truck Driver at Fault, No Within-Hour Incidents

Analysis 1.6 included critical incidents in which the subject driver was judged to have been at fault, and all multiple critical incidents that occurred within the same hour and the same trip were removed. The resulting dataset is shown in Table 13, and the plot of the relative frequency of critical incidents is shown in Figure 10.

Table 13. Critical Incidents and Total Opportunities by Driving-Hour for Hours 1 Through 11, in Which the Subject Driver was at Fault, with Multiple Within-Hour Critical Incidents Removed

Driving-Hour	Critical Incidents Per Driving-Hour	Total Opportunities Per Driving-Hour	Rate: Critical Incidents/ Total Opportunities
1	115	4,748	0.024
2	59	4,518	0.013
3	72	4,393	0.016
4	53	4,241	0.012
5	57	4,022	0.014
6	54	3,697	0.015
7	48	3,320	0.014
8	35	2,941	0.012
9	39	2,510	0.016
10	24	2,019	0.012
11	21	1,535	0.014

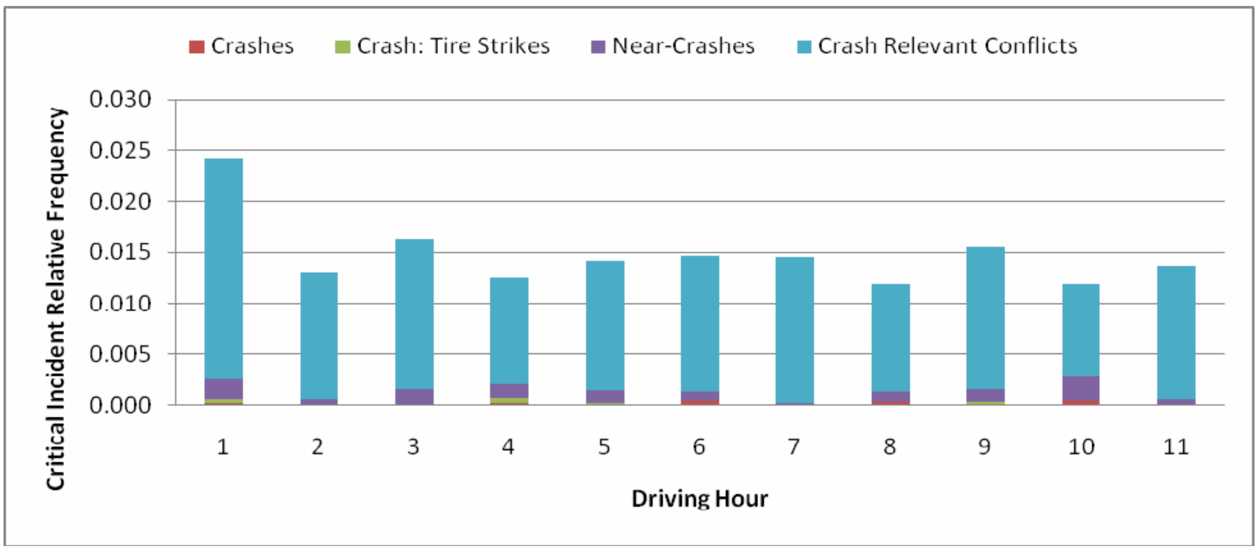

Figure 10. Critical-Incident Relative Frequency as a Function of Driving-Hour, in Which | the Subject Driver was at Fault, with Multiple Within-Hour Critical Incidents Removed

Odds ratios were examined on the critical-incident relative frequencies across the driving-hours, and the results are shown in Table 14. Once again, the relative frequency of critical incidents in the 1st driving-hour was found to be significantly greater than those in all other hours and no other hour-to-hour comparisons were statistically significant.

Table 14. Results from the Odds Ratio Analysis, in Which the Subject Driver was at Fault, with Multiple Within-Hour Critical Incidents Removed

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	1.88	1.37	2.57
1	3	1.49	1.11	2.01
1	4	1.96	1.41	2.72
1	5	1.73	1.25	2.38
1	6	1.67	1.21	2.32
1	7	1.69	1.20	2.38
1	8	2.06	1.41	3.02
1	9	1.57	1.09	2.27
1	10	2.06	1.32	3.21
1	11	1.79	1.12	2.86
3	10	1.39	0.87	2.21
9	10	1.31	0.79	2.19
11	10	1.15	0.64	2.08

Analysis 1.7: Baseline and Control Data, No Within-Hour Incidents

Analysis 1.7 considered the control and baseline data and did not include any multiple within-hour critical incidents. The resulting dataset is shown in Table 15 and a plot of the critical incident relative frequencies is shown in Figure 11.

Table 15. Critical Incidents and Total Opportunities by Driving-Hour for Hours 1 Through 11, for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

Driving-Hour	Critical Incidents Per Driving-Hour	Total Opportunities Per Driving-Hour	Rate: Critical Incidents/ Total Opportunities
1	73	2,275	0.032
2	41	2,154	0.019
3	44	2,089	0.021
4	34	2,021	0.017
5	44	1,932	0.023
6	40	1,788	0.022
7	25	1,619	0.015
8	31	1,458	0.021
9	24	1,269	0.019
10	20	1,031	0.019
11	15	796	0.019

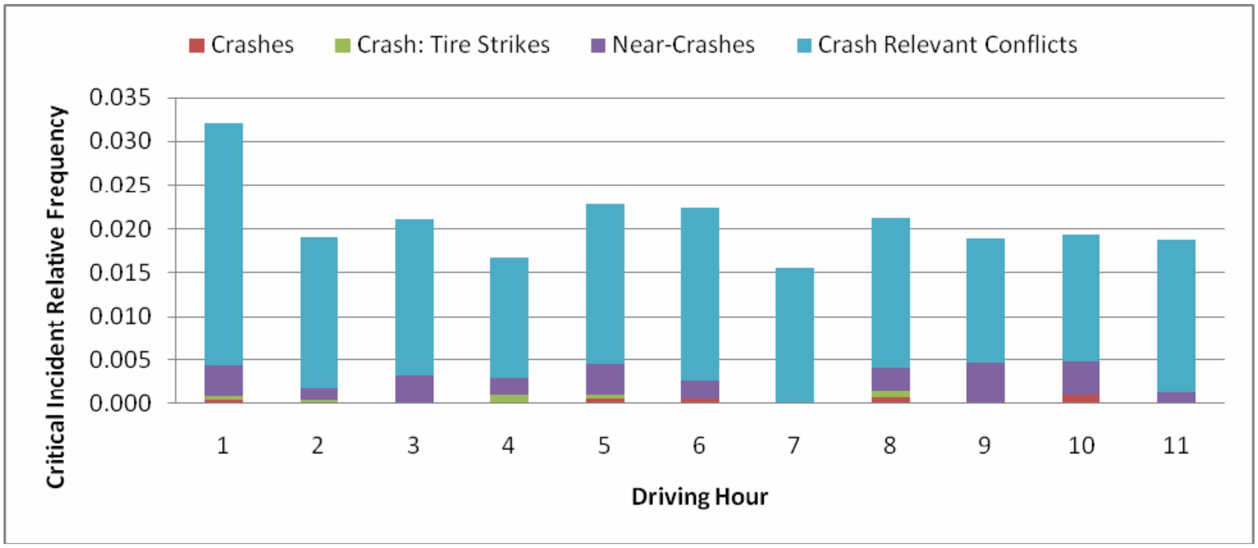

Figure 11. Critical-Incident Relative Frequency as a Function of Driving-Hour for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

Odds ratios were analyzed on this dataset and the results are shown in Table 16. The relative frequency of critical incidents in the 1st driving-hour was statistically greater than those in driving-hours 2, 3, 4, 7, 8, 9, and 10. No other hour-to-hour comparisons were significant.

Table 16. Results from the Odds Ratio Analysis for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	1.71	1.16	2.52
1	3	1.54	1.05	2.25
1	4	1.94	1.28	2.92
1	5	1.42	0.97	2.08
1	6	1.45	0.98	2.14
1	7	2.11	1.34	3.34
1	8	1.53	1.00	2.34
1	9	1.72	1.08	2.74
1	10	1.68	1.02	2.76
1	11	1.73	0.98	3.03
5	7	1.49	0.91	2.44
6	7	1.46	0.88	2.42
11	10	1.03	0.52	2.02

Analysis 1.8: Baseline and Control Data, Truck Driver at Fault, No Within-Hour Incidents

Analysis 1.8 assessed control and baseline data for subject drivers who were judged to have been at fault, with multiple within-hour critical incidents removed. The resulting dataset is shown in Table 17. Figure 12 is a plot of the critical-incident relative frequencies for the 11 driving-hours.

Table 17. Critical Incidents and Total Opportunities by Driving-Hour for Hours 1 Through 11, in Which the Subject Driver was at Fault, for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

Driving-Hour	Critical Incidents Per Driving-Hour	Total Opportunities Per Driving-Hour	Rate: Critical Incidents/ Total Opportunities
1	58	2,275	0.025
2	32	2,154	0.015
3	34	2,089	0.016
4	24	2,021	0.012
5	33	1,932	0.017
6	30	1,788	0.017
7	20	1,619	0.012
8	19	1,458	0.013
9	18	1,269	0.014
10	11	1,031	0.011
11	14	796	0.018

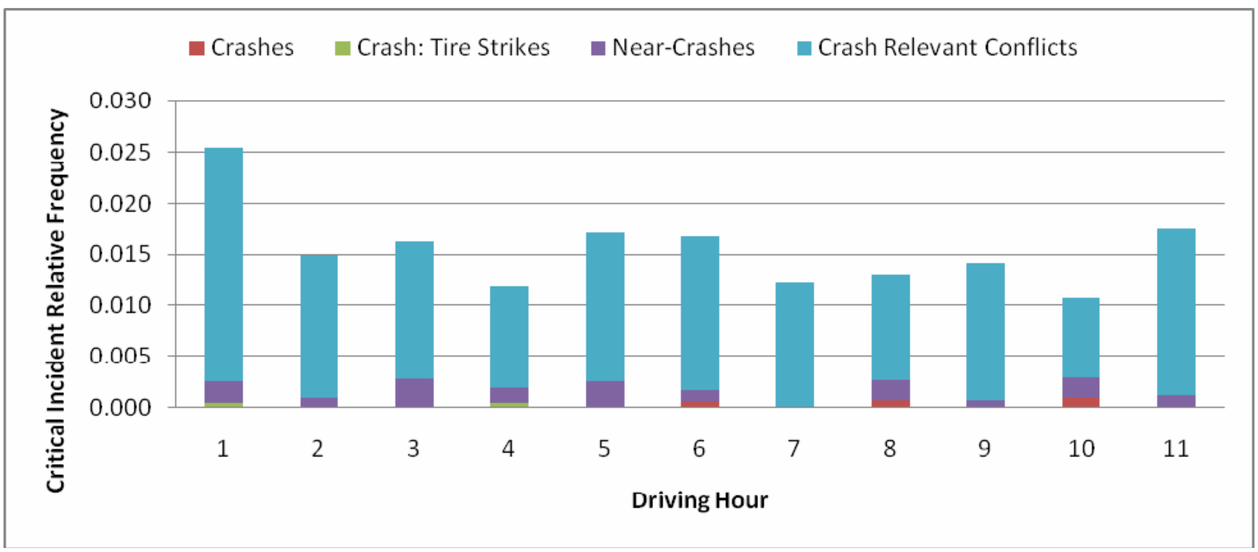

Figure 12. Critical-Incident Relative Frequency as a Function of Driving-Hour in Which the Subject Driver was at Fault, for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

The results from the odds ratio analysis conducted on this dataset are shown in Table 18. Once again, the 1st driving-hour was found to be statistically significant (greater) in terms of occurrence of critical incidents than driving-hours 2, 3, 4, 7, 8, 9, and 10. There were no other statistically significant findings.

Table 18. Results from the Odds Ratio Analysis in Whichthe Subject Driver was at Fault, for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

Hour	Hour	Odds Ratio	LCL	UCL
1	2	1.73	1.12	2.68
1	3	1.58	1.03	2.42
1	4	2.18	1.35	3.52
1	5	1.51	0.98	2.32
1	6	1.53	0.98	2.39
1	7	2.09	1.25	3.49
1	8	1.98	1.18	3.34
1	9	1.82	1.07	3.10
1	10	2.43	1.27	4.64
1	11	1.46	0.81	2.63
11	4	1.49	0.77	2.89
11	9	1.24	0.62	2.52
11	10	1.66	0.75	3.68

In summary, the key result from Analysis 1 was the finding of a 1st driving-hour spike in the critical-incident relative frequency, as compared to other driving-hours. This was a consistent finding throughout the eight different analyses conducted and suggests a robust and meaningful effect.

3.2 CRITICAL INCIDENTS AS A FUNCTION OF DRIVING-HOUR FOR HOURS 1 THROUGH 11, FOR DRIVERS THAT DROVE 11 HOURS

The second set of analyses considered only data in cases in which the driver drove into the 11th driving-hour. This provided a powerful within-subject design approach. Critical incidents where the driver did not drive into the 11th driving-hour were not included in this analysis. However, partial 11th driving-hours were included. Twenty-nine critical incidents were recorded in the 11th driving-hour. Five of these 29 incidents involved a partial 11th driving-hour, while 24 incidents involved a complete 11th driving-hour. The mean number of driving-hours for the 29 incidents that occurred in the 11th driving-hour was 10.93 h (*SD* = 0.2 h) calculated as follows: [(24 events × 11 h) + (5 events × 10.62 mean h)] ÷ 29. Since this value was, from an exposure perspective, inclusive of virtually the entire 11th driving-hour, we did not modify the statistical analyses conducted to compare these conditions.

The same eight analyses conducted in the previous focus area were again conducted, although with the reduced dataset which only included trips into the 11th driving-hour. All hours of the 11th driving-hour trips were analyzed, unlike in the previous work by Hanowski et al. (2005), which considered only the 10th and 11th driving-hours.

To fully investigate this issue, the data were parsed and analyzed in eight different ways. Once again, this thorough investigative approach was designed to help ensure that significant findings were not overlooked. The eight different analyses used the following datasets:

- Analysis 2.1: 11th Driving-Hour All Data: This included the entire dataset in which drivers made trips into the 11th hour, with the exception of information outlined in the Data Caveats section. This provided the largest dataset available.
- Analysis 2.2: 11th Driving-Hour All Data, Truck Driver at Fault: Using the dataset noted above, this analysis included only those critical incidents that were judged to have been the fault of the subject driver (i.e., the study truck driver).
- Analysis 2.3: 11th Driving-Hour, Baseline and Control Data: Only critical incidents that occurred in the control and baseline conditions (where no DDWS was used) were included.
- Analysis 2.4: 11th Driving-Hour, Baseline and Control Data, Truck Driver at Fault: Using the baseline and control data noted above, this analysis included only critical incidents in which the truck driver was judged to have been at fault.
- Analysis 2.5: 11th Driving-Hour All Data, No Within-Hour Incidents: as in Analysis 1.5, mulitple within-hour critical incidents were removed treated critical incidents as a Bernoulli random variable (i.e., for each hour there are two possible outcomes— "yes, at least one incident occurred" or "no, an incident did not occur"). As previously noted, the critical incident with the less severe classification was removed (e.g., a near-crash would be removed instead of a crash).
- Analysis 2.6: 11th Driving-Hour All Data, Truck Driver at Fault, No Within-Hour Incidents: Using the dataset noted in Analysis 2.1, this analysis considered only critical incidents in which the truck driver was at fault and removed muliple within-hour incidents.
- Analysis 2.7: 11th Driving-Hour, Baseline and Control Data, No Within-Hour Incidents: Using the baseline and control data, this analysis removed multiple within-hour incidents.
- Analysis 2.8: 11th Driving-Hour, Baseline and Control Data, Truck Driver at Fault, No Within-Hour Incidents: Using the baseline and control data, this analysis considered only critical incidents in which the truck driver was at fault and removed muliple within-hour incidents.

The findings from these eight analyses are outlined below.

Analysis 2.1: 11th Driving-Hour Trips, All Data

In Analysis 2.1, driving-hour was treated as a within-subject variable. That is, only the trips in which drivers drove into the 11th driving-hour were considered. Table 19 shows the dataset used for this analysis. As can be seen, the entire dataset is made up of 1,535 trips where the trip included an 11th driving-hour. Note that multiple critical incidents within an hour were included in this dataset but, as before, a follow-up analysis presented later removed the multiples. The rate data (critical-incident relative frequency) is shown plotted in Figure 13.

Table 19. Critical Incidents and Total Opportunities by Driving-Hour for Hours 1 Through 11, for Trips That Went into the 11th Driving-Hour

Driving-Hour	Critical Incidents Per Driving-Hour for 11th Driving-Hour Trips	Total Opportunities Per Driving-Hour for 11th Driving-Hour Trips	Rate: Critical Incidents/ Total Opportunities
1	61	1,535	0.040
2	31	1,535	0.020
3	37	1,535	0.024
4	26	1,535	0.017
5	29	1,535	0.019
6	34	1,535	0.022
7	28	1,535	0.018
8	22	1,535	0.014
9	41	1,535	0.027
10	33	1,535	0.021
11	29	1,535	0.019

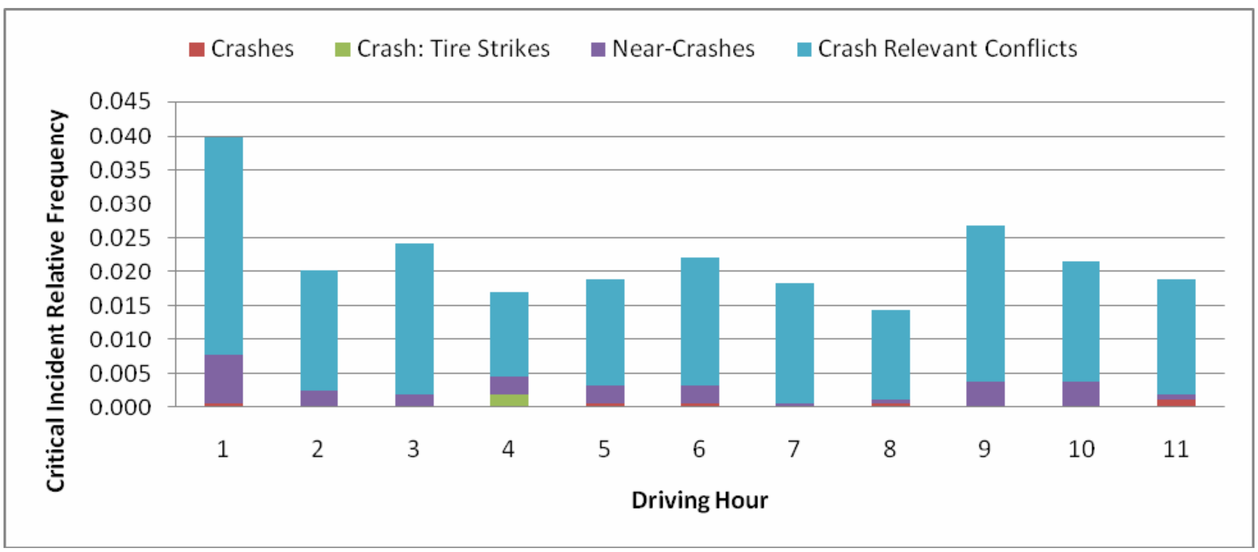

Figure 13. Critical-Incident Relative Frequency as a Function of Driving-Hour for Trips That Went into the 11th Driving-Hour

Similar to what was found with the dataset that considered all possible opportunities for involvement in a critical incident, and not just 11th driving-hour trips, there was an apparent spike in the frequency of critical incidents in the 1st driving-hour. Odds ratios were analyzed to determine statistical differences between critical-incident relative frequencies in different hours. The results from the odds ratio analyses are shown in Table 20. Critical-incident relative frequency in the 1st driving-hour was significantly greater than all other driving-hours. In addition, a significant difference was found between driving-hours 8 and 9, and driving-hours 3 and 8. There were no other significant differences.

Table 20. Results from Odds Ratio Analysis for Trips That Went into the 11th Driving-Hour

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	2.01	1.30	3.11
1	3	1.68	1.11	2.54
1	4	2.40	1.51	3.82
1	5	2.15	1.37	3.36
1	6	1.83	1.19	2.80
1	7	2.23	1.42	3.50
1	8	2.85	1.74	4.66
1	9	1.51	1.01	2.25
1	10	1.88	1.23	2.89
1	11	2.15	1.37	3.36
9	8	1.89	1.12	3.18
3	8	1.70	1.00	2.89
10	11	1.14	0.69	1.89

Analysis 2.2: 11th Driving-Hour Trips, All Data, Truck Driver at Fault

Analysis 2.2 assessed only those critical incidents in which the subject driver was judged to have been at fault. The resulting dataset is shown in Table 21 and a plot of the critical-incident relative frequency is shown in Figure 14.

