Final Report

SAFETY IMPLICATIONS OF TRANSIT OPERATOR SCHEDULE POLICIES

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SAFETY IMPLICATIONS OF TRANSIT OPERATOR SCHEDULE POLICIES

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16. Abstract

Long driving hours have a potential of causing fatigue, which is known as a contributing factor for collisions. This paper examines the influence of bus operator driving hours on the occurrence of preventable collisions by employing data from a questionnaire survey, incident reports, and operator schedules to evaluate the correlation between driving hours, amount of sleep, and operator involvement in collisions. This project employs three methods of analysis including a questionnaire survey, analysis of preventable collisions in relation to operator schedule, and fatigue analysis. According to the questionnaire survey analysis, the amount of sleep appears to be influenced by arrival time to work, leave time from work, time of driving duty, and number of days worked per week. The results of the analysis of collision occurrences in relation to operator schedule show a discernable pattern of an increased propensity of collision involvement with an increase in driving hours. Based on the fatigue analysis, drivers involved in collisions were found to be overrepresented in the red fatigue condition, i.e., fatigue scores higher than fatigue tolerance level. According to the findings of this study, it is clear that FDOT needs to consider revising the current hours of service regulations.

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1 INTRODUCTION

This project was sponsored by the Transit Office of the Florida Department of Transportation (FDOT) in order to examine safety implications of current hours of service regulations used for transit operators in the state of Florida. It was aimed at determining the adequacy of the eight-hour minimum rest period for any 24-hour period, the maximum driving limit of 12 hours per 24-hour period, and the maximum limit of 16-hour of duty time for each 24 hours.

1.1 Background

There is a great deal of concern in the transit community that bus operator schedules can lead to fatigue and increased occurrences of bus accidents. Generally, fatigue increases with prolonging duty time. Agencies such as the Florida Department of Transportation (FDOT) that deal with regulating operations of transit systems have established rules that limit operator duty periods to limit fatigue. Operating rules are created to promote safe, efficient, timely, and customer-oriented transit operations. The FDOT Bus Transit Draft Rule 14-90.006(3) states that a driver shall not be permitted or required to drive more than 12 hours in any one 24-hour period or drive after having been on duty for 16 hours in any one 24-hour period. The rule allows the 12 hours of drive time to be spread out provided that 16 hours of on-duty time is not exceeded in any one 24-hour period. For example, worst case scenario, a driver might be on duty, driving for 8 hours and then take a 4 hour break and return to on-duty status for an additional 8 hours (4 hours driving and 4 hours non-driving). This would be considered as a maximum of 12 hours drive time and 16 hours on-duty time in a 24-hour period although a driver may not have rested for 20 hours. Rule 14-90.006 (3) further states that a driver shall not be permitted to drive until the requirement of a minimum eight consecutive hours of off-duty time has been fulfilled.

Obviously, the minimum eight consecutive hours of off-duty time stipulated in Rule 14-90.006(3) is not the net resting time. Part of the eight hour off-duty time may be used by drivers for activities such as traveling back and forth from work to home and running personal errands before and/or after sleeping. Regarding split duty, it is presumed that operators would use the break time for resting to rejuvenate before assuming a subsequent shift. However, operators have been observed to use the break time for activities such as running personal errands instead of resting. This may lead to tiredness as operators work for extended long hours.

Scientific literature strongly supports the fact that long hours of work lead to fatigue that can degrade performance, alertness, and concentration which increases safety risk. Several studies on the influence of operator schedule on accident occurrence have been conducted for the aviation, rail, and trucking industries. A literature search conducted did not find similar research efforts for bus operators despite the concern that bus operator spread-hour schedules can lead to fatigue and hence increase a chance of crash occurrence. A thorough understanding of the correlation between transit accident occurrence and long duty hours caused by split schedules together with a minimum eight consecutive hours of off-duty time is crucial in setting transit operating rules.

1.2 Research Objective

This research study examines the safety impacts of the existing operator hours of duty policies in the state of Florida. Thus, this study uses incident data archived by transit agencies and bus driver schedules to determine the relationship between crash involvement and operator schedules. There are two main subjects of interest in this study – the influence of split schedule which results in prolonged duty hours of up to 16 hours and the adequacy of a minimum 8-hour off-duty time as a mandatory off-duty period for bus operators. The outcome of this study could be used by transportation officials from state to local transit agencies in determining how best to schedule bus operator hours in order to reduce safety risks that might be caused by operator fatigue.

2 LITERATURE REVIEW

Fatigue and sleep are causal factors in thousands of crashes, injuries and fatalities annually (Knipling & Wang, 1994). At the 1995 National Truck and Bus Safety Summit, driver fatigue was identified as the leading safety issue in the industry (USDOT FHWA, 1998). Literature on the influence of fatigue on bus safety is scarce. However, there is a considerably large body of literature on the influence of fatigue on safety of other modes of mass transportation including train and airline industries. Additional studies have been conducted on the same subject in the trucking industry. This literature review section is therefore extended to include gathering findings of previous research on the aforementioned modes of transportation.

2.1 Effects of Fatigue in Trucking Industry

Most studies that have investigated the influence of long hours of driving on safety for trucks have examined the presence of sleepiness and fatigue in truck drivers. McCartt et al. (2000) conducted face-to-face interviews with 593 long-distance truck drivers at rest areas and inspection points. The study found the following six factors had influence on drivers falling asleep at the wheel: (1) greater daytime sleepiness (2) more arduous schedules with more hours of work and fewer hours off-duty (3) older, more experienced drivers (4) short, poorer sleep on road (5) symptoms of sleep disorder, and (6) greater tendency to night-time drowsy driving. Based on the findings of the study, the authors further suggested limiting drivers' work hours enable drivers to get adequate sleep to reduce sleepiness-related driving by truck drivers. Williamson *et al.* (1996) conducted a controlled experiment whereby he examined twenty seven professional truck drivers who completed a 12-hour 900 km trip under three different settings – relay trip, a working-hour regulated one-way single trip, and a one-way (flexible) trip with no working hours' constraints. The results of the study indicated indifference in fatigue for the three different settings. However, the study suggested that the fatigue patterns were more related to pre-trip fatigue levels.

A study by Sang-Woo *et al.* (2005) evaluated safety implications of truck drivers' schedules from one United States less-than-truckload firm. It used schedules of 5,050 accident-involved and non-accident drivers collected in two years (1984 and 1985). The authors used the survival theory to examine the influence of driving time on crash occurrences. Crash risk was found to be associated with hours of driving, with risk increases of 30% to 80% compared to the first hour of driving. The results of this study also indicated that time of day (night and early morning schedules) and irregular schedules are associated with elevated crash risk in the range of 20% to 80%. In another similar study, Sango-Woo and Jovanis (2004) analyzed data from three trucking companies, each with different types of operations namely, primarily truckload operations, another exclusively less-than-truckload operation, and the third running a mix of operations. The study reported a non-linear increase in crash odds after the 6^{th} hour of driving. According to the study, the odds ratios increase from 50% to over 200% in the 10^{th} and 11^{th} hour.

2.2 Effects of Fatigue in Railroad Industry

There are numerous aspects of railroad operations that can cause fatigue and alertness problems: the irregularity of work schedules in freight operations, the need for split shifts in commuter and urban operations, and the high potential for complacency and boredom in some freight operations. Several studies have documented fatigue as a serious issue for the rail industry, with train operator schedules resulting in sleep-related problems (Foret and Latin, 1972; Pilcher and Coplen, 2000; Roach *et al.*, 2003). Research has identified several factors responsible for elevated fatigue among train drivers, including uncertain shift times, long commutes, and suboptimal terminal sleeping conditions. Pollard (1991, 1996) found that for shifts that started between 10p.m and 4a.m, train drivers reported that they slept fewer than 6 hours per day. These two studies indicate that some train drivers may not have daytime rest before a night shift.

2.3 Effects of Fatigue in Aviation Industry

There is a great deal of concern in the aviation community that pilot schedules can lead to fatigue and increase the chances of an aviation accident. The scientific community recognizes that there is a complex relationship between how pilot performance is impacted by pilot schedules and safety risk. Powel *et al.* (2007) investigated how length of duty, number of sectors, time of day, and departure airport affect fatigue levels in short-haul operations. Pilots completed the 7-point Samn-Perelli fatigue scale where they rated themselves as: 1 "fully alert, wide awake"; 2 "very lively, responsive but not at peak'; 3 "OK, somewhat fresh"; 4 "a little tired, less than fresh"; 5" moderately tired, let down"; 6 "extremely tired, very difficult to concentrate"; or 7 "completely exhausted, unable to function effectively" as well as a 100-mm visual analog scale rated from "alert" to "drowsy." The most important factors influencing fatigue were the number of sectors and duty length.

Goode (2003) reported on the study that was conducted to determine the influence of pilot schedules on airline safety. Parameters of interest were then calculated such as each pilot's length of duty, the amount of flight and duty time per day, the amount of rest time, and the amount of takeoffs and landings each day. Goode compared the distribution of pilot work schedule parameters for accidents to that for all pilots using a chi-square test to determine if the proportions of accidents and pilot duty time exposure were similar. The study found that there were differences between the two sets of data in some work schedule parameters examined

2.4 Effects of Fatigue in Transit Buses

Only three studies were found to have examined the influence of fatigue on city buses. Santos *et al.* (2004) evaluated daytime and nighttime sleep, as well as daytime and nighttime sleepiness of professional shift-working bus drivers in Brazil. The study revealed that the sleep of shift-working bus drivers was shorter and more fragmented when it occurred during the day than at night. A thesis by Howarth (2002) investigated differences in self-reported sleep length and aspects of fatigue for a sample of transit bus operators in the northeastern United States who were working split and straight shift schedules. The study used questionnaires which were distributed to 149 bus operators in Hartford, Connecticut. The results demonstrated expected relationships between sleep length and before/after-work measures of fatigue. Briggs et. al (2006) conducted a study that identified a number of fatigue factors relevant to metropolitan bus drivers in Australia. The study conducted a questionnaire survey of 249 bus drivers and focus groups participants. Two factors i.e., unrealistic scheduling that causes drivers to be unable to take breaks and lack of managerial support were found to be the main causes of fatigue.