Table 21. Critical Incidents and Total Opportunities by Driving-Hour for Hours 1 Through 11, for Trips That Went into the 11th Driving-Hour, in Which the Subject Driver was at Fault

Driving-Hour	Critical Incidents Per Driving-Hour for 11th Driving-Hour Trips	Total Opportunities Per Driving-Hour for 11th Driving-Hour Trips	Rate: Critical Incidents/ Total Opportunities
1	48	1,535	0.031
2	26	1,535	0.017
3	26	1,535	0.017
4	18	1,535	0.012
5	17	1,535	0.011
6	25	1,535	0.016
7	21	1,535	0.014
8	17	1,535	0.011
9	30	1,535	0.020
10	20	1,535	0.013
11	23	1,535	0.015

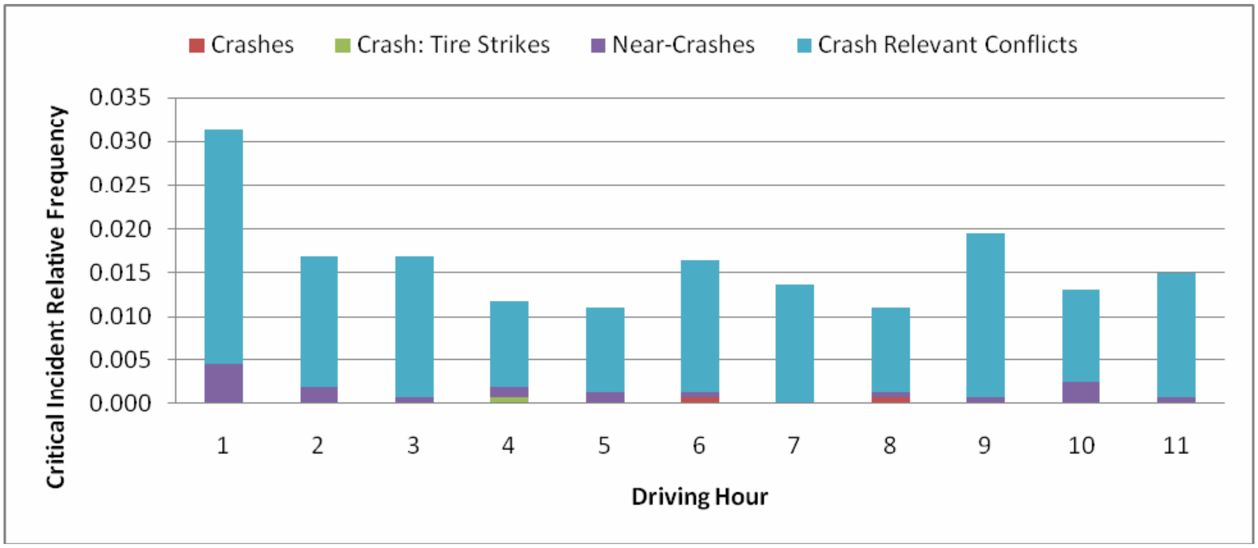

Figure 14. Critical-Incident Relative Frequency as a Function of Driving-Hour, for Trips That Went into the 11th Driving-Hour, in Which the Subject Driver was at Fault

Odds ratio analyses were examined to determine statistical differences between driving-hours, and the results are shown in Table 22. As shown in the previous results, there was a significant difference in critical-incident relative frequency between the 1st driving-hour and all other driving-hours. There were no other significant findings.

Table 22. Result from Odds Ratio Analysis for Trips That Went into the 11th Driving-Hour, In Which the Subject Driver was at Fault

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	1.87	1.16	3.04
1	3	1.87	1.16	3.04
1	4	2.72	1.58	4.70
1	5	2.88	1.65	5.03
1	6	1.95	1.20	3.18
1	7	2.33	1.39	3.91
1	8	2.88	1.65	5.03
1	9	1.62	1.02	2.57
1	10	2.45	1.44	4.14
1	11	2.12	1.28	3.51
9	5	1.78	0.98	3.24
9	10	1.51	0.85	2.67
11	10	1.15	0.63	2.11

Analysis 2.3: 11th Driving-Hour Trips, Baseline and Control Data

Analysis 2.3 considered only the baseline and control data. This dataset is shown in Table 23. Figure 15 shows a plot of the critical-incident relative frequencies.

Table 23. Critical Incidents and Total Opportunities by Driving-Hour for Driving-Hours 1 Through 11, for Trips That Went into the 11th Driving-Hour, for Baseline and Control Conditions

Driving-Hour	Critical Incidents Per Driving-Hour for 11th Driving-Hour Trips	Total Opportunities Per Driving-Hour for 11th Driving-Hour Trips	Rate: Critical Incidents/ Total Opportunities
1	31	796	0.039
2	20	796	0.025
3	20	796	0.025
4	15	796	0.019
5	15	796	0.019
6	15	796	0.019
7	11	796	0.014
8	12	796	0.015
9	24	796	0.030
10	19	796	0.024
11	17	796	0.021

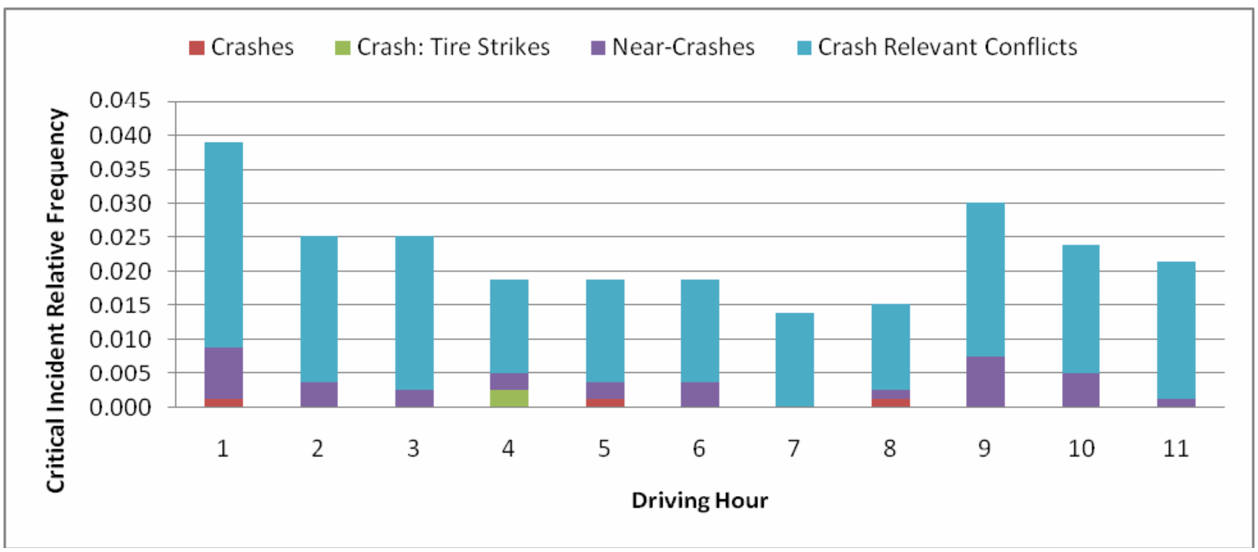

Figure 15. Critical-Incident Relative Frequency as a Function of Driving-Hour, for Trips That Went into the 11th Driving-Hour, for Baseline and Control Conditions

The results from the odds ratio analysis are shown in Table 24. The critical-incident relative frequency in the 1st driving-hour was significantly greater than the frequencies for driving-hours 4, 5, 6, 7, 8, and 11. In addition, significant differences were found for driving-hours 7 and 9, and driving-hours 8 and 9. No other significant differences were found.

Table 24. Results from the Odds Ratio for Trips That Went into the 11th Driving-Hour, for Baseline and Control Conditions

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	1.57	0.89	2.78
1	3	1.57	0.89	2.78
1	*4*	*2.11*	*1.13*	*3.94*
1	*5*	*2.11*	*1.13*	*3.94*
1	*6*	*2.11*	*1.13*	*3.94*
1	*7*	*2.89*	*1.44*	*5.79*
1	*8*	*2.65*	*1.35*	*5.19*
1	9	1.30	0.76	2.24
1	10	1.66	0.93	2.96
1	*11*	*1.86*	*1.02*	*3.38*
9	*7*	*2.22*	*1.08*	*4.56*
9	*8*	*2.03*	*1.01*	*4.09*
10	11	1.12	0.58	2.17

Analysis 2.4: 11th Driving-Hour Trips, Baseline and Control Data, Truck Driver at Fault

Analysis 2.4 considered only baseline and control data in which drivers were judged to have been at fault. The dataset for this analysis is shown in Table 25. Figure 16 shows a plot of the critical-incident relative frequency across the 11 driving-hours.

Table 25. Critical Incidents and Total Opportunities by Driving-Hour for Driving-Hours 1 Through 11, for Trips That Went into the 11th Driving-Hour, in Which the Subject Driver was at Fault, for Baseline and Control Conditions

Driving-Hour	Critical Incidents Per Driving-Hour for 11th Driving-Hour Trips	Total Opportunities Per Driving-Hour for 11th Driving-Hour Trips	Rate: Critical Incidents/ Total Opportunities
1	23	796	0.029
2	17	796	0.021
3	12	796	0.015
4	10	796	0.013
5	10	796	0.013
6	10	796	0.013
7	8	796	0.010
8	9	796	0.011
9	17	796	0.021
10	10	796	0.013
11	16	796	0.020

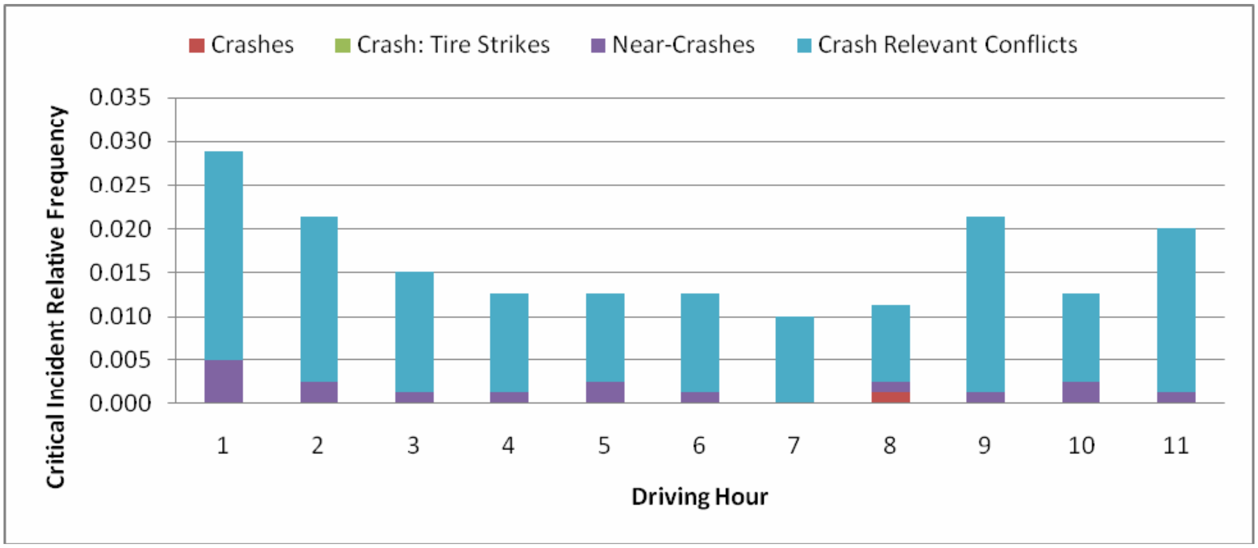

Figure 16. Critical-Incident Relative Frequency as a Function of Driving-Hour, for Trips That Went into the 11th Driving-Hour, in Which the Subject Driver was at Fault, for Baseline and Control Conditions

Odds ratios were analyzed to determine statistical significance between the critical-incident relative frequencies in different hours, and the results are shown in Table 26. The only significant differences between hours were between the 1st driving-hour and driving-hours 4, 5, 6, 7, 8, and 10. No other odds ratios were statistically significant.

Table 26. Results from the Odds Ratio Analysis for Trips That Went into the 11th Driving-Hour, In Which the Subject Driver was at Fault, for Baseline and Control Conditions

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	1.36	0.72	2.57
1	3	1.94	0.96	3.93
1	*4*	*2.34*	*1.11*	*4.95*
1	*5*	*2.34*	*1.11*	*4.95*
1	*6*	*2.34*	*1.11*	*4.95*
1	*7*	*2.93*	*1.30*	*6.59*
1	*8*	*2.60*	*1.20*	*5.66*
1	9	1.36	0.72	2.57
1	*10*	*2.34*	*1.11*	*4.95*
1	11	1.45	0.76	2.77
9	7	2.15	0.92	5.01
9	8	1.91	0.85	4.31
11	10	1.61	0.73	3.57

Analysis 2.5: 11th Driving-Hour Trips, All Data, No Within-Hour Incidents

Analysis 2.5 shows the dataset in which multiple critical incidents that occurred in the same hour, during the same trip, were removed. The resulting dataset removed these multiples and is shown in Table 27. Figure 17 plots the critical-incident relative frequencies across the hours.

Table 27. Critical Incidents and Total Opportunities by Driving-Hour for Driving-Hours 1 Through 11, for Trips That Went into the 11th Driving-Hour, with Multiple Within-Hour Critical Incidents Removed

Driving-Hour	Critical Incidents Per Driving-Hour for 11th Driving-Hour Trips	Total Opportunities Per Driving-Hour for 11th Driving-Hour Trips	Rate: Critical Incidents/ Total Opportunities
1	57	1,535	0.037
2	29	1,535	0.019
3	33	1,535	0.021
4	24	1,535	0.016
5	29	1,535	0.019
6	31	1,535	0.020
7	26	1,535	0.017
8	20	1,535	0.013
9	38	1,535	0.025
10	33	1,535	0.021
11	27	1,535	0.018

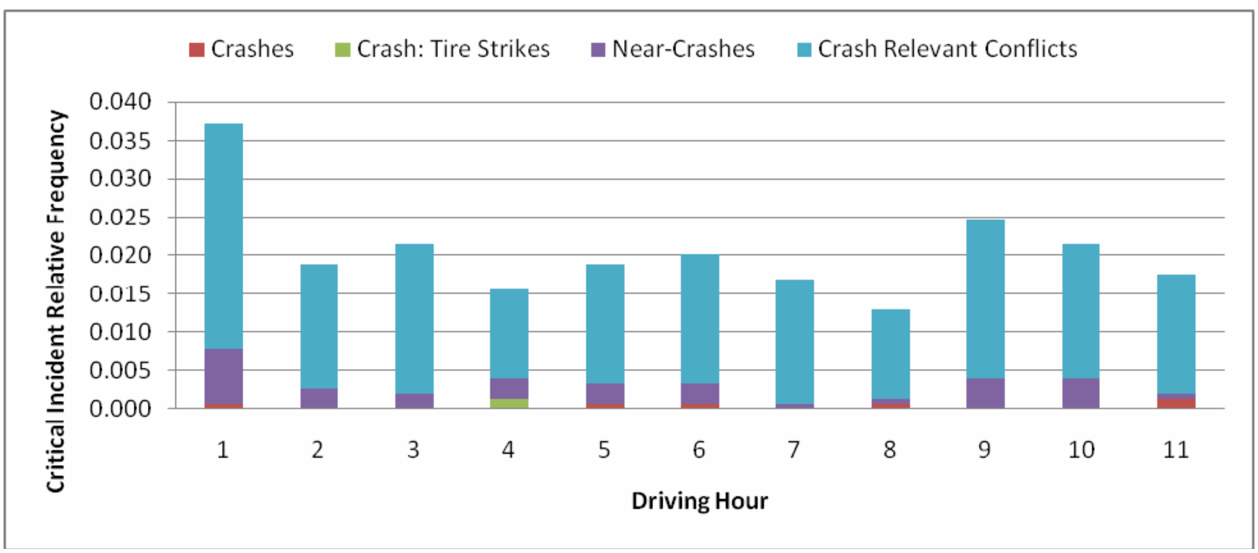

Figure 17. Critical-Incident Relative Frequency as a Function of Driving-Hour, for Trips That Went into the 11th Driving-Hour, with Multiple Within-Hour Critical Incidents Removed

The results from the odds ratio analyses are shown in Table 28. As can be seen, the critical-incident relative frequency was significantly greater in the 1st driving-hour than in all other driving-hours. In addition, a significant difference was found between the 7th driving-hour and the 9th driving-hour. There were no other significant results.

Table 28. Results from the Odds Ratio Analysis for Trips That Went into the 11th Driving-Hour, with Multiple Within-Hour Critical Incidents Removed

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	2.00	1.27	3.15
1	3	1.76	1.14	2.71
1	4	2.43	1.50	3.93
1	5	2.00	1.27	3.15
1	6	1.87	1.20	2.91
1	7	2.24	1.40	3.58
1	8	2.92	1.75	4.89
1	9	1.52	1.00	2.30
1	10	1.76	1.14	2.71
1	11	2.15	1.36	3.42
9	7	1.92	1.11	3.32
9	4	1.60	0.95	2.68
11	10	1.23	0.73	2.05

Analysis 2.6: 11th Driving-Hour Trips, All Data, Truck Driver at Fault, No Within-Hour Incidents

Analysis 2.6 assessed critical incidents in which the subject driver was at fault and removed any multiple incidents that occurred within the same hour for a given driver's trip. The dataset for this analysis is shown in Table 29 and a plot of the critical-incident relative frequencies for the driving-hours is shown in Figure 18.

Table 29. Critical Incidents and Total Opportunities by Driving-Hour for Driving-Hours 1 Through 11 for Trips That Went into the 11th Driving-Hour, in Which the Subject Driver was at Fault, with Multiple Within-Hour Critical Incidents Removed

Driving-Hour	Critical Incidents Per Driving-Hour for 11th Driving-Hour Trips	Total Opportunities Per Driving-Hour for 11th Driving-Hour Trips	Rate: Critical Incidents/ Total Opportunities
1	46	1,535	0.030
2	25	1,535	0.016
3	23	1,535	0.015
4	17	1,535	0.011
5	17	1,535	0.011
6	22	1,535	0.014
7	20	1,535	0.013
8	15	1,535	0.010
9	28	1,535	0.018
10	20	1,535	0.013
11	21	1,535	0.014

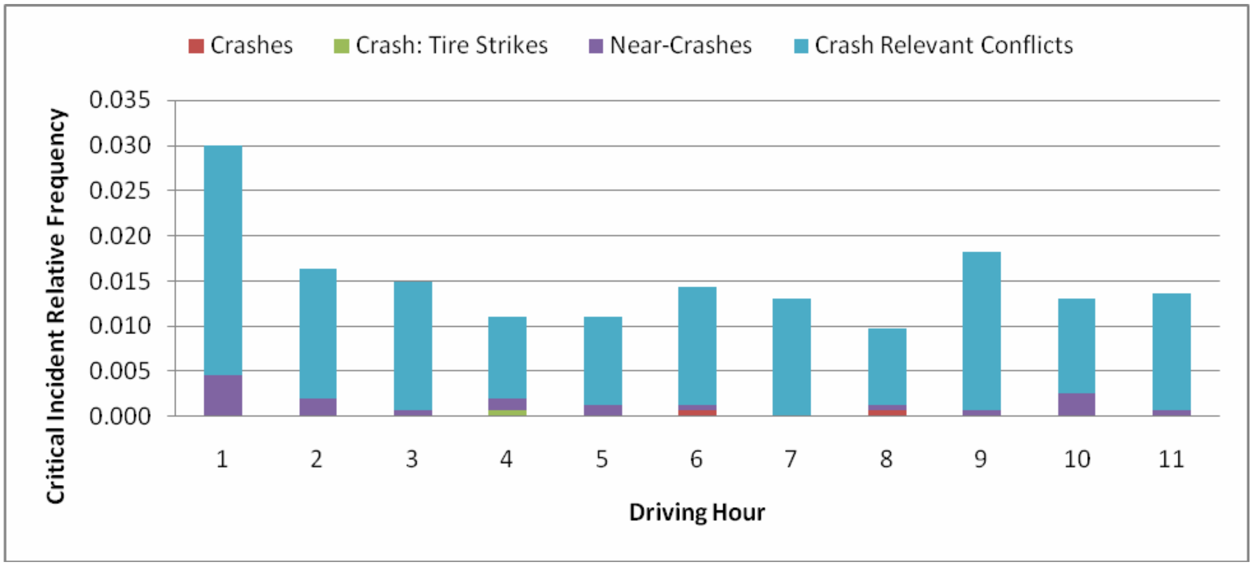

Figure 18. Critical-Incident Relative Frequency as a Function of Driving-Hour for Trips That Went into the 11th Driving-Hour, in Which the Subject Driver was at Fault, with Multiple Within-Hour Critical Incidents Removed

The results from the odds ratio analysis are shown in Table 30. Once again, these results show that the 1st driving-hour had a significantly higher critical-incident relative frequency than any other driving-hour. In addition, the 8th driving-hour was significantly different than the 9th driving-hour. There were no other statistical differences found.