It is important to recognize that the operational characteristics of city buses differ from those of other modes of mass transportation and trucking industry. For example, unlike trucks routes are scheduled during peak hours because that is the time when buses get more riders. Also, unlike truck drivers, bus drivers do not have the flexibility of choosing their schedule based on their best performance time of the day. City buses use mostly city streets while trucks mostly ride on highways. Buses stop more frequently than trucks. In addition to the driving task, bus operators in most agencies have to do other tasks such as collecting fares, validating identity cards, etc. Based on the above reasons, one may argue that the findings regarding the influence of operator fatigue on safety of vehicles other than city buses may not apply to bus operators. This study therefore examines operator schedules and bus collision records to determine if there is a correlation between the two.

2.5 Hours of Service Regulations

The hours of service for operating commercial motor vehicles (CMV) in the United States for the purpose of interstate commerce, i.e., moving goods and services from one state to another are regulated by the Federal Motor Carrier Safety Administration (FMCSA). The types of transportation modes regulated by the FMCSA include trucking and passenger-carrying CMV which includes buses and passenger vans.

The hours of service regulations for interstate passenger carrying commercial motor vehicles are published on the Federal Motor Carrier Safety Administration website (http://www.fmcsa.dot.gov/rules-regulations/topics/hos/). A report titled "Interstate Passenger Carrying Driver's Guide to Hours of Service" found on this website provides details on the three maximum duty limits, i.e., the 15-hour on-duty limit, 10-hour driving limit, and 60/70-hour duty limit. Hours of service regulations for the interstate trucking industry are also stipulated by the Federal Motor Carrier Safety Administration and found on the same webpage. Guidelines for interstate trucks can be found on the document titled "Interstate Truck Driver's Guide to Hours of Service.

Intrastate commercial motor vehicle regulations are under the jurisdiction of each state. The HOS regulations apply directly only to *interstate* commerce. However, most states have adopted intrastate regulations which are identical or very similar to the federal hours-of-service regulations. Table 1 shows differences between federal and Florida hours of service regulations. It indicates that Florida has a higher daily driving limit (12-hour compared to 10-hour and 11-hour for interstate passenger carrying and property carrying CMVs). A 16-hour on duty limit observed in Florida is higher than the 15-hour for interstate passenger-carrying CMV drivers and 14-hour on-duty limit for trucks.

TABLE 2.1 Hours of Service Rules

Federal regulation for property-carrying CMV drivers	Federal regulation for interstate passenger-carrying CMV drivers	Florida Regulation for bus transit (Rule 14-90)
11-Hour Driving Limit May drive a maximum of 11 hours after 10 consecutive hours off duty.	**10-Hour Driving Limit** May drive a maximum of 10 hours after 8 consecutive hours off duty.	**12-hour driving limit** a driver shall not be permitted or required to drive more than 12-hours in any one 24-hour period
14-Hour On-Duty Limit May not drive beyond the 14th consecutive hour after coming on duty, following 10 consecutive hours off duty. Off-duty time does not extend the 14-hour period.	**15-Hour On-Duty Limit** May not drive after having been on duty for 15 hours, following 8 consecutive hours off duty. Off-duty time is not included in the 15-hour period.	**16-Hour On-Duty Limit** May not drive after having been on duty for 16 hours, in any one 24-hour period. Off-duty time is not included in the 16-hour period.
60/70-Hour On-Duty Limit May not drive after 60/70 hours on duty in 7/8 consecutive days. A driver may restart a 7/8 consecutive day period after taking 34 or more consecutive hours off duty.	**60/70-Hour On-Duty Limit** May not drive after 60/70 hours on duty in 7/8 consecutive days.	**72-Hour On-Duty Limit** A driver who has reached the maximum 72 hours of on duty time during the seven consecutive days shall be required to have a minimum of 24 consecutive hours off duty prior to returning to on duty status.

3 RESEARCH APPROACH

The research team conducted a thorough analysis of the relationship between bus operator schedules and safety using a combination of analysis types. The analyses were geared towards investigating whether there is significant relationship between the length of duty and bus safety. Also, these analytical approaches aimed at identifying the influence of split schedules on bus safety. The following specific methods were used.

3.1 Questionnaire Survey

A survey of bus operator was conducted. The questionnaire was designed to gather information of activities performed during the on and off-duty hours. The objective of this questionnaire was to assess the adequacy of the minimum off-duty period of 8 hours. Typical activities that could be performed during the off-duty period may include operators traveling from work to home, eating, sleeping, preparing for work, and traveling back to work from home. The amount of sleep that a bus operator gets would depend of the time it takes to perform off-duty activities. General questions such as the distance from home to work and the average hours of sleep per day were also included in the questionnaire. In addition, the survey collected information on how operators use break time (for split shifts). This was done in order to determine whether the break between split shifts is used for resting and possibly establish the relationship between the length of the break and type of typical activities performed during the break.

3.2 Operator Schedule and Collision Analysis

The distribution of work schedules for coach operators who were involved in preventable accidents and determined to be at fault was statistically compared to that of all operators using inferential statistical techniques such as a chi-square test to determine if the proportions of accidents and exposure were the same. Several statistical tests were conducted to determine if different spread l[illegible] schedules have any effects on accident occurrence. Another set of statistical tests were also be conducted to correlate the amount of off-duty time and accident involvement. Additional statistical tests such as time of day analysis were conducted to determine whether accidents are more likely to occur at the beginning of a shift (e.g., a warm up phenomenon) or at the end of a shift (e.g., driver fatigue phenomenon). More statistical tests would be performed at the project manager's request.

3.3 Fatigue Analysis

Fatigue analysis was conducted using the Fatigue Audit Interdynamics (FAID) software. This is a fatigue assessment tool that evaluates worker effectiveness based on cumulative work hours and rest periods. The tools provide results using a color scheme – red, yellow, and green, based on the comparison of the FAID score and fatigue tolerance levels. These estimates are based on formulae developed by the Centre for Sleep Research at the University of South Australia and published in international peer-reviewed journals.

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4 QUESTIONNAIRE SURVEY

4.1 Questionnaire Design

The survey was carried out from December 2009 to October 2010. The research team distributed the questionnaires on site. Surveyors approached bus operators personally at a waiting lounge, where drivers meet before starting their daily schedules. Surveyors described the purpose of the study and guided respondents on filling the questionnaires as some of the questions were not clear to some operators. The questions were formulated to allow respondents to provide information on their daily routine without a need to collect additional information. A blank questionnaire is shown in Appendix A.

4.2 Survey Results

A total of 266 questionnaires were completed. The descriptive statistics of the respondents are provided in Table 2. A detailed discussion of several variables of interested presented in Table 2 is provided next.

4.2.1 Arrival and Departure

Based on combined data of all agencies summarized in Table 4.1, the earliest reporting time of 2:00 AM was reported, while the respondents reported the latest departure time of 11:00 PM. The results show that on average, drivers start driving at 5:48 AM and end their work day at 4:21 PM. A close look at agency-wide data shows that operators of metropolitan areas, i.e., large agencies, in Jacksonville and Orlando arrive to work much earlier than those of medium and small size agencies. This is certainly caused by the fact that operators in big cities start their routes early (e.g., For Orlando, 3:00 AM) and cover a greater area than most operators in small agencies. An examination of completed questionnaires revealed that most drivers who report to work early leave earlier than those who start their schedule late in the day. There are drivers who start their schedule late who indicated that they perform driving tasks to other agencies especially school bus system before they start driving transit buses. This shows that off-duty hours are not necessarily used to facilitate resting.

4.2.2 Time elapsed between arrival and leave from work

Time on duty was computed as the amount of time elapsed between the time arrived at work and the time of departure from work. The average time elapsed between arriving and leaving work was reported to be 10.56 hours. This length of time included on-duty driving time, split time, and time spent performing any other non-driving duties. Figure 4.1 shows the distribution of time on duty for the combined dataset. It can be depicted from Figure 4.1 that more than 66% percent of drivers spend between 8 to 12 hours at work while 23% percent of drivers spend between 12 and 16 hours at work. A small fraction of drivers (0.38%) reported to be on duty for more than 16 hours.