Table 30. Results from the Odds Ratio Analysis in Which the Subject Driver was at Fault for Trips That Went into the 11th Driving-Hour, with Multiple Within-Hour Critical Incidents Removed

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	1.87	1.14	3.05
1	3	2.03	1.22	3.37
1	4	2.76	1.57	4.83
1	5	2.76	1.57	4.83
1	6	2.12	1.27	3.55
1	7	2.34	1.38	3.98
1	8	3.13	1.74	5.63
1	9	1.66	1.03	2.67
1	10	2.34	1.38	3.98
1	11	2.23	1.32	3.75
9	8	1.88	1.00	3.54
9	5	1.66	0.90	3.04
11	10	1.05	0.57	1.95

Analysis 2.7: 11th Driving-Hour Trips, Baseline and Control Data, No Within-Hour Incidents

Analysis 2.7 used baseline and control data only and removed any multiple incidents that occurred within the same hour for a given driver's trip. The resulting dataset is shown in Table 31. Figure 19 shows a plot of the critical-incident relative frequencies across the driving-hours.

Table 31. Critical Incidents and Total Opportunities by Driving-Hour for Driving-Hours 1 Through 11, for Trips That Went into the 11th Driving-Hour, for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

Driving-Hour	Critical Incidents Per Driving-Hour for 11th Driving-Hour Trips	Total Opportunities Per Driving-Hour for 11th Driving-Hour Trips	Rate: Critical Incidents/ Total Opportunities
1	29	796	0.036
2	19	796	0.024
3	16	796	0.020
4	13	796	0.016
5	15	796	0.019
6	14	796	0.018
7	11	796	0.014
8	10	796	0.013
9	21	796	0.026
10	19	796	0.024
11	15	796	0.019

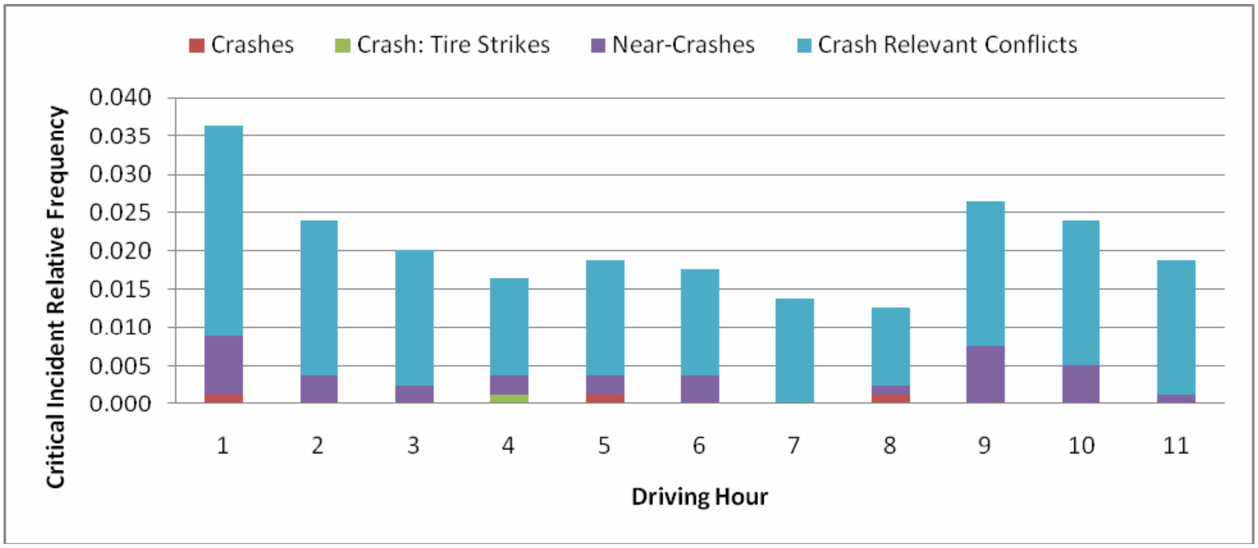

Figure 19. Critical-Incident Relative Frequency as a Function of Driving-Hour, for Trips that went into the 11th Driving-Hour, for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

Odds ratios were analyzed on the critical-incident relative frequencies, comparing one driving-hour to another. The results are shown in Table 32. Statistically significant differences were found between the 1st driving-hour and driving-hours 4, 5, 6, 7, 8, and 11. Also, the 8th and 9th driving-hours were found to be significantly different. No other comparisons were statistically significant.

Table 32. Results from the Odds Ratio Analysis for Trips that went into the 11th Driving-Hour, for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	1.55	0.86	2.78
1	3	1.84	0.99	3.42
1	*4*	*2.28*	*1.17*	*4.41*
1	*5*	*1.97*	*1.05*	*3.70*
1	*6*	*2.11*	*1.11*	*4.03*
1	*7*	*2.70*	*1.34*	*5.44*
1	*8*	*2.97*	*1.44*	*6.14*
1	9	1.40	0.79	2.47
1	10	1.55	0.86	2.78
1	*11*	*1.97*	*1.05*	*3.70*
9	*8*	*2.13*	*1.00*	*4.55*
9	7	1.93	0.93	4.04
10	11	1.27	0.64	2.52

Analysis 2.8: 11th Driving-Hour Trips, Baseline and Control Data, Truck Driver at Fault, No Within-Hour Incidents

Analysis 2.8 used baseline and control data only and considered drivers who were at fault, with the removal of multiple within-hour incidents. The dataset for this analysis is shown in Table 33. Figure 20 shows a plot of the critical-incident relative frequencies across the different driving-hours.

Table 33. Critical Incidents and Total Opportunities by Driving-Hour for Driving-Hours 1 Through 11, for Trips That Went into the 11th Driving-Hour, in Which the Subject Driver was at Fault, for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

Driving-Hour	Critical Incidents Per Driving-Hour for 11th Driving-Hour Trips	Total Opportunities Per Driving-Hour for 11th Driving-Hour Trips	Rate: Critical Incidents/ Total Opportunities
1	23	796	0.029
2	16	796	0.020
3	9	796	0.011
4	9	796	0.011
5	10	796	0.013
6	9	796	0.011
7	8	796	0.010
8	7	796	0.009
9	15	796	0.019
10	10	796	0.013
11	14	796	0.018

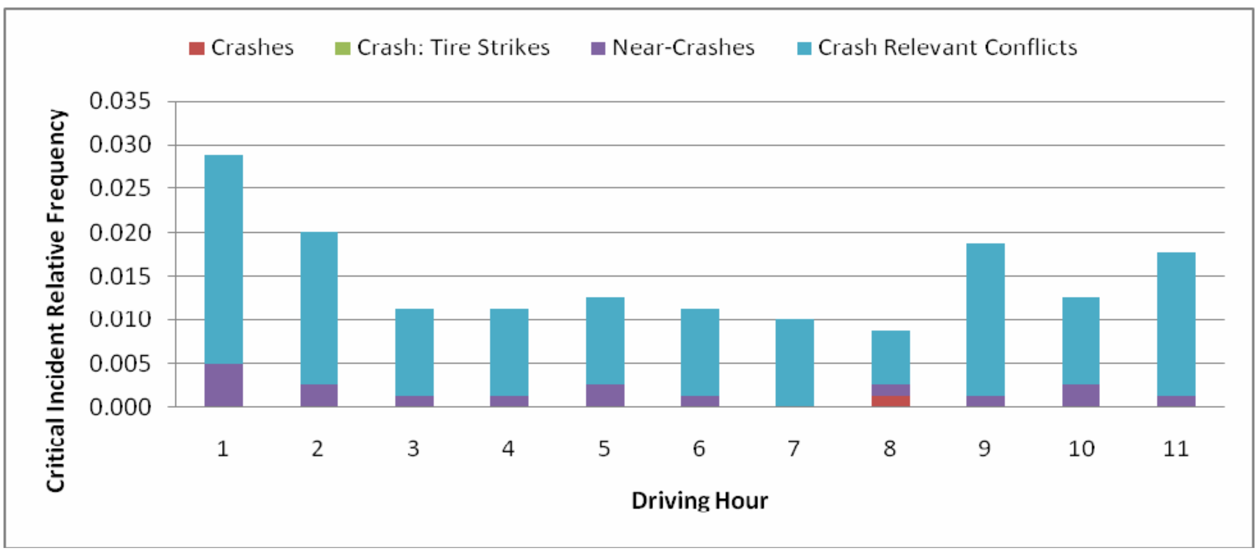

Figure 20. Critical-Incident Relative Frequency as a Function of Driving-Hour, for Trips That Went into the 11th Driving-Hour, in Which the Subject Driver was at Fault, for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

Odds ratios were examined to compare the critical incident relative frequencies across driving-hours. The results are shown in Table 34. The critical incident relative frequency for the 1st driving-hour was significantly greater than driving-hours 3, 4, 5, 6, 7, 8, and 10. No other statistically significant differences were found.

Table 34. Results From the Odds Ratio Analysis for Trips that went into the 11th Driving-Hour, in Which the Subject Driver was at Fault, for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	1.45	0.76	2.77
1	*3*	*2.60*	*1.20*	*5.66*
1	*4*	*2.60*	*1.20*	*5.66*
1	*5*	*2.34*	*1.11*	*4.95*
1	*6*	*2.60*	*1.20*	*5.66*
1	*7*	*2.93*	*1.30*	*6.59*
1	*8*	*3.35*	*1.43*	*7.86*
1	9	1.55	0.80	2.99
1	*10*	*2.34*	*1.11*	*4.95*
1	11	1.66	0.85	3.25
9	8	2.16	0.88	5.34
9	7	1.89	0.80	4.49
11	10	1.41	0.62	3.19

In summary, the results from Analysis 2 were consistent with the key findings from Analysis 1; that is, the 1st driving-hour was associated with an elevated critical-incident relative frequency as compared to the other driving-hours. In terms of significance, the specific driving-hours that were statistically different from the 1st driving-hour varied somewhat from one analysis to the next, and across the eight analyses. However, the finding that the 1st driving-hour was different from the other hours, but that the other driving-hours (i.e., 2 through 11) were not consistently different from each other, is an important finding.

3.3 MODELING THE DATA TO IDENTIFY SIGNIFICANT DIFFERENCES IN CRITICAL INCIDENTS ACROSS DRIVING-HOURS

As a follow-up to Analyses 1 and 2, Analysis 3 computed odds ratios using logistic regression modeling. One difference between this approach and the approach used in Analyses 1 and 2 is that an assumption of independence is not being made. That is, the approach used generalized estimating equations (GEE) to account for correlations that might exist between drivers and within drivers (with respect to critical incident occurrence). The model that was used in these analyses was:

$$\text{Logit}\ (P(Y_t = SCE)) = \alpha_{SCE} + \beta t$$

Where t is driving-hours 1 through 11, α_{SCE} is the intercept term, and β_t is the effect of driving in the t^{th} driving-hour.

Applying the logistic regression model to the data produces odds ratios for each driving-hour which can then be compared in a manner similar to the comparisons conducted in Analyses 1 and 2 using lower and upper confidence limits to assess statistical significance.

The logistic regression modeling approach was applied to two different datasets: (1) the entire dataset, or All Data, and (2) the subset of trips that went into the 11^{th} driving-hour. Figure 21 shows the resulting odds ratios as a function of driving-hour for the All Data dataset. As noted, the output of the model is the odds ratios for each driving-hour and not the critical-incident relative frequency, as in the previous analyses.

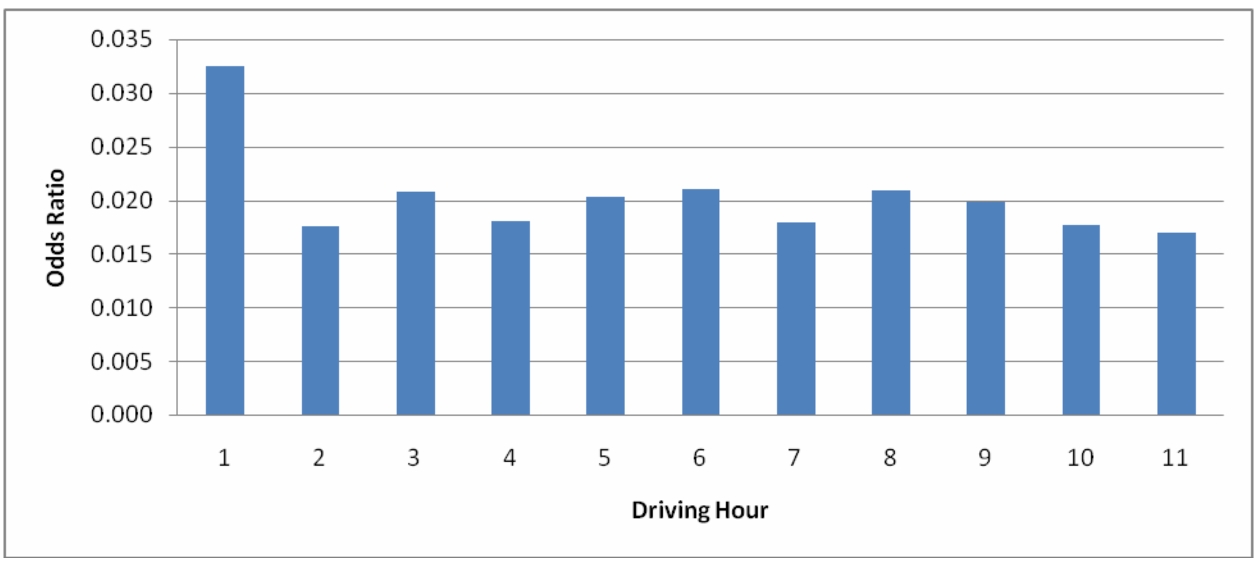

Figure 21. Odds Ratio as a Function of Driving-Hour Using Logistic Regression Modeling

The odds ratios were examined and the results are shown in Table 35. Consistent with the general Analysis 1 results, there was a spike in the critical-incident relative frequency in the st driving-hour compared to those in all other driving-hours. No other hour-by-hour comparisons were statistically significant.

Table 35. Results from the Odds Ratio Analyses Using Logistic Regression Modeling

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	1.85	1.33	2.58
1	3	1.56	1.09	2.22
1	4	1.80	1.25	2.60
1	5	1.60	1.18	2.17
1	6	1.54	1.08	2.20
1	7	1.81	1.26	2.60
1	8	1.55	1.04	2.31
1	9	1.64	1.10	2.45
1	10	1.84	1.23	2.75
1	11	1.91	1.12	3.28
3	8	1.00	0.67	1.49
9	8	0.95	0.60	1.49
10	11	1.04	0.06	1.69

The next analysis conducted was similar to Analysis 2, presented previously, in that the focus was on trips that went into the 11th driving-hour. Using this subset of data, logistic regression modeling was again used and the resulting odds ratios are shown in Figure 22.

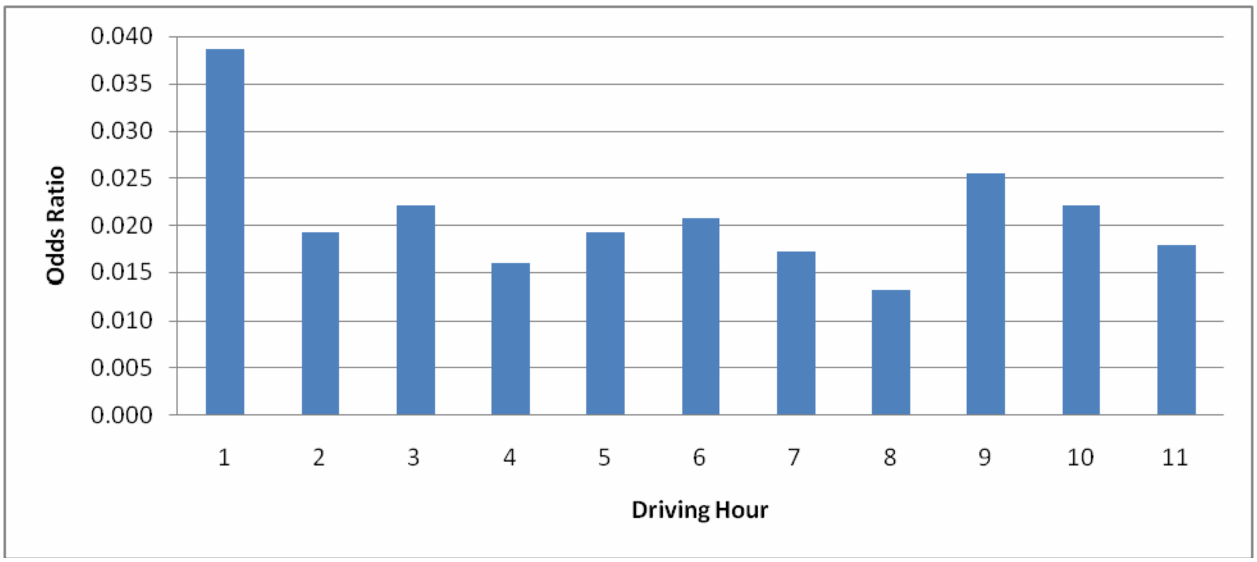

Figure 22. Odds Ratio as a Function of Driving-Hour for Trips That Went into the 11th Driving-Hour

The odds ratios were examined and are shown in Table 36. Once again, the most prominent result is the high odds ratio in the 1st driving-hour as compared to all other driving-hours.

Table 36. Results from the Odds Ratio Analyses Using Logistic Regression Modeling for Trips that Went into the 11th Driving-Hour

Driving-Hour	Driving-Hour	Odds Ratio	LCL	UCL
1	2	2.00	1.31	3.07
1	3	1.76	1.12	2.76
1	4	2.43	1.59	3.72
1	5	2.00	1.24	3.24
1	6	1.87	1.24	2.83
1	7	2.24	1.38	3.64
1	8	2.92	1.68	5.08
1	9	1.52	0.95	2.43
1	10	1.76	1.15	2.69
1	11	2.15	1.32	3.51
3	8	1.66	0.97	2.85
9	8	1.92	1.07	3.46
10	8	1.66	1.06	2.61
10	11	1.23	0.81	1.86

In summary, the results of Analysis 3 using the logistic regression modeling approach were generally consistent with the results found in Analyses 1 and 2. Nonetheless, it was important to explore the possibility of assumed independence made in Analyses 1 and 2 that might impact the results. But, again, given the consistency in the findings using both methods, this does not appear to be the case.

3.4 CRITICAL INCIDENTS AS A FUNCTION OF DRIVING-SHIFT

As noted in the Data Caveats section, a new "driving-shift" was defined as consecutive driving-hours broken up by a non-driving (assumed break) of at least 6 h, as long as it was not less than 14 h from the start of the previous driving-shift. The 1st driving-shift was always preceded by a break of at least 34 h of non-driving.

For this analysis, critical incidents were investigated as a function of driving-shift. As outlined in the 2003 revised HOS regulations, a driver may drive up to 60 h in 7 consecutive days or 70 h in 8 consecutive days before an off-duty period of time not less than 34 consecutive hours. The data used in this analysis were a subset of the data used in Analyses 1 and 2, resulting in a total of 747 critical incidents that occurred in driving-shifts 1 through 8: 10 crashes, 11 tire-strike crashes, 77 near-crashes, and 649 crash-relevant conflicts.

Once again, the critical-incident data were parsed and analyzed in eight different ways, as follows:

- <u>Analysis 4.1: All Data</u>: This included the entire dataset, with the exception of information outlined in the Data Caveats section. This provided the largest dataset available. Note that both a frequency-odds- ratio approach and a logistic regression modeling approach were used and the results of the two approaches compared.

- Analysis 4.2: All Data, Truck Driver at Fault: Using the dataset noted above, the analysis included only those critical incidents that were judged to have been the fault of the subject driver (i.e., the study truck driver).
- Analysis 4.3: Baseline and Control Data: Only critical incidents that occurred in the control and baseline conditions (where no DDWS was used) were included.
- Analysis 4.4: Baseline and Control Data, Truck Driver at Fault: Using the baseline and control data noted above, this analysis included only critical incidents in which the truck driver was judged to have been at fault.
- Analysis 4.5: All Data, No Within-Shift Incidents: Using the dataset noted in Analysis 4.1, this analysis removed multiple critical incidents that occurred in the same shift, and in the same trip. This analysis treated critical incidents as a dichotomous random variable (i.e., for each shift there are two possible outcomes—"yes, at least one incident occurred" or "no, an incident did not occur").
- Analysis 4.6: All Data, Truck Driver at Fault, No Within-Shift Incidents: Using the dataset noted in Analysis 4.1, this analysis considered only critical incidents where the truck driver was at fault and removed multiple within-shift incidents.
- Analysis 4.7: Baseline and Control Data, No Within-Shift Incidents: This analysis used the baseline and control data and removed multiple within-shift incidents.
- Analysis 4.8: Baseline and Control Data, Truck Driver at Fault, No Within-Shift Incidents: Using the baseline and control data, this analysis considered only critical incidents in which the truck driver was at fault and removed muliple within-shift incidents.

The findings from these eight analyses are outlined below.

Analysis 4.1: All Data

Table 37 shows the dataset for the first analysis, which included all critical incidents, and all driving opportunities (i.e., trips), that occurred in the 1st through 8th driving-shifts. As shown in Table 37, each driving-shift had a different number of opportunities to be involved in critical incidents. For example, a driver could have seven shifts but not eight; as such, there were fewer opportunities to be involved in a critical incident as the shift number increased. The data were normalized to adjust for the differences in opportunities across driving-shift by calculating a rate measure. This provided the relative frequency of having a critical incident in any given driving-shift. Once again, using this first dataset, the data in Table 37 include cases where multiple critical incidents were recorded in the same driving-shift.