TABLE 4.1 Summary of Questionnaire Result

Variable / Parameter	Arrival Time	Departure Time	Total Time Worked (hr)	Days Worked per Week	Driving Hours per Week	Hours On-Duty Not Driving	Driving Hours per Day	Split Time Duration	Distance Home-to-Work (mi)	Travel Time to-and-from Work (min)	Preparation Time to leave for Work (min)	Hours of Sleep per Day	Parameter	Same weekly schedule?	Different shifts?	Split schedule?	Other activities after work?
Gainesville, n=36																	
Mean	7:26 AM	4:37 PM	9.19	5.46	39.41	1.67	8.29	3:46	17.94	55.23	35.14	6.03	**Y**	47%	56%	64%	86%
Std. Dev.	02:21	02:45	2.22	0.86	15.08	1.88	1.07	1:49	9.76	22.3	19.64	1.31					
Minimum	5:00 AM	1:00 PM	5	4	4	0	6	2:00	4	8	1	4	**N**	53%	44%	36%	14%
Maximum	2:20 PM	11:00 PM	15.75	7	56	5	12	8:00	42	115	60	10					
Jacksonville, n=47																	
Mean	5:56 AM	4:57 PM	11	5.09	40.62	0.2	8.82	2:54	12.77	44.02	52.27	5.82	**Y**	72%	60%	86%	72%
Std. Dev.	02:40	03:36	3.03	0.29	10.83	0.87	1.16	0:52	7.64	20.83	26.25	1.01					
Minimum	3:00 AM	10:40 AM	5.17	5	5	0	5	0:30	2	10	5	4	**N**	28%	40%	14%	28%
Maximum	2:00 PM	11:00 PM	14.25	6	55	5	12	5:00	45	110	120	9					
Orlando, n=108																	
Mean	4:31 AM	3:24 PM	10.79	5.29	47.08	1.47	8.58	3:04	18.69	64.43	37.09	5.88	**Y**	49%	37%	62%	70%
Std. Dev.	01:10	01:35	1.16	0.46	9.96	1.81	1.64	0:48	8.5	23.17	16.03	1.06					
Minimum	00:00	12:20 PM	8.33	5	7.5	0	5	1:00	4	30	10	4	**N**	51%	63%	38%	30%
Maximum	9:00 AM	10:05 PM	13.83	6	72	5	12	4:00	40	155	60	8.5					
Tallahassee, n=55																	
Mean	6:51 AM	5:31 PM	10.68	5.11	39.38	0.69	9.13	3:00	13.08	46.2	42.08	6.64	**Y**	30%	43%	48%	41%
Std. Dev.	02:18	02:56	2.45	0.72	11.34	1.39	1.67	1:34	13.38	32.71	26.13	1.17					
Minimum	4:00 AM	12:00 PM	7	4	8	0	4	0:30	0.5	8	1	4	**N**	70%	57%	52%	59%
Maximum	2:20 PM	11:00 PM	17	7	60	5	12	8:00	70	200	150	10					
Suwannee, n=14																	
Mean	6:01 AM	5:08 PM	11.13	5.29	47.54	0.31	9.32	00:00	9.82	36.79	38.57	6.66	**Y**	93%	0%	0%	43%
Std. Dev.	1.94	0.58	2.28	0.47	17.08	0.70	3.26	00:00	5.12	15.14	21.61	1.67					
Minimum	4:30 AM	4:15 PM	4.25	5.00	4.00	0.00	3.50	00:00	2.50	10.00	15.00	4.50	**N**	7%	100%	100%	57%
Maximum	12:00 PM	6:30 PM	13.25	6.00	72.00	2.00	12.00	00:00	18.00	70.00	90.00	11.00					
Union, n=6																	
Mean	6:25 AM	4:20 PM	11.13	5.29	47.54	2.00	9.32	3:00	9.82	36.79	38.57	6.66	**Y**	100%	0%	33%	17%
Std. Dev.	0.44	1.44	2.28	0.47	17.08	2.74	3.26	2:49	5.12	15.14	21.61	1.67					
Minimum	5:45 AM	12:00 AM	4.25	5.00	4.00	0.00	3.50	1:00	2.50	10.00	15.00	4.50	**N**	0%	100%	67%	83%
Maximum	7:00 AM	7:00 PM	13.25	6.00	72.00	5.00	12.00	5:00	18.00	70.00	90.00	11.00					
Combined, n=266																	
Mean	5:48 AM	4:23 PM	10.60	5.22	42.64	1.01	8.69	3:03	15.24	52.36	41.47	6.12	**Y**	62%	46%	62%	68%
Std. Dev.	2.20	2.62	2.07	0.56	12.25	1.65	1.69	1:09	10.17	26.78	22.40	1.20					
Minimum	3:00 AM	6:00 AM	2.25	4.00	4.00	0.00	3.50	0:30	0.50	6.00	1.00	4.00	**N**	38%	54%	38%	32%
Maximum	2:20 PM	11:00 PM	17.00	7.00	72.00	5.00	12.00	8:00	70.00	200.00	150.00	11.00					

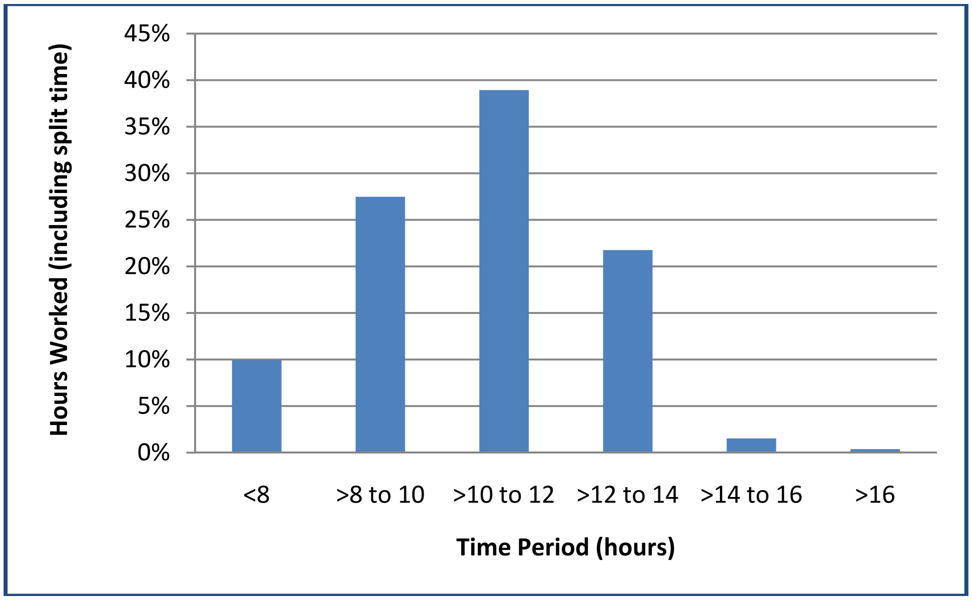

FIGURE 4.1 Amount of Time Between Arrival and Departure from Work

4.2.3 Driving hours

Driving hours account for hours that an operator spent exclusively driving a bus. Survey responses indicate that on average, bus operators drive about 8.72 hours per day. When asked about the number of hours they drive per week, bus operators of the surveyed agencies reported an average of 42.73 hours per week. Interestingly, the average driving hours of 8.72 hours is about two hours less than the total hours drivers spent at work (10.56 hours), certainly an indication of the presence of splits. The reported minimum and maximum driving hours per day were 4 hours and 12 hours, respectively, while the weekly minimum and maximum of 4 hours and 72 hours, respectively, were reported. Figure 4.2 shows the distribution of the driving hours. It can be seen from Figure 4.2 that more than half of the drivers indicated that they drive eight hours per day. Just fewer than 10% of the drivers reported to be driving 12 hours per day.

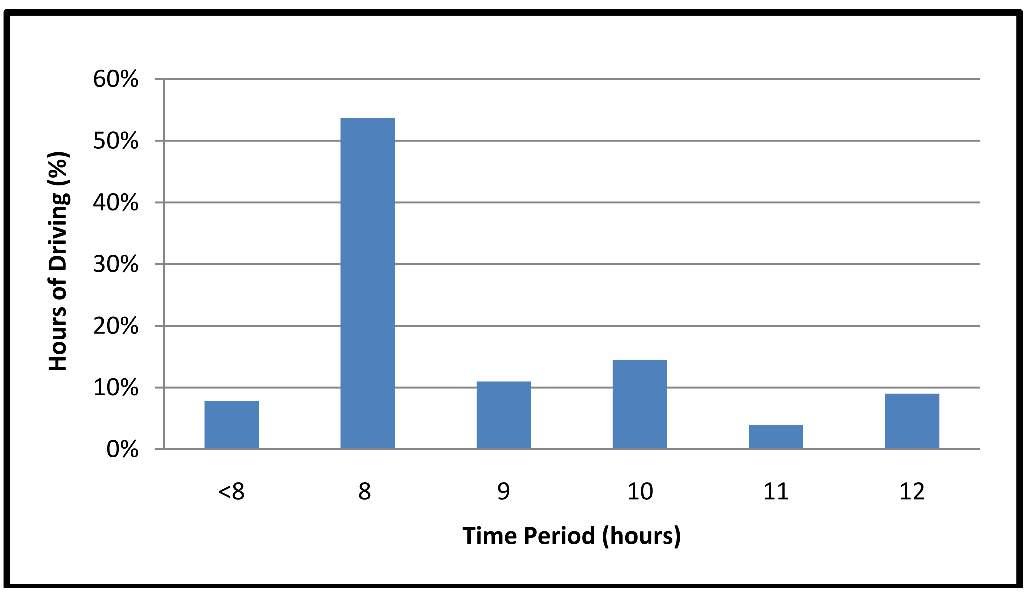

FIGURE 4.2 Amount of Time per Day Spent on Driving

The operators were also asked about the hours that they spent performing other non-driving duties. According to the respondents, most drivers (94.8%) performed only driving duties and only 5.2% were involved in other non-driving duties. For those who were involved in non-driving duties, the average number of hours on duty performing other duties was observed to be 1.65 hours per day. The maximum of non-driving duty time of 5 hours per day was reported.

4.2.4 Schedule Type

It was observed from the survey responses that on average, about 66% of all surveyed operators in six agencies were involved in split schedules. It is important to note that drivers from one small size agency (Suwannee County) did not have splits. When considering drivers with split schedules alone, the mean split time of about three hours was observed. The minimum and maximum values of split times were reported as one-half hours and eight hours, respectively. Figure 4.3 shows a distribution of the split times. Clearly, short split times are not enough for bus drivers to travel to their homes, relax, and resume driving task. On the other hand, longer split times offer an opportunity for some drivers to do other activities such as running errands between driving tasks.

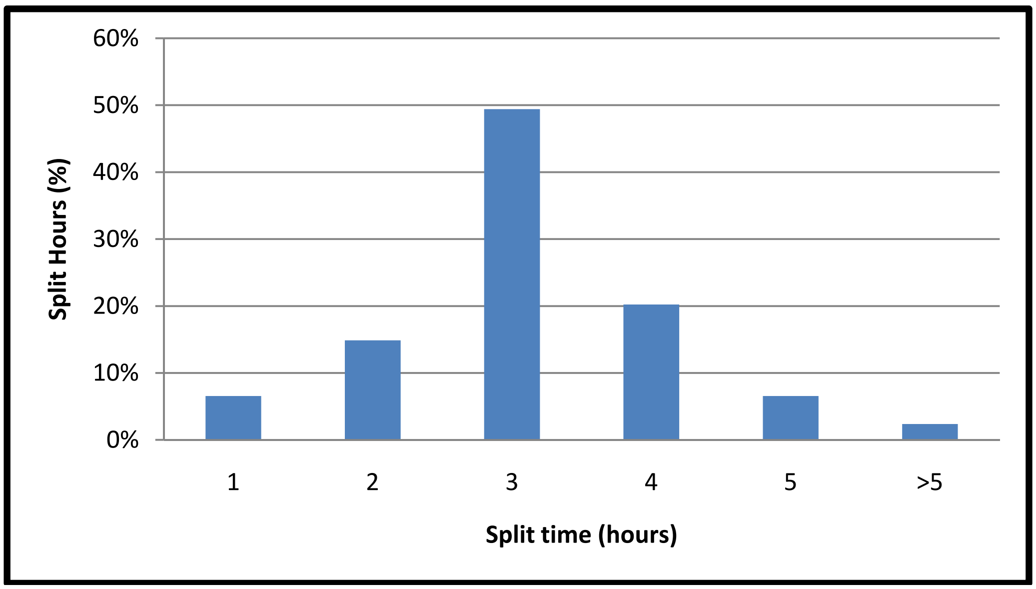

FIGURE 4.3 Amount of Split Time per Day

The distribution of activities performed during the split time is depicted in Figure 4.4. Only 24% of respondents indicated that they use split time to relax, of which 10% relax at work and 14% relax at home. It was reported that about 34 % of drivers use their split time to take a nap. About 20% of all drivers reported taking a nap at home while 7% travel to their homes for a nap. About 29% of respondents indicated that they use the split time for eating of which 10% eat at work while about 19% eat at home. The remaining 30% of the drivers indicated that they use their split time to perform other duties including running errands, performing non-driving duties, and reading. Out of all these activities, only taking a nap and relaxing (performed by just over half of operators during split time) could be generally considered as resting. Even with napping and relaxing, if done at home, a driver would still use part of the split time to travel home and get back to work, leaving only a fraction of the split as a resting time. The data indicates that most of the split time is not mainly used for resting but rather for other activities.

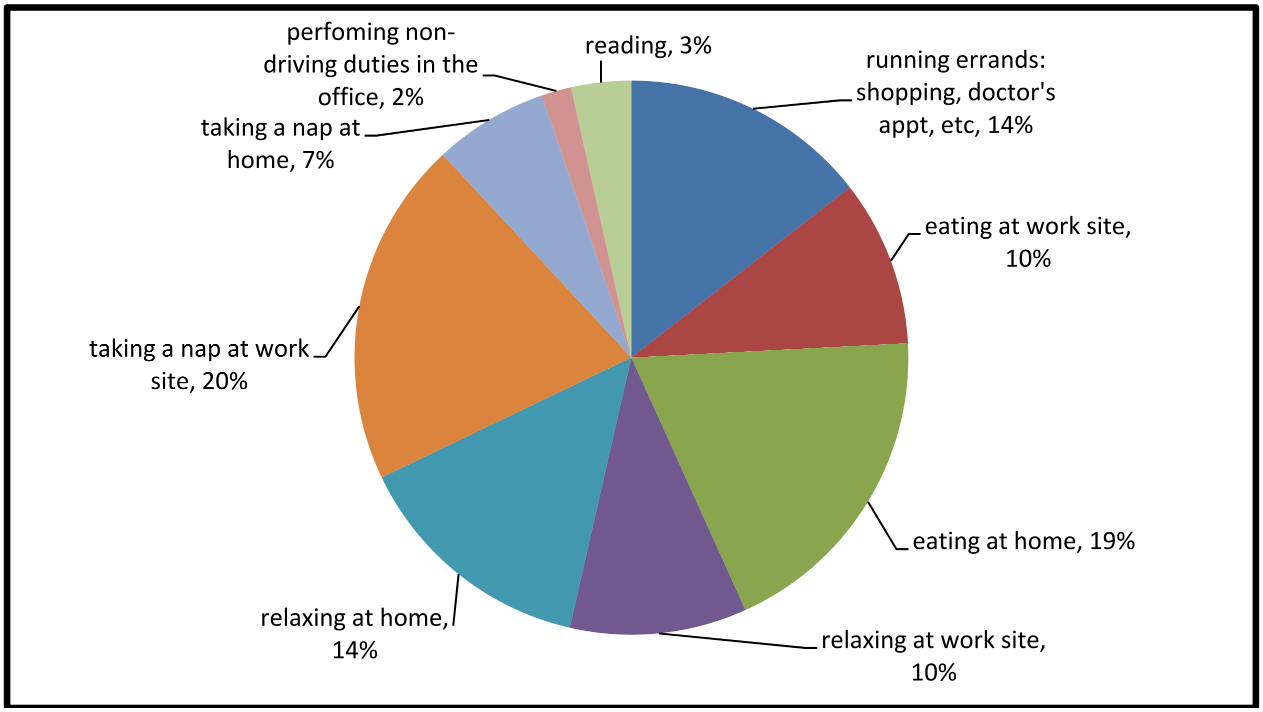

FIGURE 4.4 Distribution of Activities Performed During Split Time

Survey responses on arrival time, leave time, driving time, and split time are graphically presented in Figure 4.5. The graph shows a visibly discernible trend that distinguishes straight schedules from split schedules. It is obvious from the graph that drivers who work split shifts finish their shifts much later in the day compared to those who work straight shifts. The fact that drivers with split schedules leave work much later in the day might have an impact on the amount of sleep they receive.

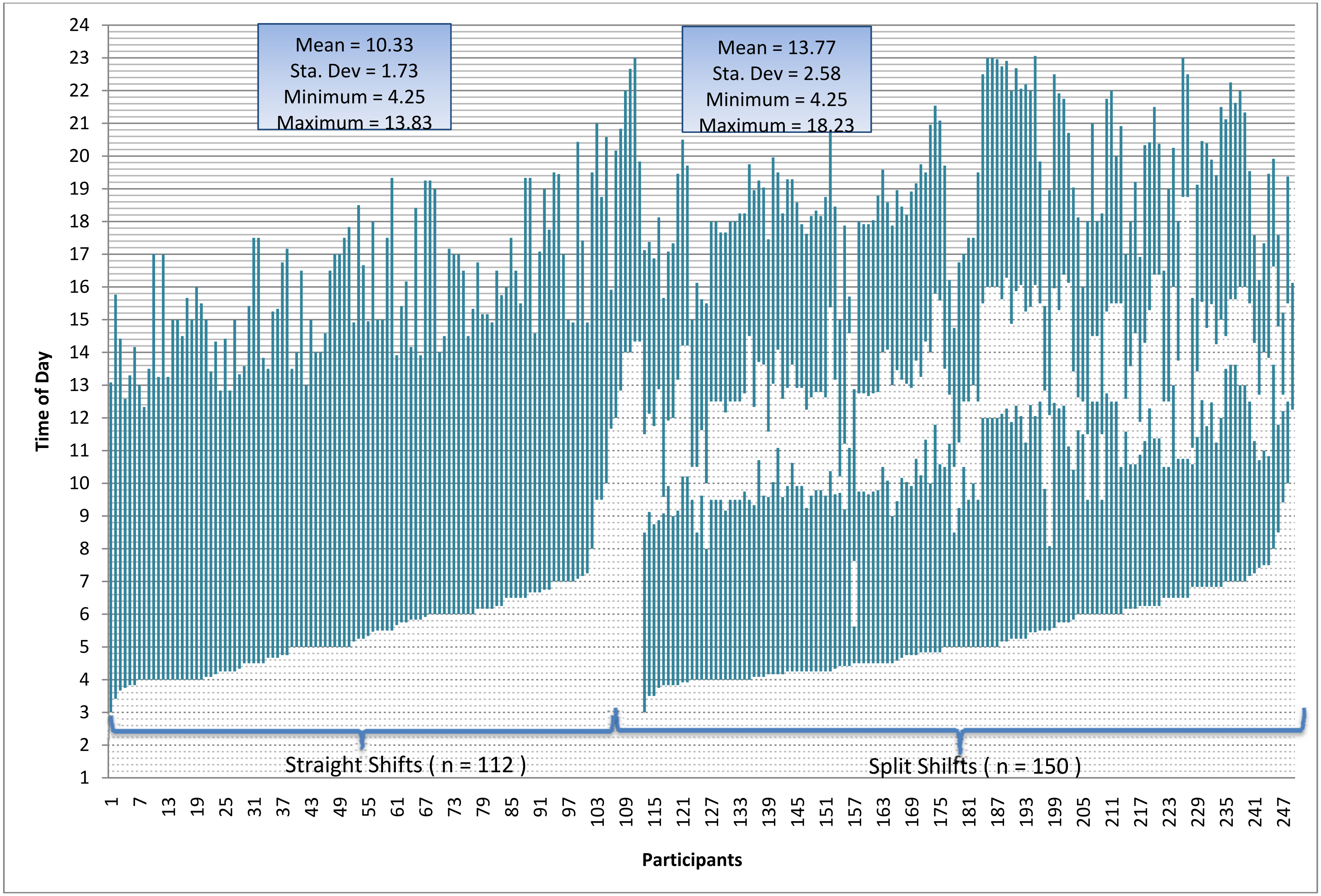

FIGURE 4.5 Arrival and Leave Time by Schedule Type (Straight and Split Schedules)

4.2.5 Travel to and from work

Three questions were designed to direct operators to provide information on how far they live from work. The first question asked about the distance from home to work, while the second and third questions dealt with the time spent driving to and from work. The time to and from work was then computed as the sum of time from home to work and vice versa. The results are summarized in Table 2.1. Responders pointed out that on average they live about 15.88 miles from work. The distance from home to work varied for as short as 0.5 miles to as long as 70 miles. As far as the time they use to travel from home to work and back home, responders reported an average of 54.13 minutes. Figure 4.6 shows the distribution of the travel time to and from work.