Table 37. Critical Incidents and Total Opportunities by Driving-Shift for Shifts 1 Through 8

Driving-Shift	Critical Incidents Per Driving-Shift	Total Opportunities Per Driving-Shift	Rate: Critical Incidents/ Total Opportunities
1	190	4748	0.040
2	193	3552	0.054
3	118	2522	0.047
4	91	1693	0.054
5	73	1087	0.067
6	32	718	0.045
7	23	571	0.040
8	27	459	0.059

Figure 23 plots the number of opportunities for each driving-shift. As with driving-hour, the number of opportunities drops off as the number of driving-shifts increased. This indicates that drivers in the current study often restarted their driving week (tour of duty) before they reached the 7th or 8th driving-shift.

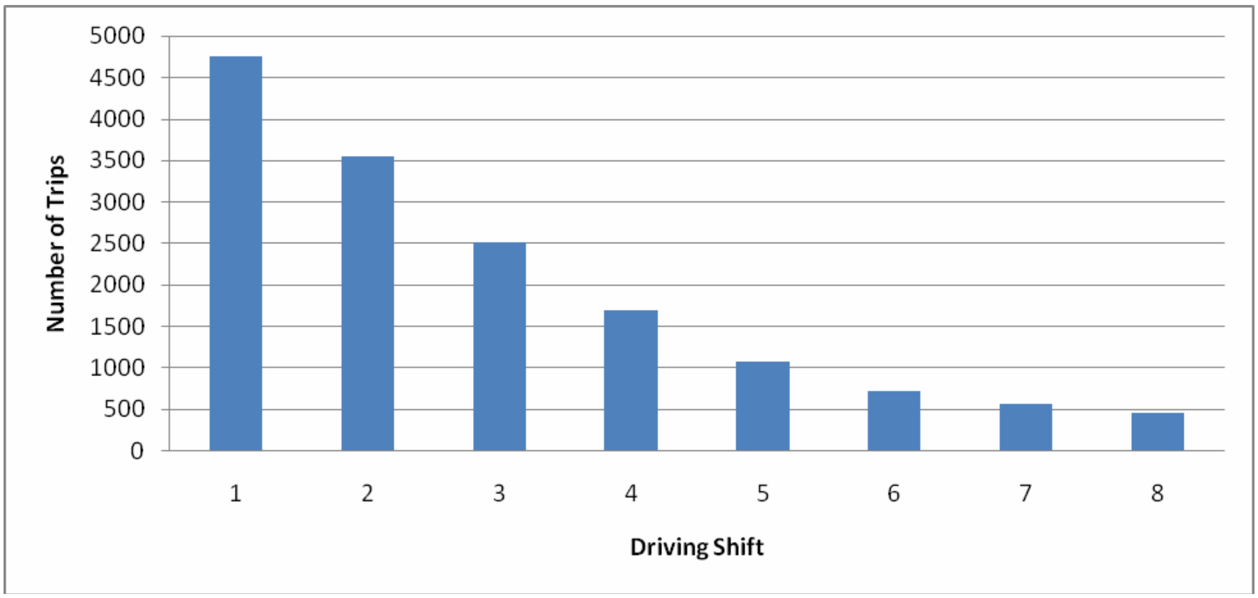

Figure 23. Total Opportunities (Trips) for Shifts 1 Through 8

Figure 24 shows the relative frequency of critical incidents as a function of driving-shifts 1 through 8. Once again, a breakdown in the frequency for each type of critical incident is indicated: crashes (red), crashes: tire strikes (green), near-crashes (purple), and crash-relevant conflicts (blue). The top of the bar is the total for all critical-incident types.

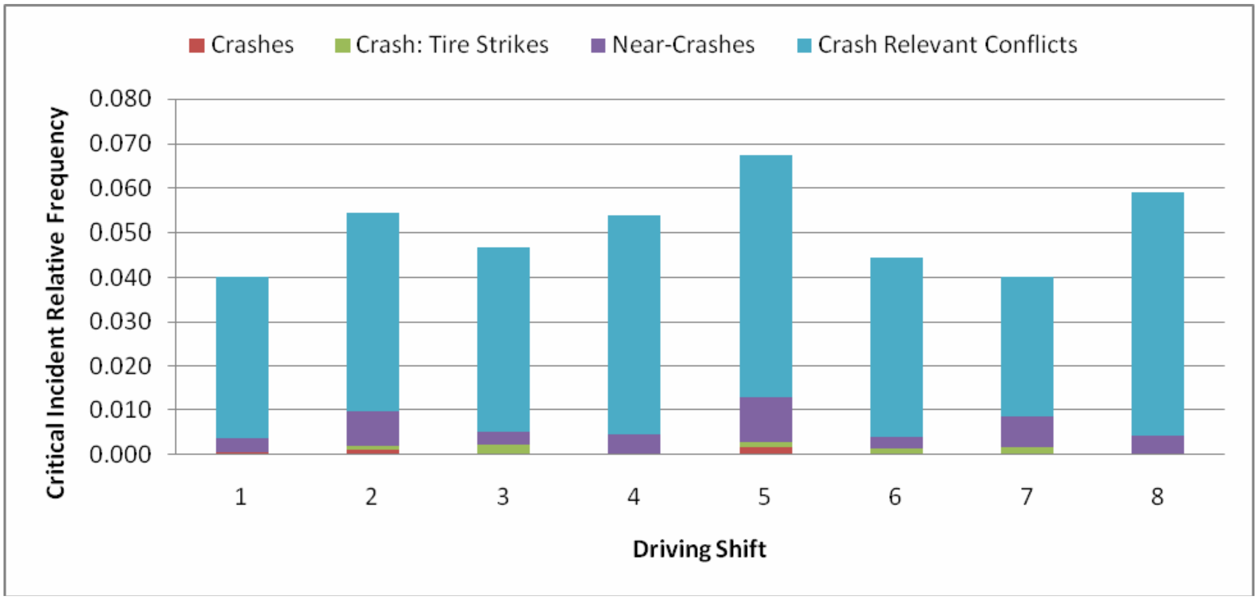

Figure 24. Critical-Incident Relative Frequency as a Function of Driving-Shift

Table 38 shows the results from the odds ratio analyses. The first two columns in Table 38 show the comparison hours (e.g., the first row compares the 5th and 7th driving-shifts), while the third column shows the calculated odds ratio and the last two columns display the LCLs and UCLs, respectively. As a reminder, odds ratios with LCLs and UCLs that contain "1" are not statistically significant (again, a 95 percent confidence level was used in these calculations). All significant odds ratios shown in Table 38 are highlighted and in italics. As before, all significant effects are included in the odds ratio tables, along with selected other analyses that were not significant. The significant findings were that the odds ratio for the 5th driving-shift is significantly higher than the 1st, 3rd, 6th, and 7th driving-shifts.

Table 38. Results from the Odds Ratio Analyses

Driving-Shift	Driving-Shift	Odds Ratio	LCL	UCL
5	7	1.72	1.06	2.77
5	1	1.73	1.31	2.28
5	6	1.54	1.01	2.36
5	3	1.47	1.09	1.98
5	2	1.25	0.95	1.66
8	7	1.49	0.84	2.63
8	1	1.50	0.99	2.27

As discussed in Analysis 3, an alternative method of analyzing the data and calculating odds ratios is logistic regression modeling. This approach was applied to this dataset and the results are shown in Figure 25. As noted in Analysis 3, the logistic regression modeling approach determines odds ratios for each driving-shift which can then be compared for statistical differences between driving-shifts (Table 39). As can be seen, both the logistic regression modeling approach and the approach that does not account for repeated measures (Table 38) produce very similar results. The 5th driving-shift is significantly greater than the 1st and 3rd driving-shifts, and the 8th driving-shift is significantly different from the 1st driving shift (the 8th driving-shift vs. the 1st driving-shift was marginally significant in the initial analysis).

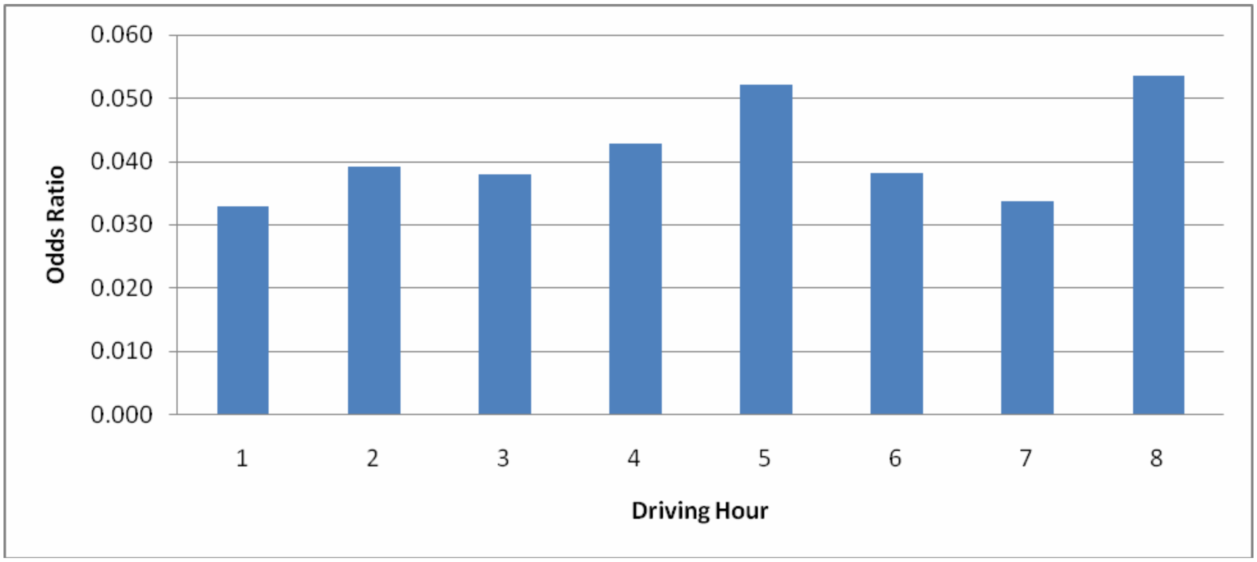

Figure 25. Odds Ratios as a Function of Driving-Shift Using Logistic Regression Modeling

Table 39. Results From Odds Ratio Analysis Using Logistic Regression Modeling

Driving-Shift	Driving-Shift	Odds Ratio	LCL	UCL
5	1	1.59	1.11	2.26
5	2	1.33	0.99	1.79
5	3	1.37	1.00	1.88
5	7	1.55	0.96	2.50
5	6	1.37	0.90	2.09
4	1	1.30	0.94	1.80
4	7	1.27	0.81	1.99
8	1	1.63	1.14	2.32
8	2	1.36	0.93	2.00
8	3	1.41	0.98	2.04
8	4	1.25	0.83	1.90
8	5	1.03	0.68	1.55
8	6	1.41	0.89	2.23
8	7	1.59	0.89	2.84

Analysis 4.2: All Data, Truck Driver at Fault

Analysis 4.2 included only critical incidents in which the subject-vehicle driver (i.e., the study truck driver) was judged, based on video review, to have been at fault. Note that these data did not include multiple critical incidents that may have occurred within the same hour. The resulting dataset is shown in Table 40 below and plotted in Figure 26.

Table 40. Critical Incidents and Total Opportunities by Driving-Shift for Shifts 1 Through 8 In Which the Subject Driver was at Fault

Driving-Shift	Critical Incidents Per Driving-Shift	Total Opportunities Per Driving-Shift	Rate: Critical Incidents/ Total Opportunities
1	154	4,748	0.032
2	141	3,552	0.040
3	87	2,522	0.034
4	68	1,693	0.040
5	47	1,087	0.043
6	26	718	0.036
7	18	571	0.032
8	24	459	0.052

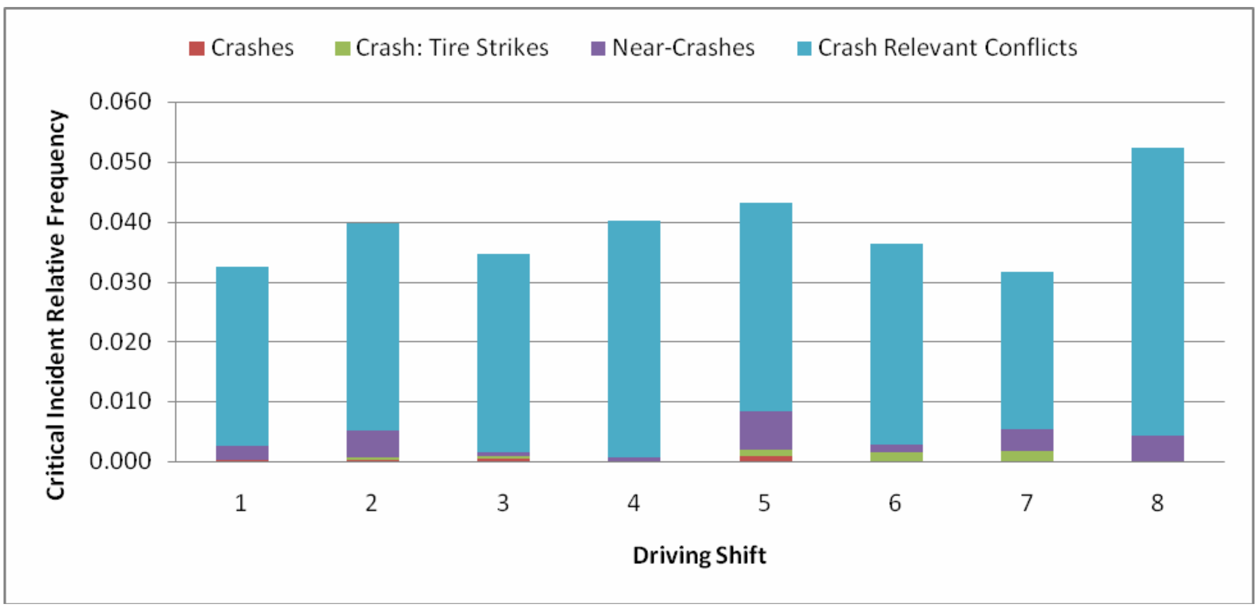

Figure 26. Critical-Incident Relative Frequency as a Function of Driving-Shift in Which the Subject Driver was at Fault

Table 41 displays the results from the odds ratio analyses, including all trips in which the subject driver was at fault. The relative frequency of critical incidents in the 8th driving-shift was significantly greater than in the 1st driving-shift.

Table 41. Results from the Odds Ratio Analyses, Including all Trips In Which the Subject Driver was at Fault

Driving-Shift	Driving-Shift	Odds Ratio	LCL	UCL
8	1	1.65	1.06	2.56
8	7	1.70	0.91	3.16
5	1	1.35	0.97	1.88

Analysis 4.3: Baseline and Control Data

Analysis 4.3 used only the data from the "control" and "baseline" conditions from the study (i.e., data collected where no DDWS was used). The resulting dataset is shown in Table 42. Figure 27 plots the critical-incident relative frequency across the driving-hours for the baseline and control conditions.

Table 42. Critical Incidents and Total Opportunities by Driving-Shift for Shifts 1 Through 8 for Baseline and Control Conditions

Driving-Shift	Critical Incidents Per Driving-Shift	Total Opportunities Per Driving-Shift	Rate: Critical Incidents/ Total Opportunities
1	103	2,275	0.045
2	97	1,679	0.058
3	65	1,183	0.055
4	50	788	0.063
5	37	501	0.074
6	18	332	0.054
7	16	254	0.063
8	16	195	0.082

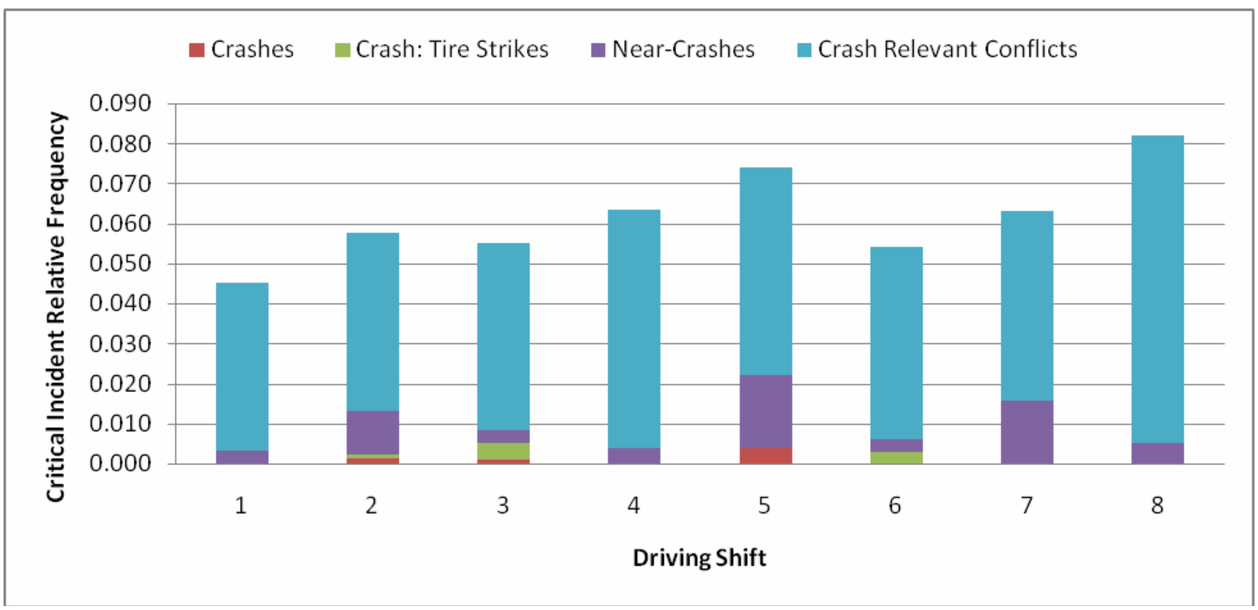

Figure 27. Critical-Incident Relative Frequency as a Function of Driving-Shift for Baseline and Control Conditions

Table 43 displays the results from the odds ratio analyses. Statistically significant differences were found between the 8th and 1st driving-shifts. In looking at the plotted data in Figure 27, there appears to be an increasing trend in critical-incident relative frequency from the 1st through 5th driving-shifts and the 6th through 8th driving-shifts. However, aside from the statistical difference betweent the 8th and 1st driving-shifts, these differences were not statistically significant.

Table 43. Results from the Odds Ratio Analysis Across all Trips for Baseline and Control Conditions

Driving-Shift	Driving-Shift	Odds Ratio	LCL	UCL
8	1	1.88	1.09	3.26
8	6	1.56	0.78	3.13
8	3	1.54	0.87	2.72

Analysis 4.4: Baseline and Control Data, Truck Driver at Fault

Analysis 4.4 used only the data from the control and baseline conditions in which the subject driver was judged at fault. Table 44 displays the dataset used and Figure 28 plots the critical-incident relative frequency across the driving-shifts.

Table 44. Critical Incidents and Total Opportunities by Driving-Shift for Shifts 1 Through 8, In Which the Subject Driver was at Fault, for Baseline and Control Conditions

Driving-Shift	Critical Incidents Per Driving-Shift	Total Opportunities Per Driving-Shift	Rate: Critical Incidents/ Total Opportunities
1	84	2,275	0.037
2	69	1,679	0.041
3	46	1,183	0.039
4	40	788	0.051
5	24	501	0.048
6	14	332	0.042
7	12	254	0.047
8	13	195	0.067

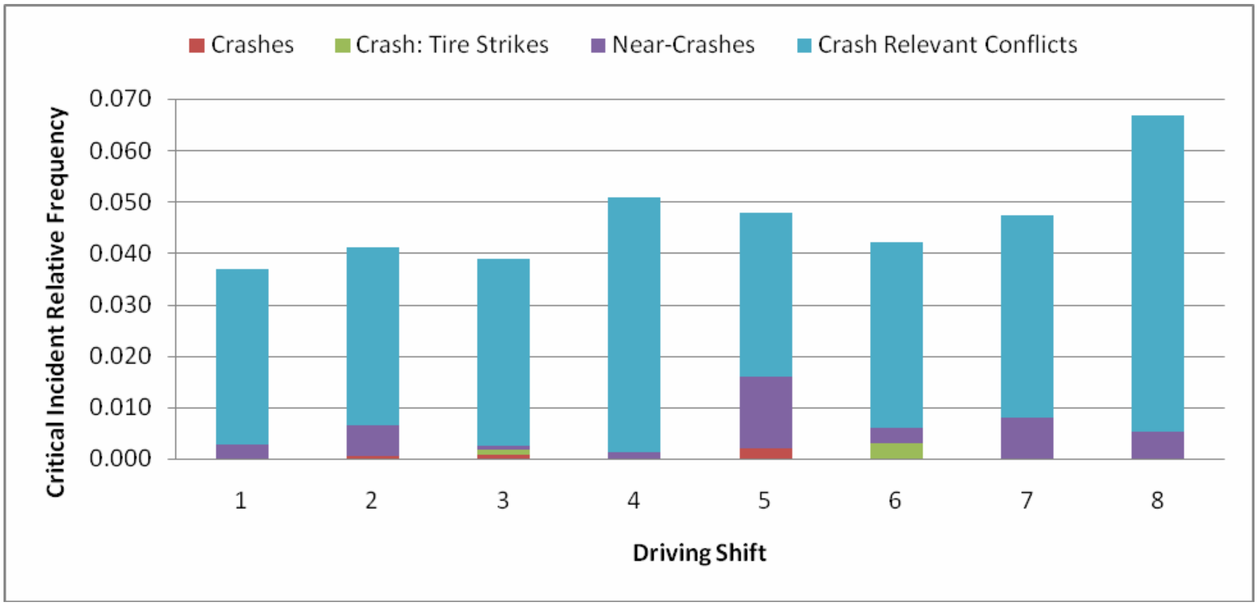

Figure 28. Critical-Incident Relative Frequency as a Function of Driving-Shift, in Which the Subject Driver was at Fault, for Baseline and Control Conditions

Odds ratios were conducted on the critical-incident relative frequency data and the results are shown in Table 45. As in the previous analysis, there was a statistically signifiant difference between the critical-incident relative frequencies in the 8th and 1st driving-shifts.