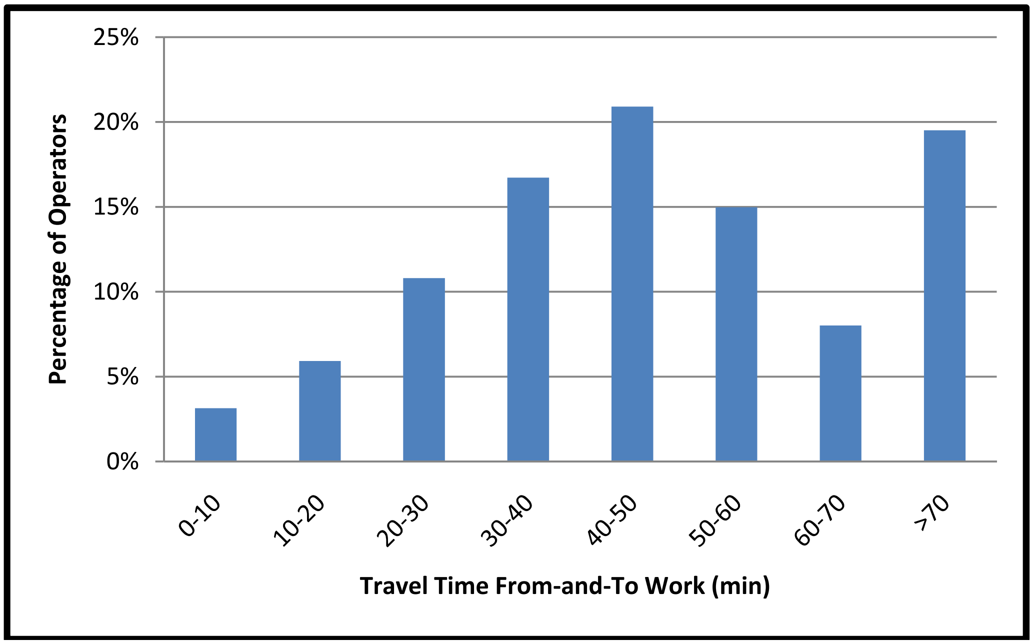

FIGURE 4.6 Distribution of Time of Travel To and From Work

4.2.6 Sleep time

The last two questions in the survey intended to solicit the information of how many hours drivers allocate for their sleep. One of the questions asked for the typical time they go to bed while the other asked for the time they awake. The sleep time was computed then as the difference between the time of waking up and time of going to bed. Responders reported an average sleep time of about 6 hours with a minimum and maximum sleep time of 4 hours and 10 hours, respectively (See Table 2.1). Figure 4.7 shows the relationship between sleep time and total time on duty, i.e., a sum of driving hours and split time. Categories of on-duty time and the associated average sleep times are represented as reported by the survey respondents. It can be seen that as operators spend more time on duty, a trend of reduced number of sleep hours in evident. According to Figure 4.7, the amount of sleep is reduced drastically when total time on duty exceeds 14 hours per day.

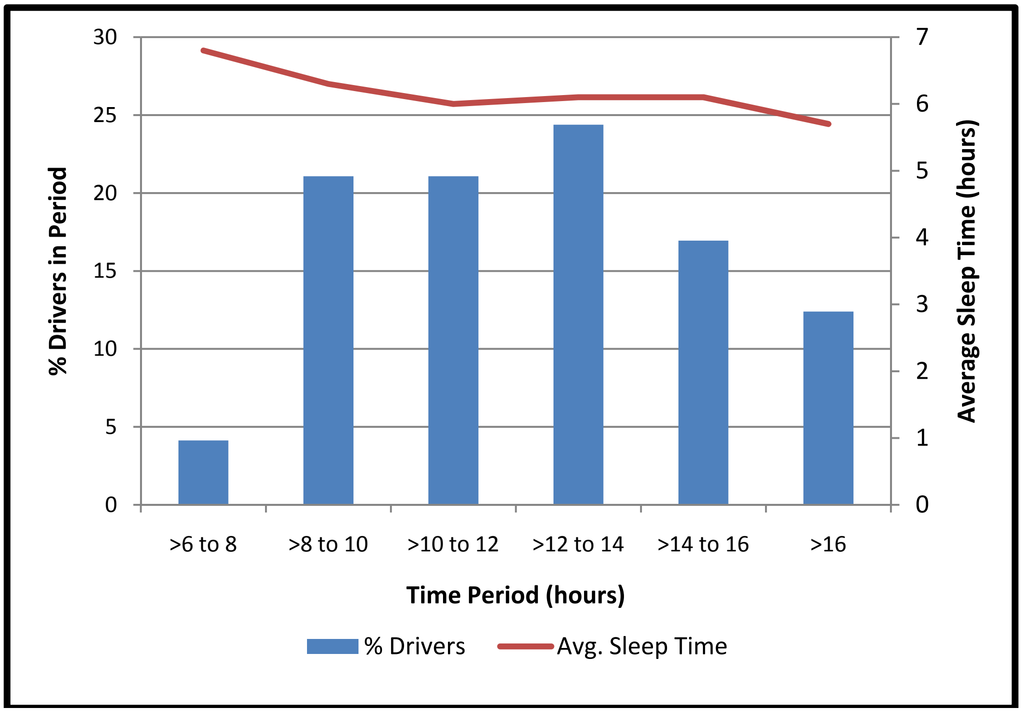

FIGURE 4.7 Relationship Between Total Time On Duty and Amount of Sleep

4.2.7 Sleep Dept Calculation

The inadequacy of the off-duty period has very serious impact on the drivers' performance due to accumulative nature of fatigue when the resting time is not enough to dissipate the daily state of weariness. It is important to note that the average off-duty period mentioned above was computed based on the entire population of the respondents; situation could be quite different, requiring more off-duty time when considering individual operators. Logically, the amount of sleep that a bus operator gets depends on the time it takes to perform off-duty activities before going to bed. A significant proportion of operators (54%) reported to have 6 hours or less of sleep within 24 hours. This makes majority of the operators in this study to have lack or poor sleep because scientifically an average person needs about 8 hours sleep every 24-hour cycle (Frakes and Kelly, 2004; Federal Motor carrier Safety Administration - Synthesis 7, 2005; SafetyNet, 2009). Sleep prior to work is the most prominent factor that influences the waking state, the level of alertness of the driver and reaction time. By the common (and admittedly simplistic) principle that each hour of sleep 'buys' two hours of subsequent wakefulness we would suggest that the ability to 'sustain alertness' is decreased by two hours for each hour of sleep loss *(*Dawson and McCulloch, 2005*)*. Making eight hours as a reference, the computation of sleep debt in terms of hours indicated that most bus operators reported a sleep debt of at least 1 hour. Further comparison depicted in Figure 5 shows that out of the operators who manifested sleep debt of at least one hour a good proportion works split schedules. This makes the operators working split schedules more susceptible to fatigue compared to the group working straight schedules.

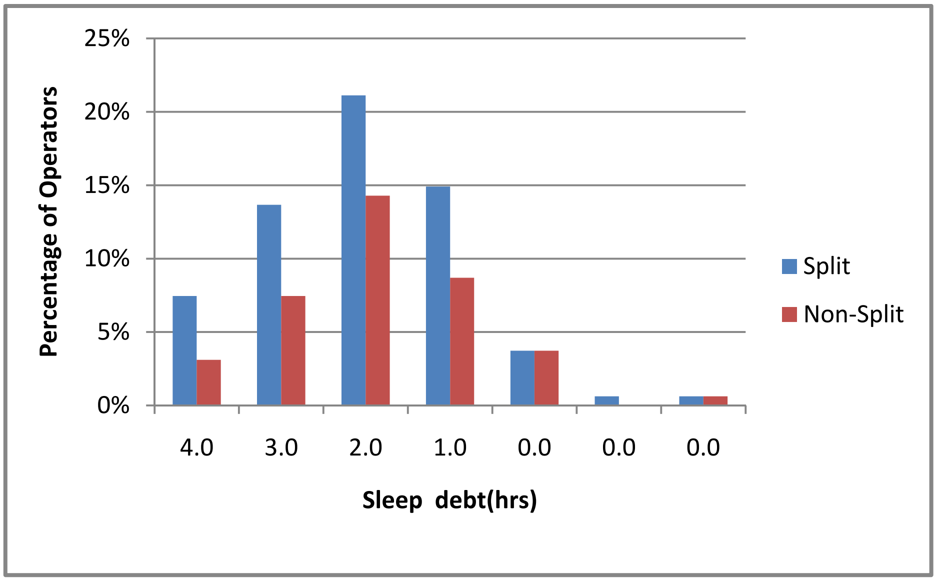

FIGURE 4.8 Calculated sleep debts among split and straight shifts

4.3 Model Estimation for Sleep time

Modeling involved survey responses from 266 completed questionnaires collected at six agencies sampled from around the state of Florida. A multivariate regression model was developed for the reported operator sleep time. The STATA statistical package was used for the multivariate regression model runs. Only three variables (schedule type, arrival, and departure time) were categorical while the remaining variables were continuous. Arrival times to work were divided into two categories. Arrival times before 6 AM were coded as "zero," while arrival times after 6 AM were coded as "one." Departure times from work of 7 PM or earlier were assigned a category "zero," while departure times of later than 7 PM were placed in category "one."

Model coefficients and their levels of significance are provided in Table 4.2. The results in Table 4.2 suggest that the earlier the drivers arrive at work, the less sleep they receive. From the results, it can also be surmised that operators who leave from work later than 7:00 PM reported having less amount of sleep. Also, the results in Table 4.2 show that the increase in driving time resulted in a decrease in the amount of sleep time as indicated by the negative model coefficient. Interestingly, the results in Table 4.2 show that the more days the operators work, the more the sleep they get. It is possible that drivers who work more days per week distribute their work week with fewer hours per day, hence resulting in more hours of sleep per day. However this variable was not significant at the 95% confidence level. Other factors that were found to be insignificant were type of schedule, and time to prepare before going to work. Although the amount of sleep was found to be lower for drivers who worked different shifts, the difference was not significant. Similarly, the model results indicate less sleep for drivers who travel longer times to and from work and those who take longer to get ready for work, but the difference was not significant.

TABLE 4.2 Parameter Estimates of Sleep Time Multivariate Regression Model

Variable	Coefficient	Standard Error	*t*-statistic	*p*-value
Arrival time	-0.3484012	0.1729179	-2.01	0.045
Leave time	0.8595988	0.243509	3.53	0.001
Time on driving duty	-0.0932854	0.0483417	-1.93	0.055
Number of days worked per week	-0.0168526	0.0067758	-2.49	0.014
Same schedule	-0.0566128	0.1538988	-0.37	0.713
Split time	-0.0534381	0.0423399	-1.26	0.208
Time to travel to and from work	-0.0469997	0.1284149	-0.37	0.715
Time to prepare before going to work	-0.2274222	0.2070622	-1.1	0.273
Model constant	8.397482	0.9190507	9.14	0

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5 OPERATOR SCHEDULE AND COLLISION ANALYSIS

5.1 Data Collection

The analysis presented in this chapter employed data from the first four transit agencies in the state of Florida listed in Table 5.1 - two large and two medium size agencies. Data from small agencies were not used as there were few accidents due to a small number of operating fleet. It should be noted that these agencies were selected based on their willingness to participate and availability of electronic incident report databases that could be exported to a Microsoft Access database. The four agencies were then ranked based on the number of buses they operate. Jacksonville Transit Authority (JTA), and Lynx (the transit agency in Orlando) were categorized as large size agencies as they operate a fleet of more than three hundred buses. StarMetro and Regional Transit System (RTS), transit agencies for Tallahassee and Gainesville, respectively, were ranked as medium size agencies. They each operate a fleet size of less than 150 buses. Two types of data were collected, bus collisions and operator schedules. The following two sections describe collection of these two data types.

TABLE 5.1 Transit Agencies Used in the Study

Agency Name	Location	Fleet size	Number of operators
Jacksonville Transit Authority (JTA)	Jacksonville	129	268
Lynx	Orlando	274	396
Regional Transit System (RTS)	Gainesville	80	148
StarMetro	Tallahassee	105	160
Hamilton, Columbia & Suwannee County Transit	Live Oak	20	14
Union Transit	Lake Butler	7	6

5.1.1 Bus Collision Data

Transit agencies maintain records of all incidents that occur when transit vehicles are in service. Incident reports considered for this study were for the years 2007 to 2009. For the purpose of this study, the incidents are divided into collisions, also referred to as "crashes", and non-collision incidents (typically, on-board passenger injury). A stepwise review of the reports was therefore employed. First, the reports were reviewed to identify collision incidents, i.e., bus crashes with other vehicles, bicycles, pedestrians, or with fixed objects. Then the data were further screened to obtain only collisions that were coded as preventable. All non-preventable collisions were excluded, as were collisions which were neither coded as non-preventable nor preventable. Further examination was done to eliminate any preventable accidents that were perceived as having been caused by factors other than fatigue. Pertinent collision attributes such as operator information, time of crash, date of crash, and type of crash were collected to enable additional analysis.

5.1.2 Operator Schedule Data

Operator schedule data was collected in two steps. First, schedules of all operators in each of the participating agencies were collected to establish the distribution of operator driving schedules for all drivers. This set of data is also referred to as comparison data in this report. A record of each bus operator included total days worked per day, driving hours, and time of reporting on and off duty. It was not possible to collect three years worth of data for all bus operators in the four agencies. Two weeks were therefore randomly selected within the study period of between year 2007 and year 2009 to constitute comparison data, i.e., schedules for all operators. One week selected from a month with the lowest number of preventable crashes and another week from the month with the highest preventable crash occurrences were used. Second, schedules of operators who have been involved in collisions that were coded as *"preventable"* were collected. A two-week schedule prior to the day of accident was collected for each operator who was involved in a preventable collision and screened as described in the previous section. Schedule attributes that were collected include number of hours worked each day, the amount of split hours if any, and begin and end of duty time. Figure 5.1 shows an example of a weekly schedule. From the pay code, details of the schedule such as sick days, holidays, and administrative work could be depicted and excluded from driving hours. Also, split times could be computed from multiple on and off duty times during the same day.

Run	207	Card #	94463
Job Title			
Hire Date	06/25/2002		

TIME CARD Date	Pay Code	IN	IN Ex	OUT	OUT Ex	Reason	Schedule	Run#	Shift/ Pay Expr	Reg Hours	OT-1 - OT-2	Daily Total
09/22/2008 Mon	3 [SICK]							207 - RUN	002	8.00		8.00
09/23/2008 Tue	3 [SICK]							207 - RUN	002	8.00		8.00
09/24/2008 Wed		06:32 AM	E 8	10:19 AM	L 4		(6:40AM - 10:15AM)	207 - RUN	002-CR	3.58		
		02:27 PM	E 13	07:10 PM	G 5		(2:40PM - 7:15PM)	217 - RUN	002-IK	4.92		8.50
09/25/2008 Thu	6 [ADMN]							207 - RUN	002	8.00		8.00
09/26/2008 Fri	6 [ADMN]							207 - RUN	002	7.50		7.50

Name: BACUS-GRAY, STEPHANIE [94463] Totals: 40.00 0.00 40.00

TIME CARD Date	Pay Code	IN	IN Ex	OUT	OUT Ex	Reason	Schedule	Run#	Shift/ Pay Expr	Reg Hours	OT-1 - OT-2	Daily Total
11/22/2008 Sat		05:20 AM*	E 80	08:20 AM*	E655		(6:40AM - 7:15PM)	76 -	001-DD	2.00		2.00
11/24/2008 Mon		06:40 AM*		07:15 PM*			(6:40AM - 7:15PM)	76 -	001-DD	11.58		11.58
11/25/2008 Tue		06:40 AM*		07:15 PM*			(6:40AM - 7:15PM)	76 -	001-DD	10.42	1.16	11.58
11/26/2008 Wed		06:40 AM*		07:15 PM*			(6:40AM - 7:15PM)	76 -	001-DD		11.84	11.84
11/27/2008 Thu	1 [HOLI]							76 -	001	8.00		8.00
11/28/2008 Fri	1 [HOLI]							76 -	001	8.00		8.00

Name: CRAWFORD, DEBRA J [11011] Totals: 40.00 13.00 53.00

FIGURE 5.1 Example of Raw Data of Bus Operator Schedule

5.2 Data Analysis

5.2.1 Descriptive Statistics of Preventable Crashes

5.2.1.1 Time of day

The distribution of preventable collisions by time of day is depicted in Figure 5.2. The fewest collisions occurred between midnight and 4 AM, a reflection of reduced routes and exposure late at night. Preventable collisions happened more often in the afternoon between the hours of 1 PM and 7 PM (56%) with the greatest number of collisions occurring between the hours of 1:00 and 3:00 PM (26%).

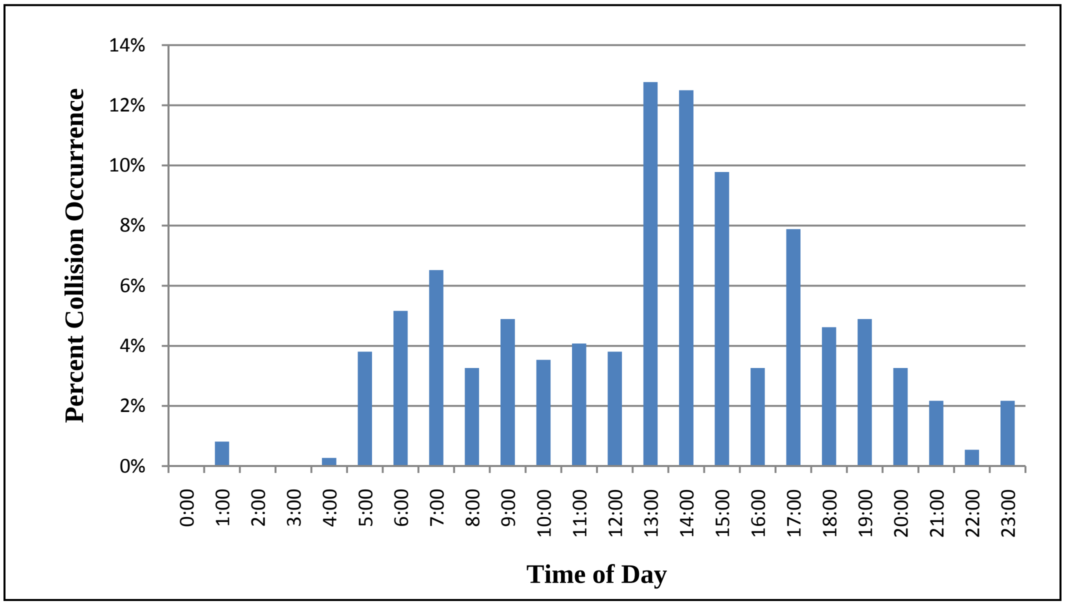

FIGURE 5.2 Bus Preventable Collisions by Time of Day

5.2.1.2 Day of week

Of 222 recorded preventable collisions examined from four Florida agencies, the majority occurred on a weekday (81%) with 14% occurring on a Saturday, and only 5% happening on a Sunday, perhaps a reflection of reduced exposure (Figure 5.3). Examination of the incident reports revealed that most of bus collisions that occur on Saturday happen at night and involve buses that shuttle patrons to events such as football and basketball games. The greatest number of collisions occurs on Wednesday, followed by Monday and Tuesday.

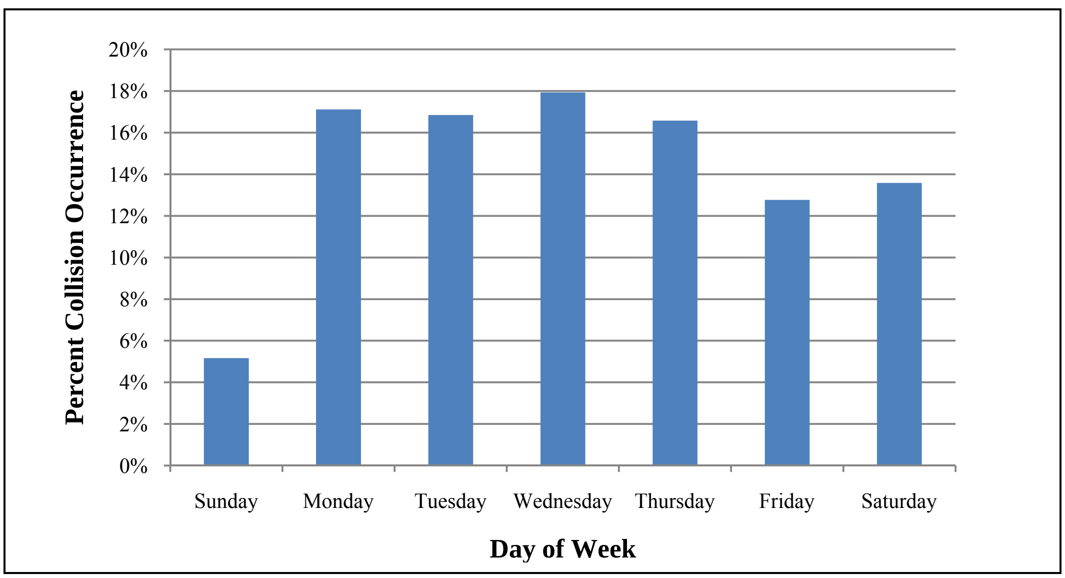

FIGURE 5.3 Preventable Bus Collisions by Day of Week

5.2.2 Descriptive Statistics of Operator Schedule

The 95% confidence interval for the combined mean weekly driving time for operators involved in preventable collisions was computed. A total of 222 collision occurrences were examined as summarized in Table 5.2. The results show a combined mean driving time of 49.8 hours for non-split driving periods with a 95% confidence interval of 48.7-hr to 50.9-hr. This suggests a 95% likelihood for a collision to happen when an operator's weekly driving hours exceed 45 hours and contain no split-time intervals. For operator weekly driving times containing split-time intervals, a combined mean driving time of 53.7 hours with a 95% confidence interval of 52.3-hr to 55.0-hr was computed indicating a 95% chance that a collision would occur when an operator's total hours, including split-times, exceeds 50 hours per week.