Table 45. Results from the Odds Ratio Analysis Including All Trips in Which the Subject Driver Was at Fault, for Baseline and Control Conditions

Driving-Shift	Driving-Shift	Odds Ratio	LCL	UCL
8	1	1.86	1.02	3.41
8	2	1.67	0.90	3.07
8	3	1.77	0.94	3.33

Analysis 4.5: All Data, No Within-Shift Incidents

Analysis 4.5 removed multiple within-shift critical incidents such that a dichotomous varible was created (either "yes, at least one critical incident occurred" or "no critical incident occurred.") Table 46 shows the resulting dataset. Figure 29 shows the plot of the critical-incident relative frequencies for each driving-shift. The resulting odds ratios are shown in Table 47. The spike in the critical-incident relative frequency in the 5th driving shift was significantly greater than the critical-incident relative frequencies in the 1st and 7th driving shifts. There was also a significant difference between the 4th and 7th driving shifts.

Table 46. Critical Incidents and Total Opportunities by Driving-Shift for Shifts 1 Through 8, with Multiple Within-Shift Critical Incidents Removed

Driving-Shift	Critical Incidents Per Driving-Shift	Total Opportunities Per Driving-Shift	Rate: Critical Incidents/ Total Opportunities
1	162	4,748	0.034
2	144	3,552	0.041
3	99	2,522	0.039
4	73	1,693	0.043
5	53	1,087	0.049
6	23	718	0.032
7	14	571	0.025
8	19	459	0.041

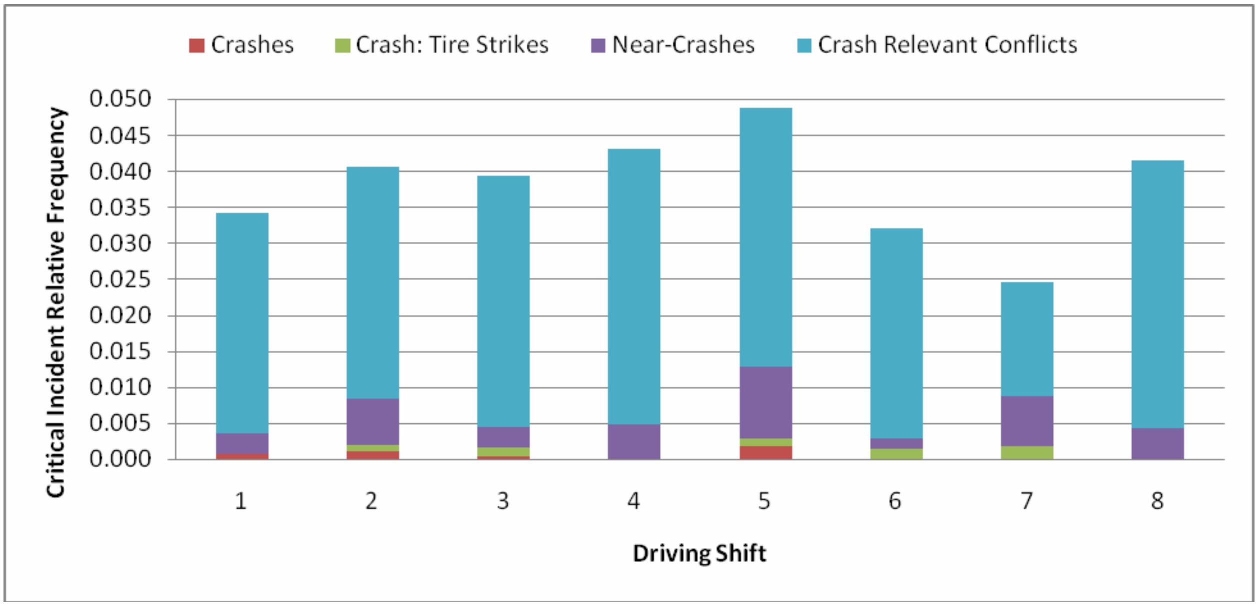

Figure 29. Critical-Incident Relative Frequency as a Function of Driving-Shift, with Multiple Within-Shift Critical Incidents Removed

Table 47. Results from the Odds Ratio Analysis with Multiple Within-Shift Critical Incidents Removed

Shift	Shift	Odds Ratio	LCL	UCL
5	7	2.04	1.12	3.71
5	1	1.45	1.06	1.99
5	6	1.55	0.94	2.55
5	3	1.25	0.89	1.77
5	2	1.21	0.88	1.67
8	7	1.72	0.85	3.47
8	1	1.22	0.75	1.99
4	7	1.79	1.00	3.20
4	1	1.28	0.96	1.69

Analysis 4.6: All Data, Truck Driver at Fault, No Within-Shift Incidents

Analysis 4.6 included critical incidents in which the subject driver was judged to have been at fault, and all multiple critical incidents that occurred within the same shift were removed. The resulting dataset is shown in Table 48 and the plot of the relative frequency of critical incidents is shown in Figure 30.

Table 48. Critical Incidents and Total Opportunities by Driving-Shift for Shifts 1 Through 8, in Which the Subject Driver was at Fault, with Multiple Within-Shift Critical Incidents Removed

Driving-Shift	Critical Incidents Per Driving-Shift	Total Opportunities Per Driving-Shift	Rate: Critical Incidents/ Total Opportunities
1	129	4748	0.027
2	105	3552	0.030
3	74	2522	0.029
4	55	1693	0.032
5	32	1087	0.029
6	18	718	0.025
7	11	571	0.019
8	17	459	0.037

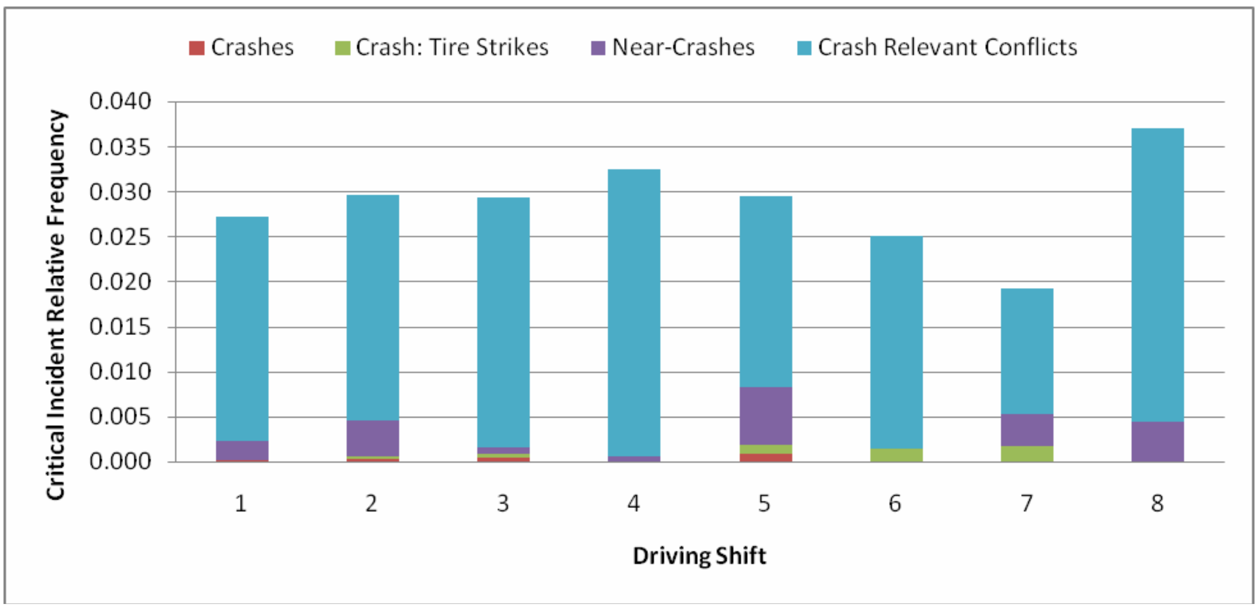

Figure 30. Critical-Incident Relative Frequency as a Function of Driving-Shift in Which the Subject Driver was at Fault, with Multiple Within-Shift Critical Incidents Removed

Odds ratios were examined on the critical-incident relative frequencies across the driving-shifts and the results are shown in Table 49. None of the shift-by-shift comparisons was statistically significant.

Table 49. Results from the Odds Ratio Analysis in Which the Subject Driver was at Fault, with Multiple Within-Shift Critical Incidents Removed

Driving-Shift	Driving-Shift	Odds Ratio	LCL	UCL
8	1	1.38	0.82	2.30
8	7	1.96	0.91	4.22
4	1	1.20	0.87	1.66
4	7	1.71	0.89	3.29

Analysis 4.7: Baseline and Control Data, No Within-Shift Incidents

Analysis 4.7 used the control and baseline data and removed all multiple within-shift critical incidents. The resulting dataset is shown in Table 50 and a plot of the critical-incident relative frequencies is shown in Figure 31.

Table 50. Critical Incidents and Total Opportunities by Driving-Shift for Shifts 1 Through 8, for Baseline and Control Conditions, with Multiple Within-Shift Critical Incidents Removed

Driving-Shift	Critical Incidents Per Driving-Shift	Total Opportunities Per Driving-Shift	Rate: Critical Incidents/ Total Opportunities
1	88	2,275	0.039
2	69	1,679	0.041
3	53	1,183	0.045
4	37	788	0.047
5	28	501	0.056
6	12	332	0.036
7	10	254	0.039
8	11	195	0.056

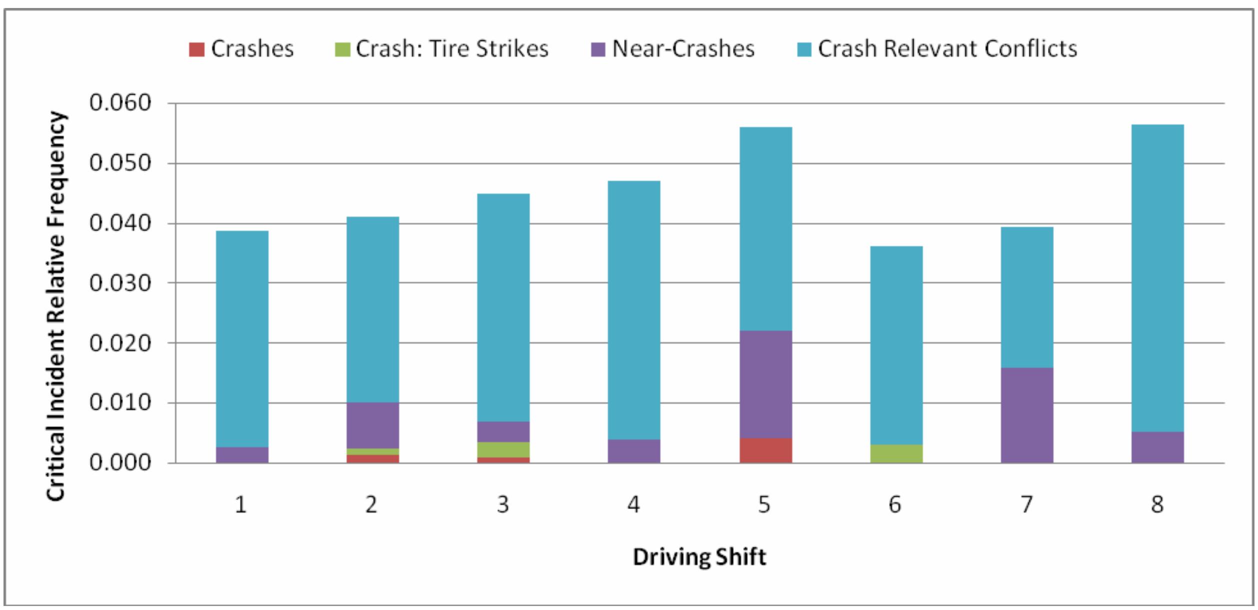

Figure 31. Critical Incident Relative Frequency as a Function of Driving-Shift, for Baseline and Control Conditions, with Multiple Within-Shift Critical Incidents Removed

Odds ratios were analyzed on this dataset and the results are shown in Table 51. None of the shift-by-shift comparisons was significant.

Table 51. Results from the Odds Ratio Analysis for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

Shift	Shift	Odds Ratio	LCL	UCL
8	1	1.49	0.78	2.83
8	2	1.39	0.73	2.68
8	6	1.59	0.69	3.69
5	6	1.58	0.79	3.15
5	1	1.47	0.95	2.28
5	7	1.44	0.69	3.02

Analysis 4.8: Baseline and Control Data, Truck Driver at Fault, No Within-Shift Incidents

Analysis 4.8 analyzed control and baseline data for subject drivers who were judged to have been at fault, with multiple within-shift critical incidents removed. The resulting dataset is shown in Table 52. Figure 32 displays a plot of the critical-incident relative frequencies.

Table 52. Critical Incidents and Total Opportunities by Driving-Shift for Shifts 1 Through 8, in Which the Subject Driver was at Fault, for Baseline and Control Conditions, with Multiple Within-Shift Critical Incidents Removed

Driving-Shift	Critical Incidents Per Driving-Shift	Total Opportunities Per Driving-Shift	Rate: Critical Incidents/ Total Opportunities
1	70	2,275	0.031
2	50	1,679	0.030
3	38	1,183	0.032
4	31	788	0.039
5	17	501	0.034
6	9	332	0.027
7	7	254	0.028
8	9	195	0.046

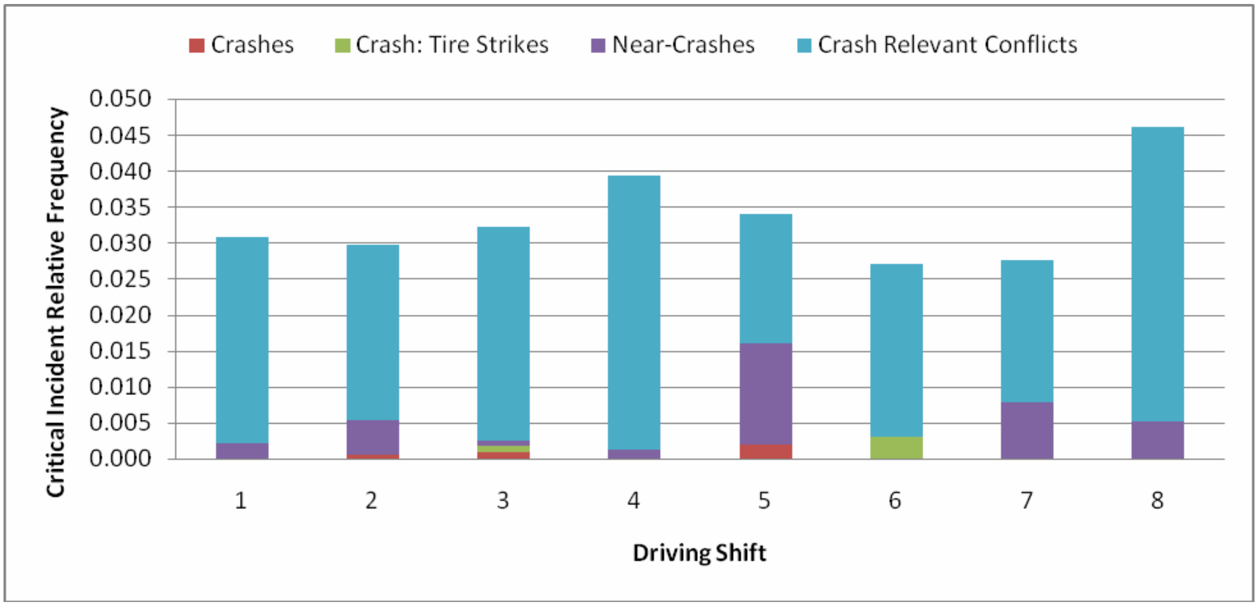

Figure 32. Critical-Incident Relative Frequency as a Function of Driving-Shift, in Which the Subject Driver was at Fault, for Baseline and Control Conditions, with Multiple Within-Shift Critical Incidents Removed

The results from the odds ratio analysis conducted on this dataset are shown in Table 53. There were no statistically significant differences between any of the shifts.

Table 53. Results from the Odds Ratio Analysis in Which the Subject Driver was at Fault, for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

Driving-Shift	Driving-Shift	Odds Ratio	LCL	UCL
8	7	1.71	0.62	4.67
8	1	1.52	0.75	3.10
8	2	1.58	0.76	3.26
4	7	1.44	0.63	3.32
4	1	1.29	0.84	1.98
4	2	1.33	0.85	2.11

To summarize the findings from Analysis 4, there were no results that were consistent across all of the different analyses conducted. When there was a significant finding, it often involved the 5th or 8th driving-shift. However, when multiple critical incidents were accounted for (as in Analyses 4.5 to 4.8), these significant findings were not found (with the exception of Analysis 4.5, which did find significant differences between the 5th driving-shift and the 1st and 7th driving-shifts). Because of the inconsistency of the findings across the different analyses, these results do not seem to provide strong, convincing support for a driving-shift effect.

3.5 CRITICAL INCIDENTS AS A FUNCTION OF TIME-OF-DAY

Each truck in the study was equipped with a Global Positioning System (GPS). The data from the GPS provided not only location information of the truck, but also an accurate time-stamp. Using these data, it was possible to determine the time-of-day that each critical incident occurred.

Since the time-of-day variable did not rely on the driver history software that was used to calculate driving-hour and driving-shift in Analyses 1 through 4, it was possible to use a larger critical-incident dataset for Analysis 5. The reader will note that for previous analyses, as outlined in the Data Caveats section, not all of the data were usable for Analyses 1 through 4, because of an unreliable time history data for five drivers. That being the case, the previous analyses included 819 critical incidents. For Analysis 5, 854 critical incidents were available for the analysis. This was not the entire critical-incident dataset collected in the study; some data could not be used due to unavailability or presumed unreliability of the GPS data. A breakdown of the 854 critical incidents that did have reliable GPS, (and consequently time-stamp) data, was as follows: 10 crashes, 12 tire-strike crashes, 86 near-crashes, and 746 crash-relevant conflicts.

As in Analyses 1, 2, and 4, Analysis 5 conducted separate analyses with eight datasets, parsed in different ways to help ensure that no potentially significant findings were being overlooked. These eight datasets were:

- Analysis 5.1: All Data: This included the entire dataset, with the exception of information outlined in the Data Caveats section. This provided the largest dataset available.
- Analysis 5.2: All Data, Truck Driver at Fault: Using the dataset noted above, this analysis included only those critical incidents that were judged to have been the fault of the subject driver.
- Analysis 5.3: Baseline and Control Data: Only critical incidents that occurred in the control and baseline conditions (where no DDWS was used) were included.
- Analysis 5.4: Baseline and Control Data, Truck Driver at Fault: Using the baseline and control data noted above, this analysis included only critical incidents in which the truck driver was judged to have been at fault.
- Analysis 5.5: All Data, No Within-Hour Incidents: Using the dataset noted in Analysis 5.1, this analysis removed multiple critical incidents that occurred in the same hour, on the same day. This analysis treated critical incidents as a dichotomous random variable (i.e., for each shift there are two possible outcomes—“yes, at least one incident occurred” or “no, an incident did not occur”). As before, for the plots, the critical incident with the less severe classification was removed (e.g., a near-crash would be removed instead of a crash).
- Analysis 5.6: All Data, Truck Driver at Fault, No Within-Hour Incidents: Using the dataset noted in Analysis 4.1, this analysis considered only critical incidents in which the truck driver was at fault and removed multiple within-hour incidents.
- Analysis 5.7: Baseline and Control Data, No Within-Hour Incidents: This analysis used the baseline and control data and removed multiple within-hour incidents.

- Analysis 5.8: Baseline and Control Data, Truck Driver at Fault, No Within-Hour Incidents: Using the baseline and control data, this analysis considered only critical incidents in which the truck driver was at fault and removed muliple within-hour incidents.

The findings from these eight analyses are outlined below.