TABLE 5.2 Average Weekly Driving Hours of Operators Involved in Preventable Collisions and All Operators

Weekly average driving hours without splits								
Location	Average		Std. Deviation		Minimum		Maximum	
	Involved	All Drivers	Involved	All Drivers	Involved	All Drivers	Involved	All Drivers
Gainesville	49.22	40.24	7.36	2.70	35.75	32.10	68.55	60.50
Jacksonville	49.94	46.39	7.58	6.99	36.77	32.60	70.00	64.22
Orlando	50.02	43.90	7.54	9.09	31.25	6.25	68.68	65.02
Tallahassee	49.71	41.26	10.71	3.71	16.90	27.00	70.00	56.00
Combined	49.81	43.52	8.64	7.50	16.90	6.25	70.00	65.02
Weekly average driving hours with splits								
Location	Average		Std. Deviation		Minimum		Maximum	
	Involved	All Drivers	Involved	All Drivers	Involved	All Drivers	Involved	All Drivers
Gainesville	50.43	42.26	7.54	3.71	35.75	32.10	69.88	60.50
Jacksonville	54.34	51.79	8.46	10.90	39.95	32.60	71.56	85.67
Orlando	54.62	47.89	9.66	12.62	31.25	6.25	83.45	80.22
Tallahassee	53.35	46.73	11.82	9.41	30.50	27.00	81.35	70.50
Combined	53.67	47.65	9.85	11.06	30.50	6.25	81.35	85.67

From the 222 examined collision occurrences, the 95% confidence interval for the combined mean daily driving time for operators involved in preventable collisions was also computed. Summarized in Table 5.3, the results show a combined mean driving time of 9.8 hours for non-split driving periods with a 95% confidence interval of 8.8-hr to 11.5-hr. This suggests that for operators driving more than 9-hours per day without split-time intervals, there exists a 95% possibility of being involved in a preventable collision. For operator daily driving times containing split-time intervals, the combined mean driving time was 11 hours with a 95% confidence interval of 10.2-hr to 11.9-hr, suggesting a 95% possibility of being involved in a preventable collision when daily schedules exceed 11 hours per day.

TABLE 5.3 Average Daily Driving Hours of Operators Involved in Preventable Collisions and All Operators

Daily average driving hours without splits								
Location	Average		Std. Deviation		Minimum		Maximum	
	Involved	All drivers	Involved	All drivers	Involved	All drivers	Involved	All drivers
Gainesville	9.85	8.34	1.55	0.82	7.10	6.67	14.10	10.21
Jacksonville	9.13	8.70	1.03	0.96	5.18	7.50	12.10	12.84
Orlando	10.84	8.70	1.50	1.54	8.00	2.87	14.40	11.75
Tallahassee	9.94	8.26	2.14	0.88	3.38	6.40	16.27	10.00
Combined	9.83	8.58	1.72	1.23	3.38	2.87	16.27	12.84
Daily average driving hours with splits								
Location	Average		Std. Deviation		Minimum		Maximum	
	Involved	All drivers	Involved	All drivers	Involved	All drivers	Involved	All drivers
Gainesville	10.46	9.37	1.77	1.69	7.10	7.84	14.10	14.91
Jacksonville	10.89	9.73	3.08	1.87	7.88	7.50	21.65	14.55
Orlando	12.01	10.09	2.04	3.12	8.00	2.87	17.28	22.90
Tallahassee	10.67	9.36	2.37	1.95	6.10	6.40	18.94	15.30
Combined	11.01	9.77	2.58	2.49	6.10	2.87	21.65	22.90

5.2.3 Inferential Statistics Analysis

A one-tailed two-sample *t*-test was used to determine whether the population of operators involved in preventable collisions predominantly work longer hours or if driving schedules with split-time intervals played a role in collision occurrences compared to the overall population sampled with similar schedules. The *t*-test results for weekly driving hours without splits and with splits are summarized in Table 5.4. The results show that on average, drivers who were involved in preventable collisions drove over six hours more per week than that of the general population of drivers. The results of the one-tailed two-sample *t*-test revealed that a significant difference exists for all four agencies and for combined data. It is therefore evident from the data that statistically, operators who are involved in preventable collisions drive more hours compared to the population of all drivers.

TABLE 5.4 *t*-Test Results – Weekly Driving Hours

t-Test Results - Collisions for driving periods without splits						
Location	N		Mean Hours		T-Value	P-Value
	Involved	All drivers	Involved	All drivers		
Gainesville	23	132	49.22	40.24	-5.78	0.00
Jacksonville	80	172	49.94	46.39	-3.55	0.00
Orlando	47	296	50.02	43.90	-5.02	0.00
Tallahassee	72	77	49.70	41.26	-6.34	0.00
Combined	222	677	49.81	43.52	-9.71	0.00
t-Test Results - Collisions for driving periods with splits						
Location	N		Mean Hours		T-Value	P-Value
	Involved	All drivers	Involved	All drivers		
Gainesville	23	132	50.43	42.26	-5.09	0.00
Jacksonville	80	172	54.34	51.80	-2.02	0.022
Orlando	47	296	54.62	47.90	-4.24	0.00
Tallahassee	72	77	53.30	46.73	-3.76	0.00
Combined	222	677	53.67	47.70	-7.66	0.00

A one-tailed two-sample *t*-test was also used to examine if the population of operators involved in preventable collisions worked longer hours per day or if daily schedules containing split-time intervals influenced the likelihood of preventable collisions compared to the overall population of operators. The one-tailed two-sample *t*-test results for daily driving periods are summarized in Table 5.5. The results show a statistically significant difference between the studied populations indicating that operators driving longer hours per day or had split-time intervals during the day were more likely to be involved in a preventable collision.

TABLE 5.5 *t*-Test Results – Daily Driving Hours

t-Test Results – Collisions for Daily driving periods without splits						
Location	N		Mean Hours		T-Value	P-Value
	Involved	All drivers	Involved	All drivers		
Gainesville	23	132	9.85	8.34	-4.59	0.00
Jacksonville	80	172	9.13	8.70	-3.13	0.001
Orlando	47	296	10.84	8.70	-9.02	0.00
Tallahassee	72	77	9.94	8.26	-6.17	0.00
Combined	222	677	9.83	8.58	-9.99	0.00
t-Test Results – Collisions for Daily driving periods with splits						
Location	N		Mean Hours		T-Value	P-Value
	Involved	All drivers	Involved	All drivers		
Gainesville	23	132	10.46	9.37	-2.73	0.011
Jacksonville	80	172	10.89	9.73	-3.10	0.003
Orlando	47	296	12.01	10.09	-5.53	0.00
Tallahassee	72	77	10.67	9.36	-3.68	0.00
Combined	222	677	11.01	9.77	-6.24	0.00

5.2.4 Comparative Analysis

Table 5.6 shows the proportion of weekly driving periods of varying lengths for preventable collisions and all operators. The first column shows the number of driving hours per week divided into seven categories. The second column shows the number of preventable collisions for each driving period. Collision proportion as a ratio of number of preventable collisions for each category to the total number of preventable collisions is recorded in the fourth column. The fifth and sixth column shows the percentage of drivers in each driving hour category (drawn from all drivers schedule data) for driving hours without splits and with splits, respectively. Collision proportions relative to the exposure proportion for driving hours without splits and with splits are shown in columns seven and eight, respectively.

Table 5.7 shows a similar analysis for the proportion of daily driving periods of varying lengths for preventable collisions and all operators with the first column showing the number of driving hours per day divided into six categories.

TABLE 5.6 Comparative Analysis of Weekly Driving Hours for Combined Data

Combined Agency Weekly Summary							
Driving Period (1)	Collisions (2)	Collision proportion (without splits) (3)	Collision proportion (with splits) (4)	Exposure percentage (without splits) (5)	Exposure percentage (with splits) (6)	Collision prop. Relative to exposure prop. (without splits) (7)	Collision prop. Relative to exposure prop. (with splits) (8)
0- 40	17	0.08	0.05	34.0	23.4	0.23	0.23
>40-45	53	0.24	0.18	30.9	27.9	0.77	0.63
>45-50	59	0.27	0.17	16.5	15.9	1.61	1.05
>50-55	40	0.18	0.18	12.4	12.6	1.45	1.47
>55-60	25	0.11	0.15	4.0	7.6	2.82	2.00
>60-65	12	0.05	0.13	1.9	6.4	2.81	1.96
>65	16	0.07	0.14	0.3	6.1	24.40	2.27
Total	222	1.00	1.00	100	100	1.00	1.00

TABLE 5.7 Comparative Analysis of Daily Driving Hours for Combined Data

Combined Agency Daily Summary							
Driving Period (1)	Collisions (2)	Collision proportion (without splits) (3)	Collision proportion (with splits) (4)	Exposure percentage (without splits) (5)	Exposure percentage (with splits) (6)	Collision prop. Relative to exposure prop. (without splits) (7)	Collision prop. Relative to exposure prop. (with splits) (8)
0-8	21	0.09	0.05	39.88	26.44	0.24	0.20
>8-9	54	0.24	0.20	32.50	24.82	0.75	0.80
>9-10	59	0.27	0.19	11.96	11.37	2.22	1.66
>10-11	43	0.19	0.13	11.52	13.74	1.68	0.95
>11-12	22	0.10	0.11	3.55	8.71	2.80	1.24
>12	23	0.10	0.32	0.59	14.92	17.53	2.14
Total	222	1.00	1.00	100	100	1.00	1.00

For the first two weekly categories, i.e., driving periods below 45 hours per week, the proportion of drivers in the general population was higher than the proportion of drivers involved in preventable collisions. Collision proportions increased relative to the general population for driving hours exceeding 45 hours per week. Figure 5.4 shows the relationship between number of weekly driving hours and the collision and exposure proportion. It is clear from Figure 5.4 that preventable collisions are more prevalent as the length of the driving period increases.