Analysis 5.1: All Data

Table 54 shows the dataset that included the largest number of critical incidents, and driving opportunities (i.e., trips), broken out as a function of the time-of-day (in one-hour segments). As in previous analyses, the data were normalized and a rate was calculated (critical incidents divided by opportunities). Figure 33 plots the opportunity data that show when drivers were driving, while Figure 34 plots the critical-incident relative frequency for each of the 24 hours. In Figure 34, a breakdown in the frequency for each type of critical incident is indicated: crashes (red), crashes: tire strikes (green), near-crashes (purple), and crash-relevant conflicts (blue). The top of the bar is the total for all critical incident types.

Table 54. Critical Incidents and Total Opportunities by Time-of-Day

Time-of-Day	Critical Incidents Per Time-of-Day	Total Opportunities Per Time-of-Day	Rate: Critical Incidents/ Total Opportunities
0:00–0:59	19	3,396	0.006
1:00–1:59	9	2,866	0.003
2:00–2:59	6	2,577	0.002
3:00–3:59	8	2,479	0.003
4:00–4:59	9	2,532	0.004
5:00–5:59	6	2,625	0.002
6:00–6:59	24	2,714	0.009
7:00–7:59	16	3,045	0.005
8:00–8:59	40	3,765	0.011
9:00–9:59	50	4,457	0.011
10:00–10:59	49	4,879	0.010
11:00–11:59	62	5,157	0.012
12:00–12:59	70	5,291	0.013
13:00–13:59	58	5,469	0.011
14:00–14:59	83	5,422	0.015
15:00–15:59	64	5,376	0.012
16:00–16:59	71	5,303	0.013
17:00–17:59	54	5,120	0.011
18:00–18:59	38	4,860	0.008
19:00–19:59	36	4,702	0.008
20:00–20:59	30	4,704	0.006
21:00–21:59	25	4,621	0.005
22:00–22:59	15	4,487	0.003
23:00–23:50	12	3,968	0.003

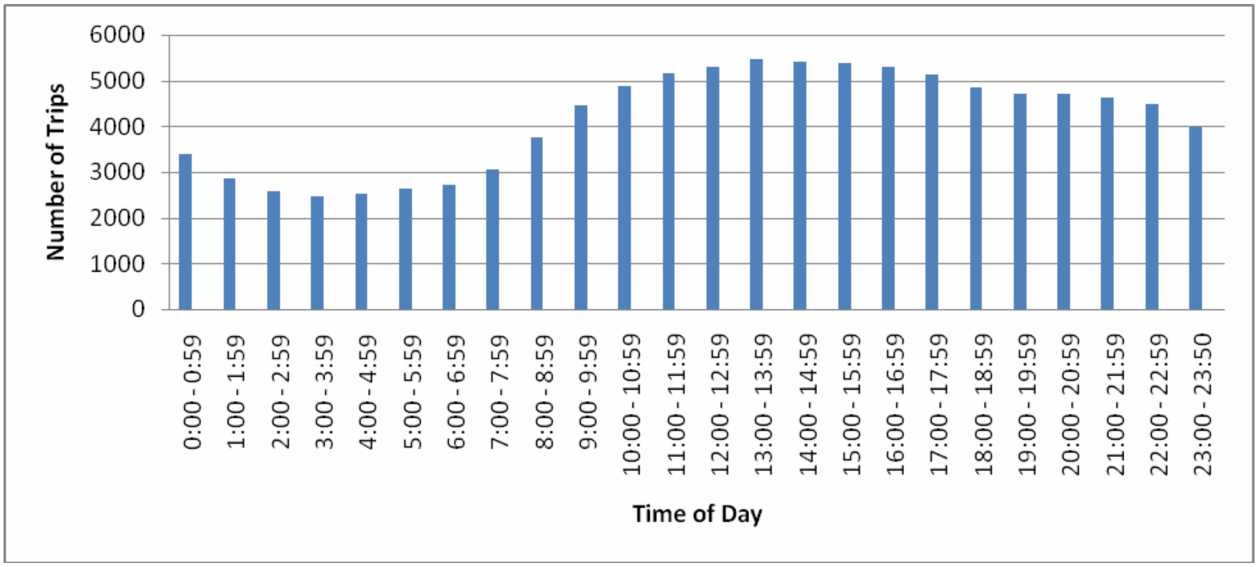

Figure 33. Number of Trips as a Function of Time-of-Day

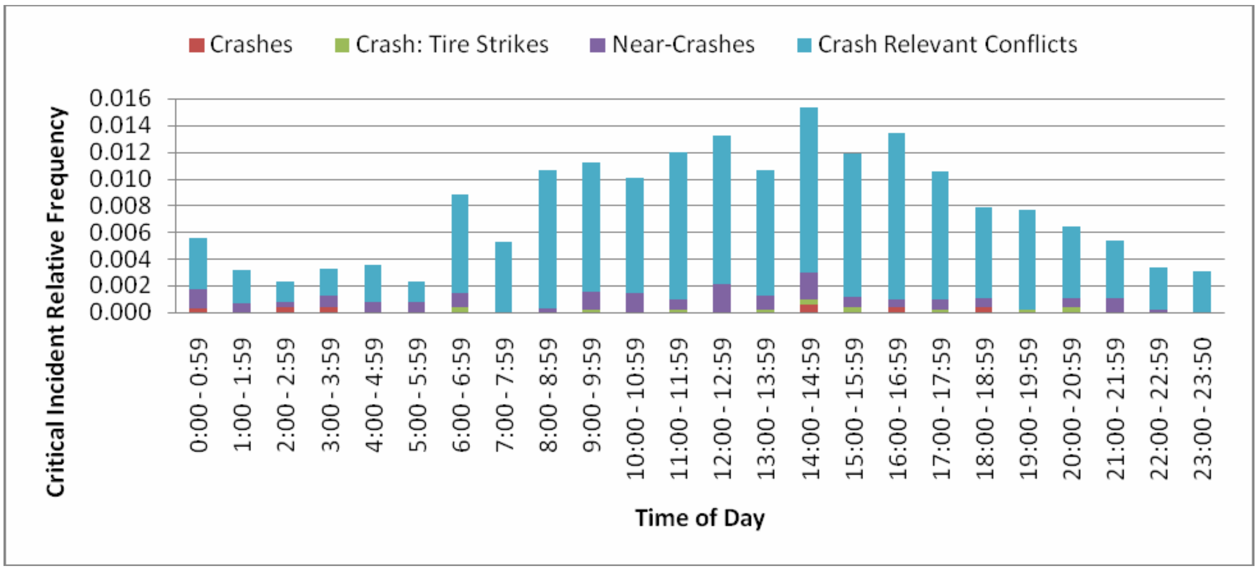

Figure 34. Critical-Incident Relative Frequency as a Function of Time-of-Day

Table 55 shows the results from the odds ratio analyses. The first two columns in Table 55 show the comparison hours (e.g., the first row compares 2:00 to 2:59 p.m. and midnight to 12:59 a.m.), while the third column shows the calculated odds ratio and the last two columns show the lower and upper confidence limits, respectively. As a reminder, odds ratios with LCLs and UCLs that contain "1" are not statistically significant (again, a 95 percent confidence level was used in these calculations). As before, all significant effects are included in the odds ratio tables along with selected other analyses that were not significant.

Table 55. Results from the Odds Ratio Analyses

Hour	Hour	Odds Ratio	LCL	UCL
14:00–14:59	0:00–0:59	2.76	1.68	4.56
14:00–14:59	1:00–1:59	4.93	2.48	9.83
14:00–14:59	2:00–2:59	6.66	2.90	15.28
14:00–14:59	3:00–3:59	4.80	2.32	9.94
14:00–14:59	4:00–4:59	4.36	2.19	8.68
14:00–14:59	5:00–5:59	6.79	2.96	15.56
14:00–14:59	6:00–6:59	1.74	1.10	2.75
14:00–14:59	7:00–7:59	2.94	1.72	5.04
14:00–14:59	8:00–8:59	1.45	0.99	2.12
14:00–14:59	9:00–9:59	1.37	0.96	1.95
14:00–14:59	10:00–10:59	1.53	1.07	2.19
14:00–14:59	11:00–11:59	1.28	0.92	1.78
14:00–14:59	12:00–12:59	1.16	0.84	1.60
14:00–14:59	13:00–13:59	1.45	1.03	2.03
14:00–14:59	15:00–15:59	1.29	0.93	1.79
14:00–14:59	16:00–16:59	1.15	0.83	1.58
14:00–14:59	17:00–17:59	1.46	1.03	2.06
14:00–14:59	18:00–18:59	1.97	1.34	2.90
14:00–14:59	19:00–19:59	2.01	1.36	2.99
14:00–14:59	20:00–20:59	2.42	1.59	3.68
14:00–14:59	21:00–21:59	2.86	1.82	4.48
14:00–14:59	22:00–22:59	4.63	2.67	8.04
14:00–14:59	23:00–23:50	5.12	2.79	9.40
8:00–8:59	0:00–0:59	1.91	1.10	3.30
8:00–8:59	1:00–1:59	3.41	1.65	7.04
8:00–8:59	2:00–2:59	4.60	1.95	10.87
8:00–8:59	3:00–3:59	3.32	1.55	7.10
8:00–8:59	4:00–4:59	3.01	1.46	6.21
8:00–8:59	5:00–5:59	4.69	1.98	11.07
8:00–8:59	7:00–7:59	2.03	1.14	3.64
8:00–8:59	20:00–20:59	1.67	1.04	2.69
8:00–8:59	21:00–21:59	1.97	1.20	3.26
8:00–8:59	22:00–22:59	3.20	1.77	5.80
8:00–8:59	23:00–23:50	3.54	1.85	6.76
9:00–9:59	0:00–0:59	2.02	1.19	3.43
9:00–9:59	1:00–1:59	3.60	1.77	7.33
9:00–9:59	2:00–2:59	4.86	2.08	11.35
9:00–9:59	3:00–3:59	3.50	1.66	7.40
9:00–9:59	4:00–4:59	3.18	1.56	6.48
9:00–9:59	5:00–5:59	4.95	2.12	11.57
9:00–9:59	7:00–7:59	2.15	1.22	3.78
9:00–9:59	20:00–20:59	1.77	1.12	2.78

Hour	Hour	Odds Ratio	LCL	UCL
9:00–9:59	21:00–21:59	2.09	1.29	3.38
9:00–9:59	22:00–22:59	3.38	1.90	6.03
9:00–9:59	23:00–23:50	3.74	1.99	7.03
11:00–11:59	18:00–18:59	1.54	1.03	2.32
11:00–11:59	19:00–19:59	1.58	1.04	2.38
11:00–11:59	6:00–6:59	1.36	0.85	2.19
12:00–12:59	6:00–6:59	1.50	0.94	2.39

At first glance, the data plotted in Figure 34 and the results from the odds ratios do not seem to indicate any clear pattern; however, there is obviously a strong time-of-day effect. Note that both a frequency-odds-ratio approach and a logistic regression modeling approach were used and similar results were found using both approaches.

In an attempt to interpret what might be going on, two follow-up analyses were conducted. The first analysis considered "circadian rhythm," which refers to the human body's natural tendency to be alert or drowsy at different points within the 24-hour cycle (Figure 35). This follow-up analysis compared the circadian low periods (2 a.m. to 5 a.m. and 3 p.m. to 5 p.m.; Missoula Technology and Development Center, n.d.) with the approximate circadian high periods (9 a.m. to 11 a.m. and 8 p.m. to 9 p.m.), as estimated from Figure 36.

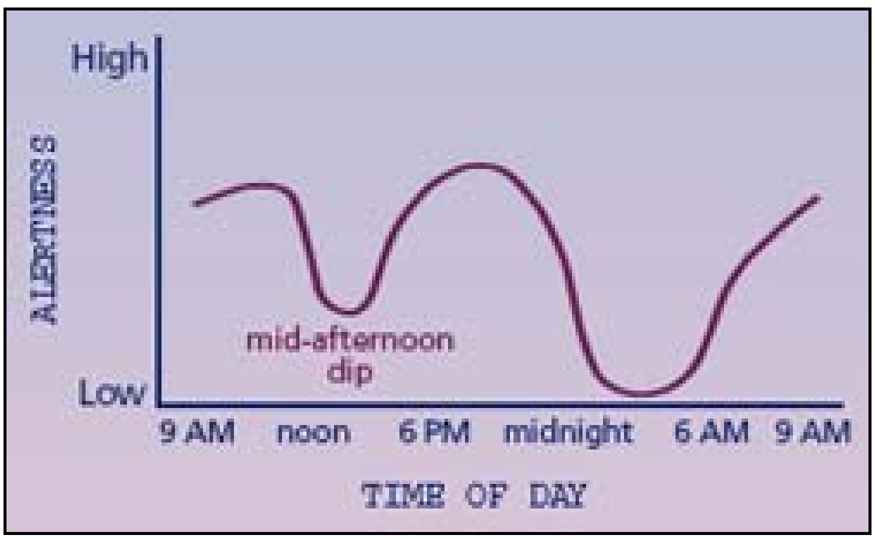

Figure 35. Circadian Rhythm Showing Alertness as a Function of Time-of-Day

Using these circadian low and high periods, the relevant hours were combined. Figure 36 shows a plot of the critical-incident relative frequencies for each circadian low and high period. If circadian rhythm effects were significant, the plots would show significantly higher relative frequencies for the low periods and vice versa for the high periods. However, this was not the case and as a result, it does not appear that circadian rhythm effects had a meaningful impact on the critical-incident relative frequencies.

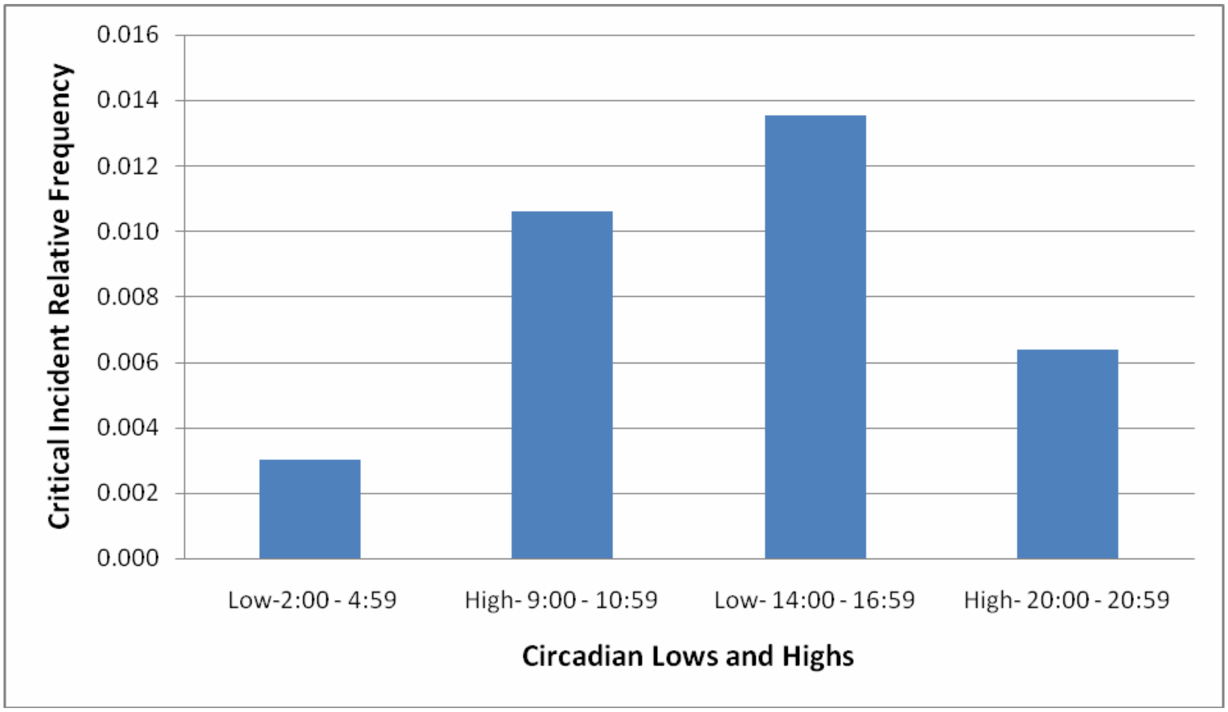

Figure 36. Critical-Incident Relative Frequencies for the Circadian Lows (2 a.m. to 5 a.m., 3 p.m. to 5 p.m.) and Highs (9 a.m. to 11 a.m. and 8 p.m. to 9 p.m.)

A second follow-up analysis considered traffic density as a function of driving-hour. Traffic-density data were plotted against the hour-by-hour critical-incident relative frequency plots shown in Figure 37. Please note that the traffic-density overlay in Figure 37 is based on visual inspection of plots found in Festin (1996).

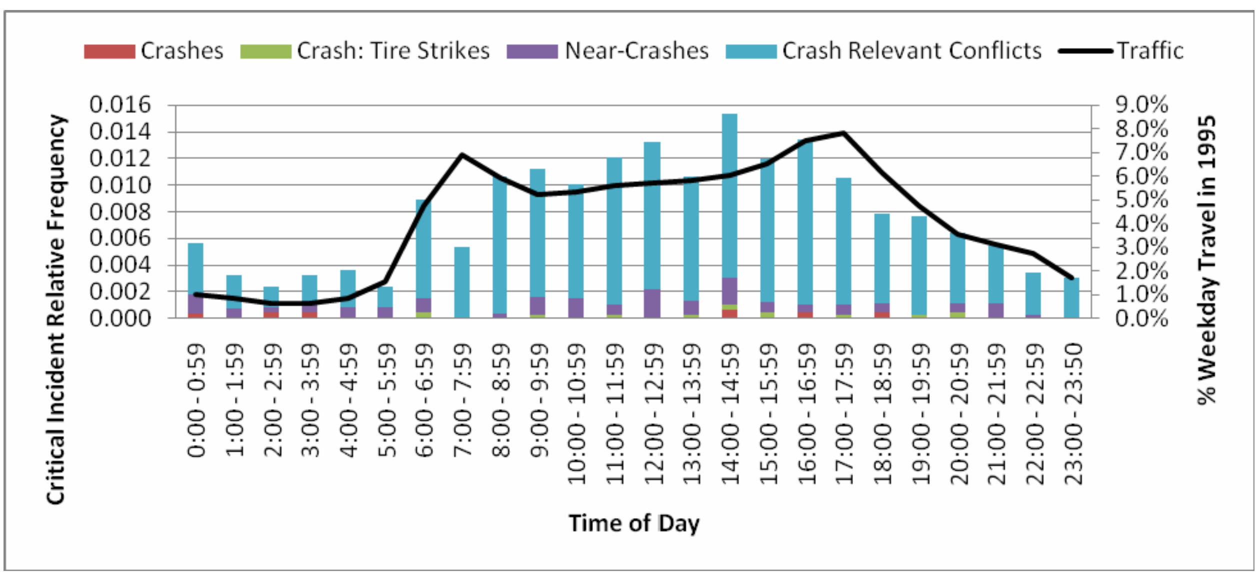

Figure 37. Critical-Incident Relative Frequency as a Function of Time-of-Day, with Traffic-Density Plot Superimposed

The black line in Figure 37 displays the U.S. distribution of daily weekday traffic across each hour of the day in 1995 (Festin, 1996). Festin (1996) used two primary data sources, highway statistics for annual vehicle miles traveled (VMT), and 5,000 automatic traffic recorder sites across the United States, to estimate annual travel trends in the United States. Please note that these traffic data represent national weekday averages and are not location-specific. The distribution is likely to change based on region, setting (i.e., urban vs. rural), and day of week (i.e., weekday vs. weekend). Nonetheless, the traffic-density plot follows the critical-incident relative frequency plot, particularly with regard to the sharp onset (around 6 a.m.) and slow decline after what presumably would be the evening rush period. As such, it is hypothesized that the hour-by-hour differences observed in the current study may be primarily a function of traffic density (i.e., increased exposure to other vehicles leading to increased critical incidents). To investigate this hypothesis further, a Pearson correlation coefficient was calculated between the daily weekday traffic across each hour of the day and the relative frequency of safety-critical events across each hour of the day. As suggested by the plotted data, the results showed a strong positive linear relationship between the two variables with a correlation (r) of 0.83. With an R^2 of 0.69, there is a strong linear relationship between these two variables (i.e., both increase and decrease with a similar pattern).

Analysis 5.2: All Data, Truck Driver at Fault

Analysis 5.2 included only critical incidents in which the subject-vehicle driver (i.e., the study truck driver) was judged, based on video review, to have been at fault. The resulting dataset is shown in Table 56 below and plotted in Figure 38.

Table 56. Critical Incidents and Total Opportunities by Time-of-Day In Which the Subject Driver was at Fault

Time-of-Day	Critical Incidents Per Time-of-Day	Total Opportunities Per Time-of-Day	Rate: Critical Incidents/ Total Opportunities
0:00–0:59	12	3,396	0.004
1:00–1:59	6	2,866	0.002
2:00–2:59	2	2,577	0.001
3:00–3:59	3	2,479	0.001
4:00–4:59	7	2,532	0.003
5:00–5:59	4	2,625	0.002
6:00–6:59	18	2,714	0.007
7:00–7:59	13	3,045	0.004
8:00–8:59	33	3,765	0.009
9:00–9:59	34	4,457	0.008
10:00–10:59	41	4,879	0.008
11:00–11:59	51	5,157	0.010
12:00–12:59	55	5,291	0.010
13:00–13:59	41	5,469	0.007
14:00–14:59	57	5,422	0.011
15:00–15:59	47	5,376	0.009
16:00–16:59	53	5,303	0.010
17:00–17:59	41	5,120	0.008
18:00–18:59	31	4,860	0.006
19:00–19:59	31	4,702	0.007

Time-of-Day	Critical Incidents Per Time-of-Day	Total Opportunities Per Time-of-Day	Rate: Critical Incidents/ Total Opportunities
20:00–20:59	25	4,704	0.005
21:00–21:59	13	4,621	0.003
22:00–22:59	9	4,487	0.002
23:00–23:50	12	3,968	0.003

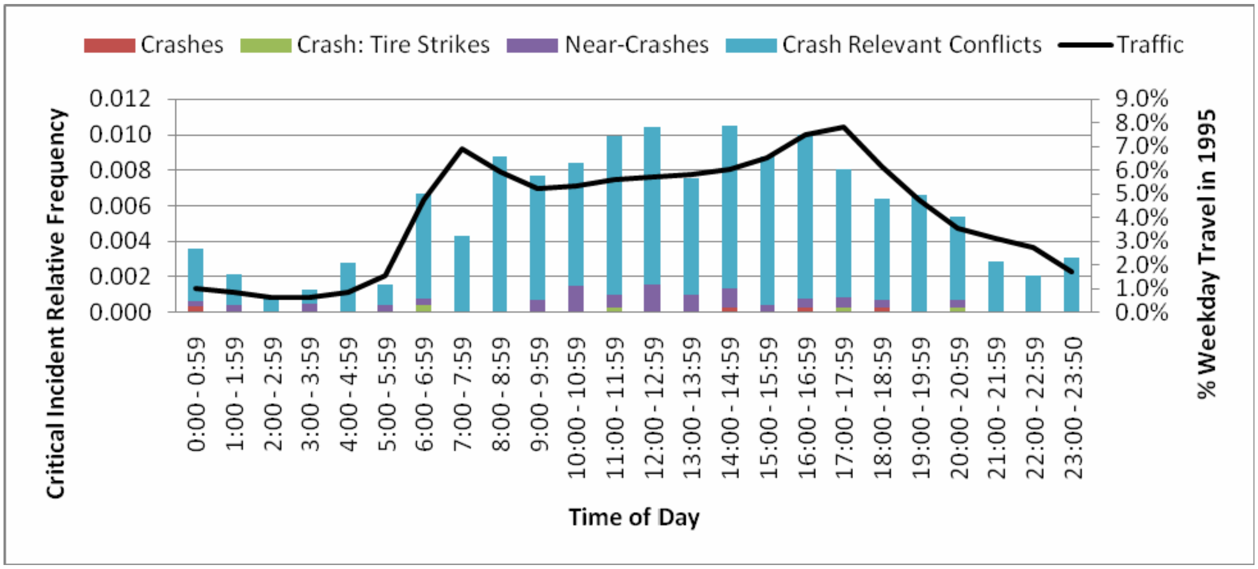

Figure 38. Critical-Incident Relative Frequency as a Function of Time-of-Day in Which the Subject Driver was at Fault

Analysis 5.3: Baseline and Control Data

Analysis 5.3 used only the data from the "control" and "baseline" conditions from the study (i.e., data collected where no DDWS was used). The resulting dataset is shown in Table 57. Figure 39 plots the critical-incident relative frequency across the driving-hours for the baseline and control conditions and the national traffic-density data described earlier are overlaid.

Table 57. Critical Incidents and Total Opportunities by Time-of-Day for Baseline and Control Conditions

Time-of-Day	Critical Incidents Per Time-of-Day	Total Opportunities Per Time-of-Day	Rate: Critical Incidents/ Total Opportunities
0:00–0:59	9	1,419	0.006
1:00–1:59	4	1,146	0.003
2:00–2:59	3	998	0.003
3:00–3:59	0	971	0.000
4:00–4:59	3	1,028	0.003
5:00–5:59	4	1,125	0.004
6:00–6:59	10	1,141	0.009
7:00–7:59	7	1,275	0.005
8:00–8:59	14	1,624	0.009

Time-of-Day	Critical Incidents Per Time-of-Day	Total Opportunities Per Time-of-Day	Rate: Critical Incidents/ Total Opportunities
9:00–9:59	20	1,933	0.010
10:00–10:59	23	2,188	0.011
11:00–11:59	33	2,311	0.014
12:00–12:59	32	2,357	0.014
13:00–13:59	26	2,470	0.011
14:00–14:59	37	2,478	0.015
15:00–15:59	32	2,421	0.013
16:00–16:59	33	2,385	0.014
17:00–17:59	24	2,293	0.010
18:00–18:59	18	2,191	0.008
19:00–19:59	15	2,096	0.007
20:00–20:59	11	2,111	0.005
21:00–21:59	12	2,068	0.006
22:00–22:59	8	1,917	0.004
23:00–23:50	1	1,643	0.001

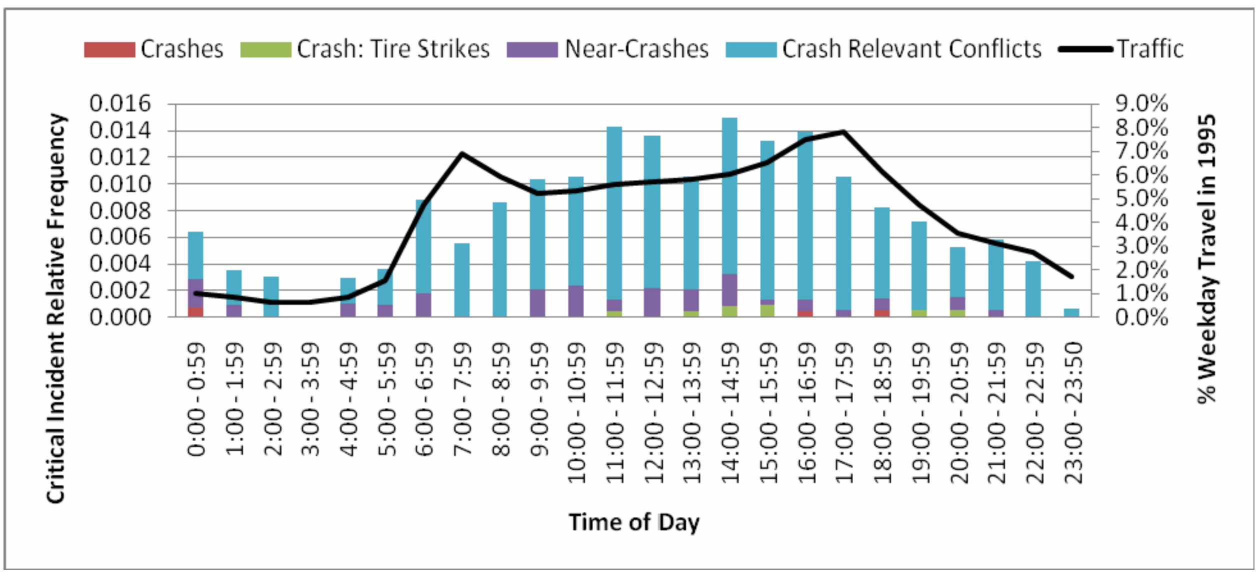

Figure 39. Critical-Incident Relative Frequency as a Function of Time-of-Day for Baseline and Control Conditions

Analysis 5.4: Baseline and Control Data, Truck Driver at Fault

Analysis 5.4 used only the data from the control and baseline conditions in which the subject driver was judged at fault. Table 58 displays the dataset used and Figure 40 plots the critical-incident relative frequency across driving-hours. Again, a traffic-density-by-hour function is overlaid on the critical-incident relative frequency data.

Table 58. Critical Incidents and Total Opportunities by Time-of-Day, In Which the Subject Driver was at Fault, for Baseline and Control Conditions

Time-of-Day	Critical Incidents Per Time-of-Day	Total Opportunities Per Time-of-Day	Rate: Critical Incidents/ Total Opportunities
0:00–0:59	5	1,419	0.004
1:00–1:59	1	1,146	0.001
2:00–2:59	1	998	0.001
3:00–3:59	0	971	0.000
4:00–4:59	2	1,028	0.002
5:00–5:59	2	1,125	0.002
6:00–6:59	7	1,141	0.006
7:00–7:59	5	1,275	0.004
8:00–8:59	11	1,624	0.007
9:00–9:59	13	1,933	0.007
10:00–10:59	20	2,188	0.009
11:00–11:59	28	2,311	0.012
12:00–12:59	25	2,357	0.011
13:00–13:59	19	2,470	0.008
14:00–14:59	24	2,478	0.010
15:00–15:59	26	2,421	0.011
16:00–16:59	25	2,385	0.010
17:00–17:59	21	2,293	0.009
18:00–18:59	15	2,191	0.007
19:00–19:59	12	2,096	0.006
20:00–20:59	8	2,111	0.004
21:00–21:59	6	2,068	0.003
22:00–22:59	5	1,917	0.003
23:00–23:50	1	1,643	0.001

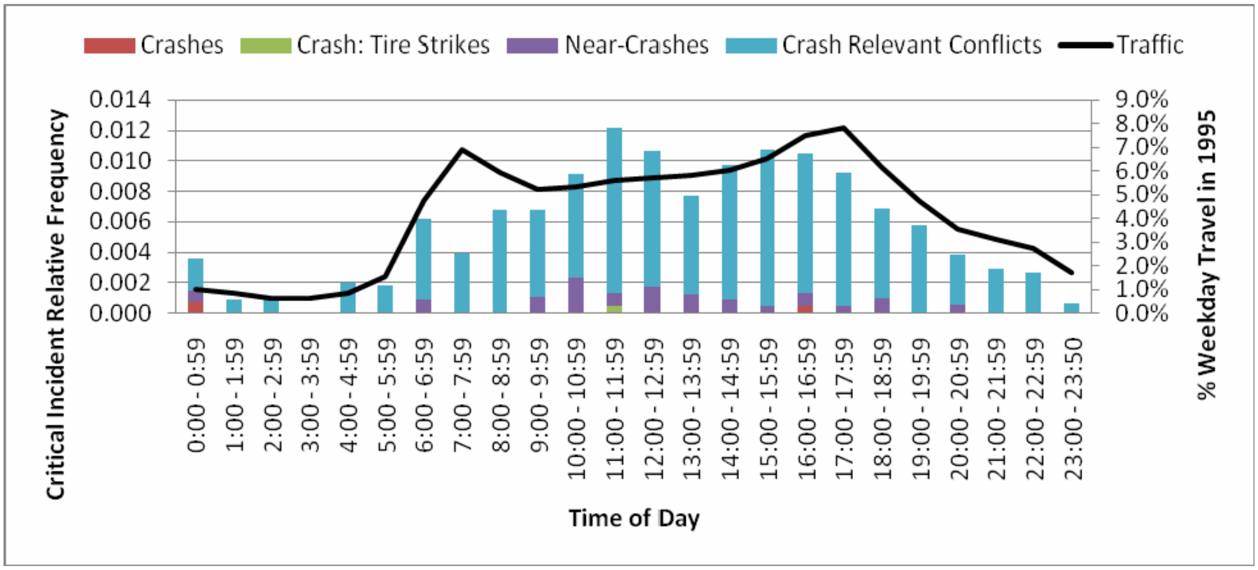

Figure 40. Critical-Incident Relative Frequency as a Function of Time-of-Day, in Which the Subject Driver was at Fault, for Baseline and Control Conditions

Analysis 5.5: All Data, No Within-Hour Incidents

Analysis 5.5 removed multiple within-hour critical incidents such that a dichotomous variable was created (either “yes, at least one critical incident occurred” or “no critical incident occurred”). Table 59 displays the resulting dataset and Figure 41 plots the critical-incident relative frequencies for each hour of the day.

Table 59. Critical Incidents and Total Opportunities by Time-of-Day, with Multiple Within-Hour Critical Incidents Removed

Time-of-Day	Critical Incidents Per Time-of-Day	Total Opportunities Per Time-of-Day	Rate: Critical Incidents/ Total Opportunities
0:00–0:59	18	3,396	0.005
1:00–1:59	7	2,866	0.002
2:00–2:59	6	2,577	0.002
3:00–3:59	8	2,479	0.003
4:00–4:59	9	2,532	0.004
5:00–5:59	6	2,625	0.002
6:00–6:59	23	2,714	0.008
7:00–7:59	16	3,045	0.005
8:00–8:59	37	3,765	0.010
9:00–9:59	48	4,457	0.011
10:00–10:59	45	4,879	0.009
11:00–11:59	57	5,157	0.011
12:00–12:59	65	5,291	0.012
13:00–13:59	55	5,469	0.010
14:00–14:59	76	5,422	0.014
15:00–15:59	57	5,376	0.011
16:00–16:59	64	5,303	0.012

Time-of-Day	Critical Incidents Per Time-of-Day	Total Opportunities Per Time-of-Day	Rate: Critical Incidents/ Total Opportunities
17:00–17:59	49	5,120	0.010
18:00–18:59	33	4,860	0.007
19:00–19:59	33	4,702	0.007
20:00–20:59	29	4,704	0.006
21:00–21:59	25	4,621	0.005
22:00–22:59	14	4,487	0.003
23:00–23:50	11	3,968	0.003

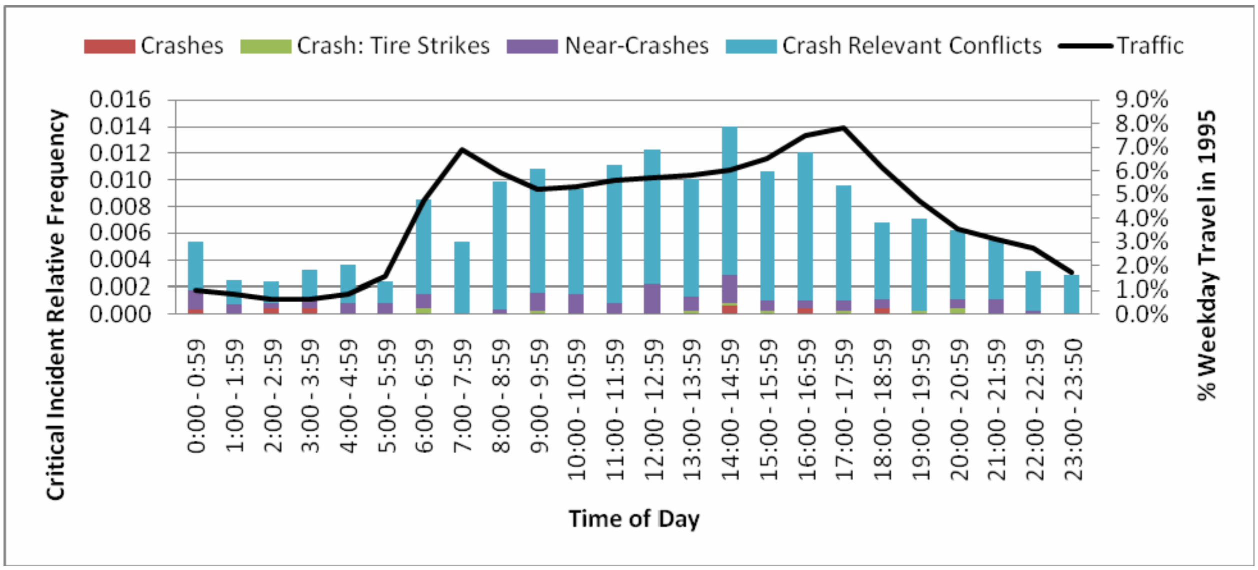

Figure 41. Critical-Incident Relative Frequency as a Function of Time-of-Day, with Multiple Within-Hour Critical Incidents Removed

Analysis 5.6: All Data, Truck Driver at Fault, No Within-Hour Incidents

Analysis 5.6 included critical incidents in which the subject driver was judged to have been at fault and multiple critical incidents that occurred within the same hour of the day were removed. The resulting dataset is shown in Table 60 and the plot of the relative frequency of critical incidents is shown in Figure 42.

Table 60. Critical Incidents and Total Opportunities by Time-of-Day, in Which the Subject Driver Was at Fault, with Multiple Within-Hour Critical Incidents Removed

Time-of-Day	Critical Incidents Per Time-of-Day	Total Opportunities Per Time-of-Day	Rate: Critical Incidents/ Total Opportunities
0:00–0:59	11	3,396	0.003
1:00–1:59	4	2,866	0.001
2:00–2:59	2	2,577	0.001
3:00–3:59	3	2,479	0.001
4:00–4:59	7	2,532	0.003
5:00–5:59	4	2,625	0.002
6:00–6:59	17	2,714	0.006
7:00–7:59	13	3,045	0.004
8:00–8:59	30	3,765	0.008
9:00–9:59	31	4,457	0.007
10:00–10:59	38	4,879	0.008
11:00–11:59	48	5,157	0.009
12:00–12:59	51	5,291	0.010
13:00–13:59	40	5,469	0.007
14:00–14:59	54	5,422	0.010
15:00–15:59	41	5,376	0.008
16:00–16:59	50	5,303	0.009
17:00–17:59	37	5,120	0.007
18:00–18:59	26	4,860	0.005
19:00–19:59	29	4,702	0.006
20:00–20:59	24	4,704	0.005
21:00–21:59	13	4,621	0.003
22:00–22:59	8	4,487	0.002
23:00–23:50	11	3,968	0.003

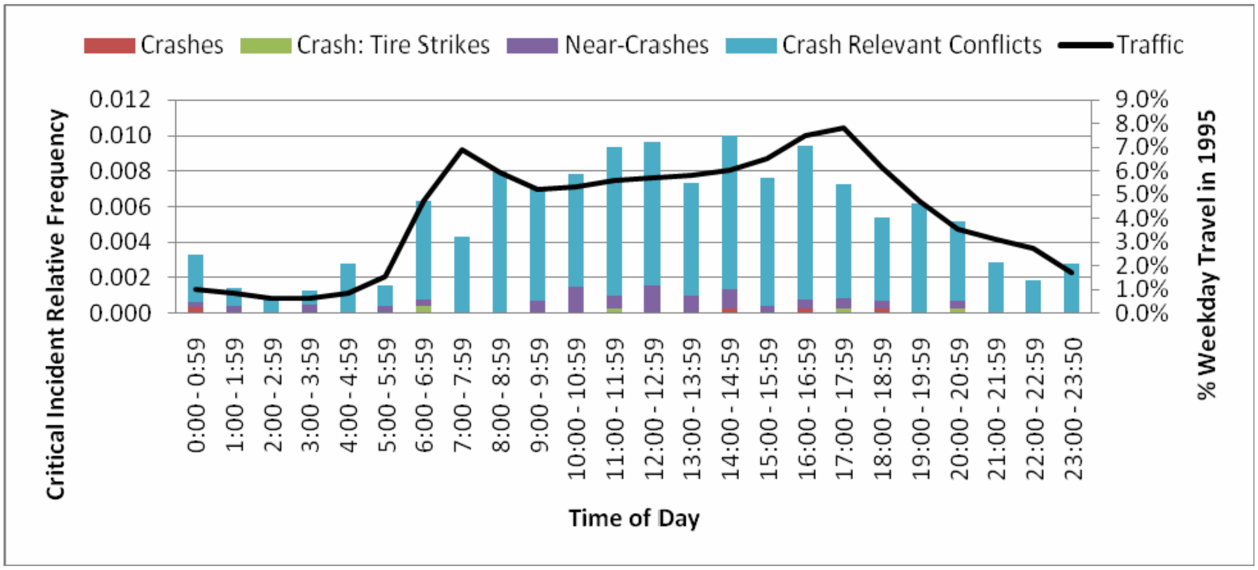

Figure 42. Critical-Incident Relative Frequency as a Function of Time-of-Day, in Which the Subject Driver was at Fault, with Multiple Within-Hour Critical Incidents Removed

Analysis 5.7: Baseline and Control Data, No Within-Hour Incidents

Analysis 5.7 used the control and baseline data and removed all multiple within-hour critical incidents. The resulting dataset is shown in Table 61 and a plot of the critical-incident relative frequencies is shown in Figure 43.

Table 61. Critical Incidents and Total Opportunities by Time-of-Day, for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

Time-of-Day	Critical Incidents Per Time-of-Day	Total Opportunities Per Time-of-Day	Rate: Critical Incidents/ Total Opportunities
0:00–0:59	8	1,419	0.006
1:00–1:59	4	1,146	0.003
2:00–2:59	3	998	0.003
3:00–3:59	0	971	0.000
4:00–4:59	3	1,028	0.003
5:00–5:59	4	1,125	0.004
6:00–6:59	9	1,141	0.008
7:00–7:59	7	1,275	0.005
8:00–8:59	12	1,624	0.007
9:00–9:59	20	1,933	0.010
10:00–10:59	20	2,188	0.009
11:00–11:59	30	2,311	0.013
12:00–12:59	27	2,357	0.011
13:00–13:59	24	2,470	0.010
14:00–14:59	33	2,478	0.013
15:00–15:59	27	2,421	0.011

Time-of-Day	Critical Incidents Per Time-of-Day	Total Opportunities Per Time-of-Day	Rate: Critical Incidents/ Total Opportunities
16:00–16:59	30	2,385	0.013
17:00–17:59	20	2,293	0.009
18:00–18:59	16	2,191	0.007
19:00–19:59	13	2,096	0.006
20:00–20:59	10	2,111	0.005
21:00–21:59	12	2,068	0.006
22:00–22:59	7	1,917	0.004
23:00–23:50	1	1,643	0.001

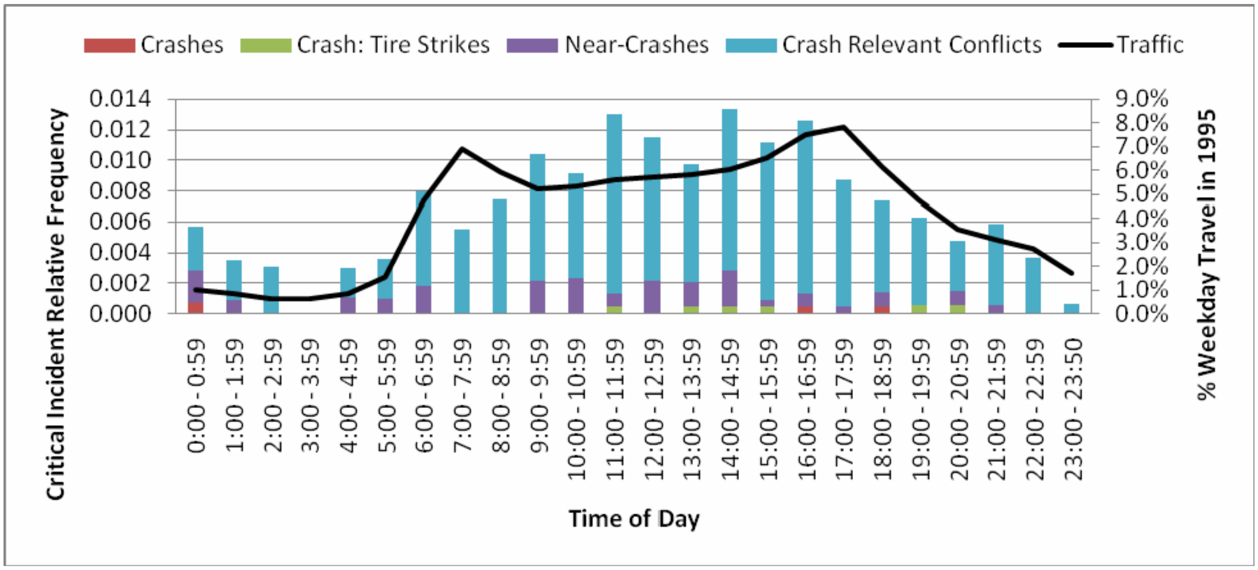

Figure 43. Critical-Incident Relative Frequency as a Function of Time-of-Day for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

Analysis 5.8: Baseline and Control Data, Truck Driver at Fault, No Within-Hour Incidents

Analysis 5.8 analyzed control and baseline data for subject drivers who were judged to have been at fault, with multiple within-hour critical incidents removed. The resulting dataset is shown in Table 62, while Figure 44 displays a plot of the critical-incident relative frequencies with traffic density overlaid.

Table 62. Critical Incidents and Total Opportunities by Time-of-Day, in Which the Subject Driver Was at Fault, for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

Time-of-Day	Critical Incidents Per Time-of-Day	Total Opportunities Per Time-of-Day	Rate: Critical Incidents/ Total Opportunities
0:00–0:59	4	1,419	0.003
1:0–1:59	1	1,146	0.001
2:00–2:59	1	998	0.001
3:00–3:59	0	971	0.000
4:00–4:59	2	1,028	0.002
5:00–5:59	2	1,125	0.002
6:00–6:59	6	1,141	0.005
7:00–7:59	5	1,275	0.004
8:00–8:59	9	1,624	0.006
9:00–9:59	13	1,933	0.007
10:00–10:59	17	2,188	0.008
11:00–11:59	26	2,311	0.011
12:00–12:59	21	2,357	0.009
13:00–13:59	18	2,470	0.007
14:00–14:59	23	2,478	0.009
15:00–15:59	22	2,421	0.009
16:00–16:59	24	2,385	0.010
17:00–17:59	18	2,293	0.008
18:00–18:59	13	2,191	0.006
19:00–19:59	11	2,096	0.005
20:00–20:59	7	2,111	0.003
21:00–21:59	6	2,068	0.003
22:00–22:59	4	1,917	0.002
23:00–23:50	1	1,643	0.001

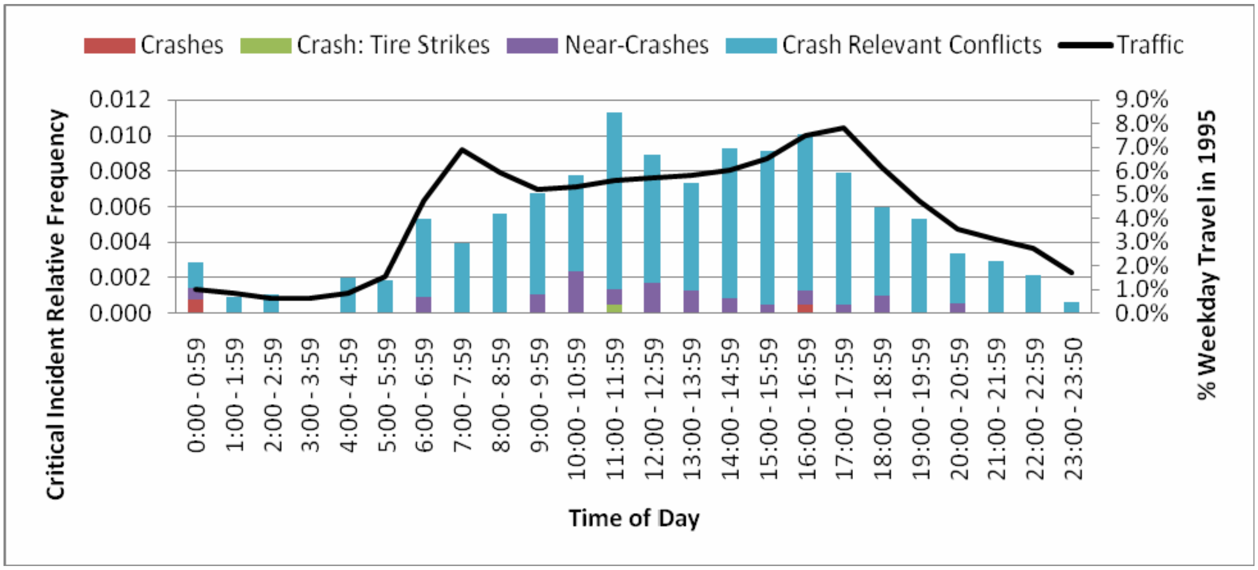

Figure 44. Critical-Incident Relative Frequency as a Function of Time-of-Day, in Which the Subject Driver was at Fault, for Baseline and Control Conditions, with Multiple Within-Hour Critical Incidents Removed

To summarize the findings from Analysis 5: There was a strong effect of critical-incident occurrence as a function of time-of-day. In suggesting *why* this may be the case, an hour-by-hour plot of traffic density seems to follow a similar pattern. Keep in mind that the current study was not designed to look specifically for traffic density, and therefore, available national data were used. However, based on the similarity of the functions, it is hypothesized that hour-by-hour fluctuations in critical-incident relative frequency can be explained by comparable fluctuations in traffic density on an hour-by-hour basis. This hypothesis makes intuitive sense in that, as the number of vehicles increases, so does the chance of being involved in a multi-vehicle incident.

4. CONCLUSIONS

This study has resulted in a major finding that is relevant to the assessment of the 2003 HOS regulations. Specifically, the results from the analysis on critical incident relative frequency, used as a surrogate for driver performance decrement, generally showed no statistical difference between the 2nd through 11th driving-hours (for almost all analyses); and the statistical difference between the 1st driving-hour and the 11th driving-hour lies in the direction opposite to what would be expected, had there been a time-on-task effect. That is, the results from this study do not support the hypothesis that there is an increased risk resulting from CMV drivers driving in the 11th driving-hour as compared to the 10th driving-hour, or any hour, although caution must be used in interpreting these results, due to the small sample of drivers represented in the study as compared to the larger CMV driver population. That is, although a dataset of over 2 million VMT collected from 98 drivers driving 46 instrumented trucks is the largest known continuously collected naturalistic dataset available, it captures only a small segment of the approximately 3 million current Commercial Driver's License holders (ATRI, 2007), the 8.5 million registered vehicles, and the 222 billion miles driven each year (FMCSA, 2007a). Nonetheless, these are perhaps the best data available to investigate this important safety question.

These results from this research are consistent with Wylie et al. (1996) with regard to time-on-task being a poor predictor of crashes and safety-related traffic events. In fact, a significant spike in the rate of critical incidents was found during the 1st driving-hour. These results are not consistent with the contention that crash risk increases as hours of driving increase (see Kaneko and Jovanis, 1992; Lin, Jovanis, and Yang, 1993; Park et al., 2005). This spike was found across all possible trips and only those trips on which the truck driver drove into the 11th driving-hour. The latter statement is noteworthy because it suggests that even in those trips on which the driver drove into the 11th driving-hour, the critical-incident relative frequency was highest in the 1st driving-hour (significantly more than in driving-hours 2 though 11 for almost all analyses).

A cursory examination of FMCSA's LTCCS database shows a finding similar to the current study. When looking at truck crashes by hours driving—that is, across all hours—we see that most crashes occurred in the 1st driving-hour (FMCSA, 2007b). More specifically, findings from the LTCCS database indicate the 1st driving-hour is associated with the highest raw percentage of crashes (14.7 percent). Note that exposure (opportunities) was not accounted for, per se, in the LTCCS dataset. However, the current study, which does account for exposure, found a similar spike in critical-incident relative frequency during the 1st driving-hour.

There are at least three possible explanations for the significant spike in the critical-incident relative frequency found in the 1st driving-hour. The first reason may be *sleep inertia*. Sleep inertia refers to the decrease or impairment of alertness and performance immediately upon waking from sleep. Sleep inertia refers to impairment in a variety of performance tasks, including short-term memory, vigilance, cognitive functioning, reaction time, and ability to resist sleep (Bonnet and Arand, 1995; Dinges, 1990; Mullington and Broughton, 1994). Dinges (1990) suggested sleep inertia can endure for up to 15 min after waking. However, more recent studies by Bruck and Pisani (1999) and Jewett et al. (1999) indicate, respectively, that the effects of sleep inertia may last for 30 min or 60 min after waking. Obviously, personnel who are expected to perform work duties immediately on awaking, such as over-the-road drivers who sleep in sleeper berths in their trucks, may be most affected by sleep inertia. Moreover, sleep deprivation can compound the effects of sleep inertia. Wertz et al. (2006) found the effects of sleep inertia were detectable for at least 2 h after waking when subjects were sleep-deprived. While Hanowski et al. (2005) found that drivers were getting more sleep under the 2003 HOS regulations (6.28 h vs. 5.18 h each night), the amount of sleep they were getting was still below the 7 to 9 h recommended by the National Sleep Foundation for healthy adults (NSF, 2007).

Another possible reason for the spike found in the 1st driving-hour could be related to road type and/or traffic density. Drivers may start their trips on local and other undivided roads with higher traffic densities (as compared to what they might find on the open road). Similarly, for line-haul operations specifically, drivers may end their trips on local and other undivided roads, again experiencing higher traffic density than might occur on a highway. These can be conceived as "take-off" and "landing" effects. Hickman et al. (2005), using the same dataset as Hanowski et al. (2005), found that drivers were almost five times as likely to be involved in a critical incident on an undivided highway as on a divided highway. Additionally, the results from Analysis 5 in the current study on time-of-day indicated a potential explanation for the time-of-day effects as attributable to traffic density. These results suggest a possible "take-off" and "landing" effect. While the spike in the 1st driving-hour reflects a constant "take-off" effect across all trips (regardless of trip length), the "landing" effect would be indistinguishable, as it would be distributed across different trip lengths. This hypothesis is supported when we look at the critical-incident relative frequency across all trip lengths. However, the study was not set up to have drivers ending at a set time or being at a set destination after, say, 10 or 11 driving-hours. For the line-haul operators, who represented approximately 24 percent of the drivers in the study, this was indeed the case. However, for the other 76 percent of the drivers, who were typically out on the road for a week at a time, there was no known consistent set destination at the end of a shift. Under these circumstances, it was difficult to investigate the hypothesis of "landing" effects with the current dataset. Future research is needed, using a methodology that would facilitate further investigation of this hypothesis.

The third possible explanation for the spike found in the 1st driving-hour could reflect time-of-day effects. The current study found a strong time-of-day effect, but it seemed that these effects were related to traffic density. Wylie et al. (1996) indicated time-of-day effects to be the strongest and most consistent factor influencing driver fatigue. The current analysis did not focus on driver fatigue events specifically, so the impact of time-of-day on driver fatigue is unknown with respect to the dataset used for this analysis effort. An analysis was conducted looking at all critical incidents that occurred in the circadian low and high periods (presumably including both fatigue and alert incidents), but the results did not point to a circadian effect. Future research could be directed at pulling out the critical incidents, or other drowsy episodes not associated with a critical incident, that occurred during circadian lows to investigate this further. Nonetheless, for the current analysis, time-of-day effects seemed to be associated with traffic density.

Note that these three possible explanations for the spike in critical-incident relative frequency during the 1st driving-hour are not mutually exclusive. That is, it could very well be the case that a combination of these effects may be involved. For example, sleep inertia may be more attributable to the long-haul drivers who sleep in sleeper berths and who may go, in a relatively short period of time, from sleeping in the sleeper berth to driving. This may be exacerbated by complex driving environments (e.g., urban environments, loading areas, undivided highways, intersections) and higher traffic density levels that may occur in loading (i.e., "take-off") and drop-off (i.e., "landing") situations which occur at the beginning and, depending on the fleet operation, end of the shift. Time-of-day effects, which are influenced by internal factors (i.e., circadian rhythm) and external factors (e.g., rush hours, traffic density), also play a role. However, based on the current research and other findings in the literature, the impact of time-on-task, which is the basis for the 10^{th} vs. 11^{th} driving-hour debate, does not seem to be an obvious or significant factor when considering increased critical-incident risk.

REFERENCES

Balkin, T., Thome, D., Sing, H., Thomas, M., Redmond, D., Wesenstein, N., Williams, J., Hall S., & Belenky, G. (2000). *Effects of Sleep Schedules on Commercial Motor Vehicle Driver Performance*. Federal Motor Carrier Safety Administration, Report No.DOTMC-00-133.

Bonnet, M., & Arand, D. L. (1995). Consolidated and distributed nap schedules and performance. *Journal of Sleep Research, 4,* 71–77.

Bruck, D., & Pisani, D.L. (1999). The effects of sleep inertia on decision-making performance. *Journal of Sleep Research, 8*, 95–103.

Dinges, D. (1990). Are you awake? Cognitive performance and reverie during the hypnopompic state. In R. Bootzin, J. Kihlstrom, and D. Schacter (editors) *Sleep and Cognition*. American Psychological Association, Washington, DC, 159–175.

Dingus, T.A., Neale, V.L. Garness, S.A., Hanowski, R.J., Keisler, A.S., Lee, S.E., Perez, M.A., Robinson, G.S., Belz, S.M., Casali, J.G., Pace-Schott, E.F., Stickgold, R.A., & Hobson, J.A. (2002). *Impact of sleeper berth usage on driver fatigue: Final project report.* Contract No. DTFH61-96-00068. Washington, DC: U.S. Department of Transportation, Federal Motor Carrier Safety Administration.

Federal Motor Carrier Safety Administration. (2007a). Data, Analysis and Statistics. Retrieved on November 14, 2007 at *http://www.fmcsa.dot.gov/facts-research/facts-figures/analysis-statistics/dashome.htm.*

Federal Motor Carrier Safety Administration. (2007b). *The Large Truck Crash Causation Study*. Retrieved on November 14, 2007 at http://ai.fmcsa.dot.gov/ltccs/default.asp

Federal Motor Carrier Safety Administration. (2006). *Report to Congress on the Large Truck Crash Causation Study*. U.S. Report MC-R/MC-RRA. Washington, DC: Department of Transportation, Federal Motor Carrier Safety Administration.

Festin, S. M. (1996). *Summary of National and Regional Travel Trends: 1970–1995*. U.S. Department of Transportation, Washington, DC.

Hanowski, R.J., Blanco, M., Nakata, A., Hickman, J.S., Schaudt, W.A., Fumero, M.C., Olson, R.L., Jermeland, J., Greening, M., Holbrook, G.T., Knipling, R.R., and Madison, P. (in press). *The drowsy driver warning system field operational test, data collection methods final report*. Contract No. DTNH22-00-C-07007, Task Order 14. Blacksburg, VA: Virginia Tech Transportation Institute.

Hanowski, R.J., Wierwille, W.W., Garness, S.A., & Dingus, T.A. (2000). *Impact of local/short haul operations on driver fatigue, final report*. Report No. DOT-MC-00-203. Washington, DC: U.S. Department of Transportation, Federal Motor Carrier Safety Administration.

Kaneko, T., & Jovanis, P.P. (1992). Multiday driving patterns and motor carrier accident risk: A disaggregate analysis. *Accident Analysis and Prevention, 24*(5), 437–456.

Jewett, M.E., Wyatt, J.K., Ritz-De Cecco, S., Khalsa, S.B., Dijk, D-J., & Czeisler, C.A. (1999). Time course of sleep inertia dissipation in human performance and alertness. *Journal of Sleep Research, 8*, 1–8.

Jovanis, P.P., Kaneko, T., Lin, T-D. (1991). Exploratory analysis of motor carrier accident risk and daily driving patterns. *Transportation Research Record, 1322*, 34–43.

Lin, T-D., Jovanis, P.P., & Yang, C-Z. (1993). Modeling the safety of truck driver service hours using time-dependent logistic regression. *Transportation Research Record, 1407*, 1–10.

Maycock, G. (1997). Sleepiness and driving: the experience of U.K. car drivers. *Accident Analysis and Prevention, 29*, 453–462.

Mackie, R., & Miller, J. (1978). *Effects of Hours of Service, Regularity of Schedules, and Cargo Loading on Truck and Bus Driver fatigue*. Report DOT HS-803 799. Human Factors Research, Inc, Goleta, CA.

Missoula Technology and Development Center (n.d.). Fatigue awareness: USDA Forest Service. Retrieved on December 11, 2007: www.fs.fed.us/fire/training/fatigue/fatigue.ppt

Mitler, M.M., Miller, J.C., Lipsitz, J.J., Walsh, J.K., & Wylie, C.D. (1997). The sleep of long-haul truck drivers. *The New England Journal of Medicine, 337*, 755–761.

Mullington, J., & Broughton, R. (1994). Daytime sleep inertia in narcolepsy cataplexy. *Sleep, 17*, 69–76.

National Highway and Transportation Safety Administration. (2007). *Traffic Safety Facts 2005*. Washington, DC: U.S. Department of Transportation.

National Sleep Foundation. (2007). *How Much Sleep is Enough?* Retrieved on November 13, 2007 at: http://www.sleepfoundation.org/site/c.huIXKjM0IxF/b.2419131/k.6C23/How_Much_Sleep_is_Enough.htm.

Olson, R.L. (2006). *Assessment of Drowsy-Related Critical Incidents and the 2004 Revised Hours-of-Service Regulations*. Unpublished Master's Thesis. Virginia Polytechnic Institute and State University, Blacksburg, VA.

Orris, P., Buchanan, S., Smiley, A., Davis, D., Dinges, D., & Bergoffen, G. (2005). *Literature Review on Health and Fatigue Issues Associated with Commercial Motor Vehicle Driver Hours of Work*. Commercial Truck and Bus Safety Synthesis Program, Synthesis 9. Transportation Research Board, Washington, DC.

Park, S-W., Mukherjee, A., Gross, F., & Jovanis, P.P. (2005). Safety implications of multiday driving schedules for truck drivers: A comparison of field experiments and crash data analysis. *Transportation Research Record, 1922*, 167–174.

Van Dongen, H.P.A., Maislin, G., Mullington, J.M., & Dinges, D.F. (2003). The cumulative cost of additional wakefulness: dose–response effects on neurobehavioral function and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep, 26*, 117–126.

Wertz, A.T., Ronda, J.M., Czeisler, C.A., & Wright, K.P. (2006). Effects of sleep inertia on cognition. *Journal of the American Medical Association, 295*(2), 163–164.

Wylie, C.D., Schultz, T., Miller, C.C., Mitler, M.M., Mackie, R.R. (1996). *Commercial Motor Vehicle Driver Fatigue and Alertness Study: Technical Summary*. MC-97-001. U.S. Department of Transportation.