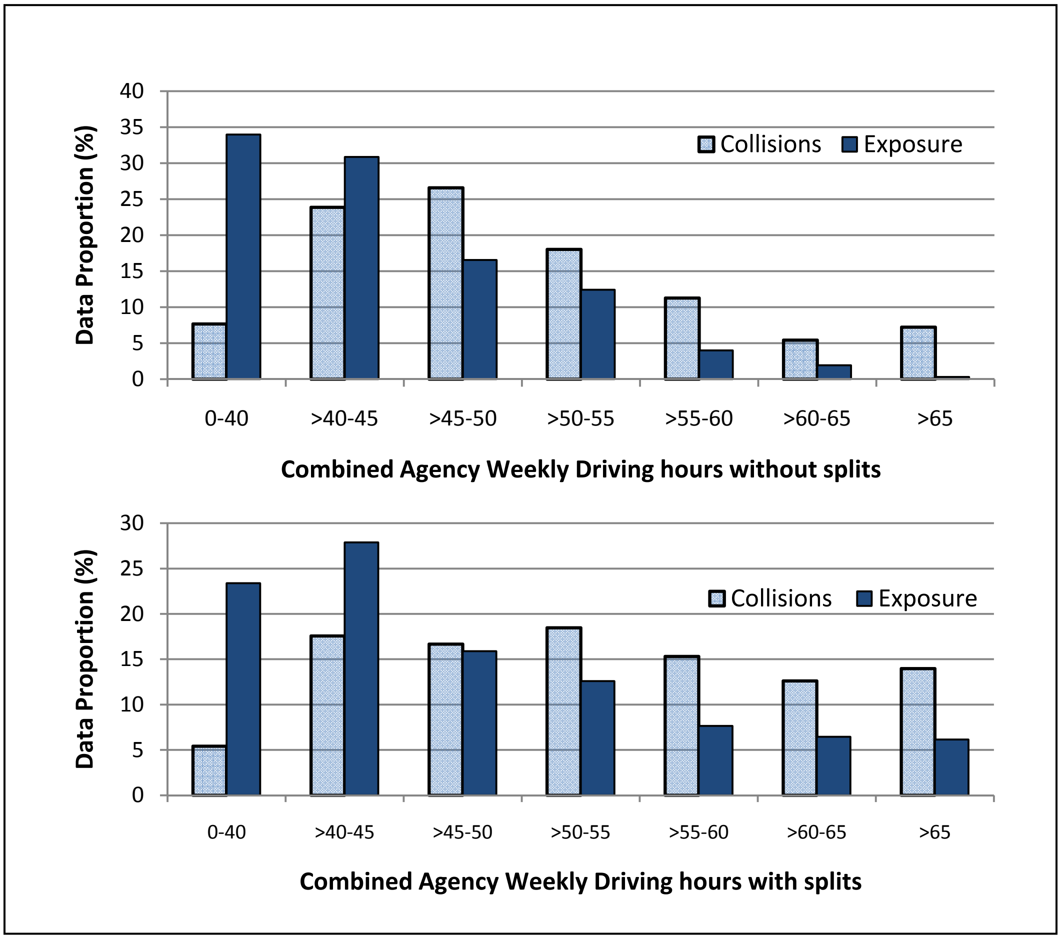

FIGURE 5.4 Comparative Analyses for Combined Weekly Hours

Similarly, the first two daily categories, representing driving periods below 9 hours per day, the proportion of drivers in the general population was higher than the proportion of drivers involved in preventable collisions. Figure 5.5 shows the relationship between number of daily driving hours and the collision and exposure proportion. In general, collision proportions increased relative to the general population for driving hours exceeding 9 hours per day. Collision proportions greatly increased for driving hours exceeding 12 hours per day for both operators with and without split-time intervals, further indicating that preventable collisions are more likely as the length of daily driving time increases.

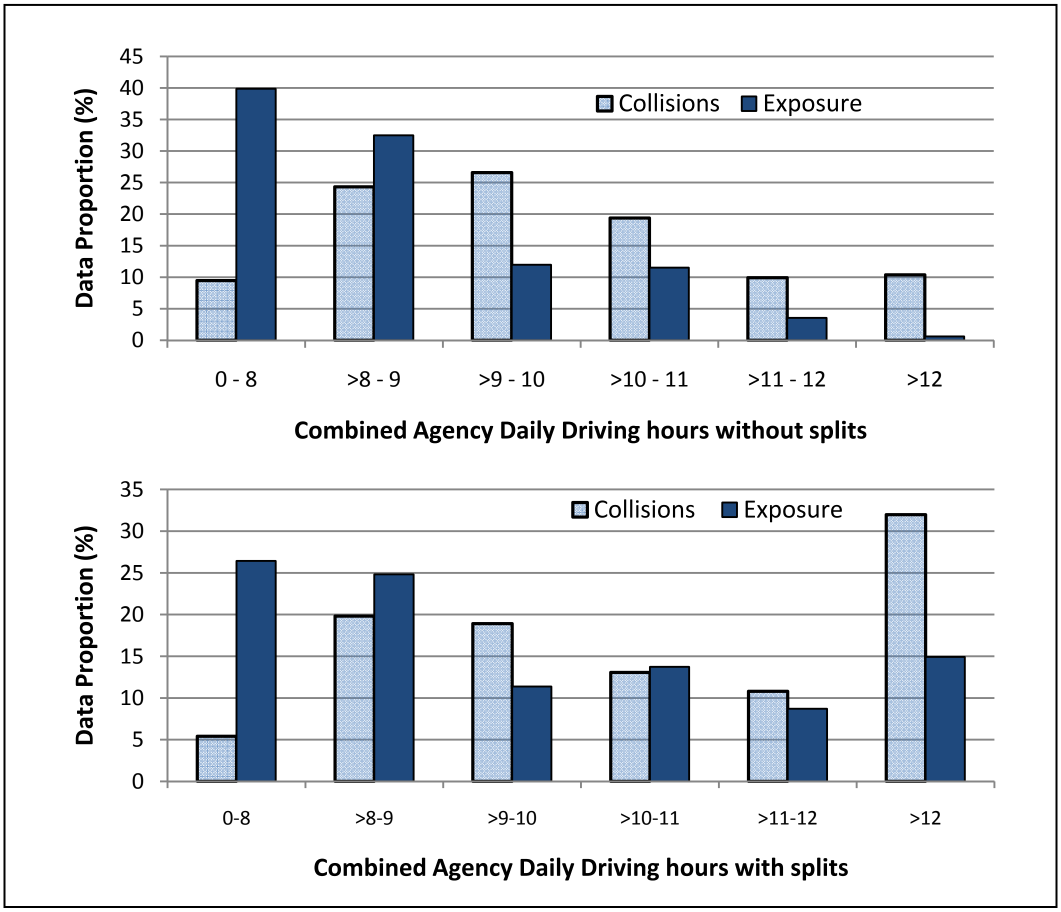

FIGURE 5.5 Comparative Analyses for Combined Daily Hours

5.2.5 Overrepresentation Analysis

The results of the comparative analysis were used to determine long driving hour's overrepresentation ratios for each driving hour duration category. The overrepresentation ratio was computed as collision proportions relative to the exposure proportions for driving hours (columns 7 and 8 in Table 5.6 and 5.7). The ratios for weekly proportions are shown in Figure 5.6. According to Figure 5.6, the ratio of collision proportion to the exposure proportion increases with the length of driving hours for both split and non-split schedules. For the same categories, drivers driving straight hours, i.e. without splits, were found to have a higher propensity of being involved in preventable collisions. The overrepresentation ratio increases drastically from 2.81 to 24.40 from driving hour category 55-65 hours to >65 hours for schedules with splits.

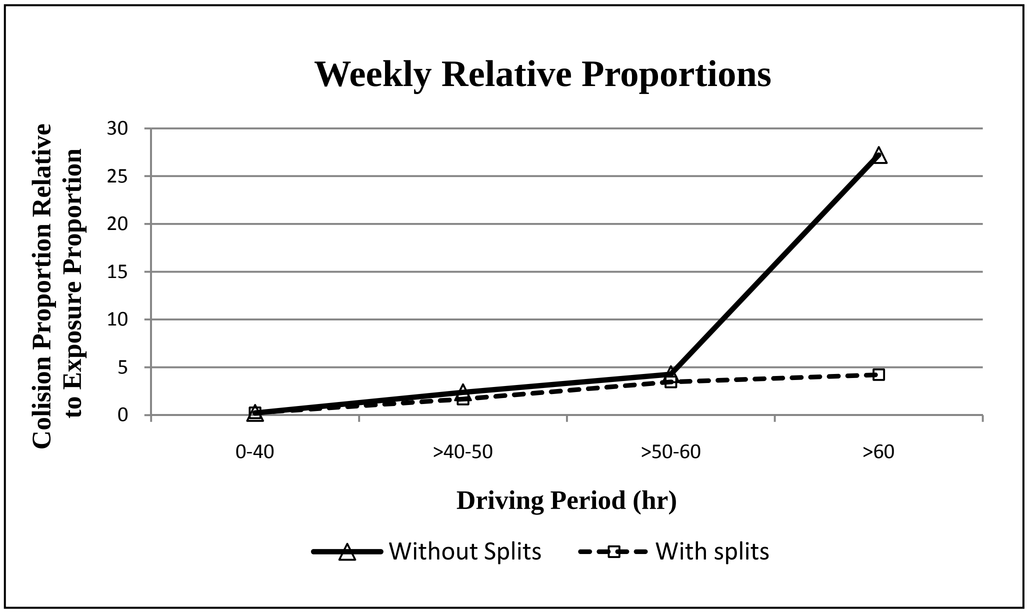

FIGURE 5.6 Weekly Proportions of Preventable Collisions Relative to Exposure by Driving Period

Figure 5.7 shows the ratios for daily proportions. From Figure 5.7 it can be seen that operators driving more than 10 hours per day for both split and non-split schedules, reflect a greater propensity for being involved in preventable collisions. This tendency further increases for daily driving hours greater than 12 hours per day where the overrepresentation ratio significantly increases from 2.80 to 17.53 for non-split schedules. The overrepresentation ratio also showed a steady increase for daily driving hours greater than 10 hours and containing split-time intervals.

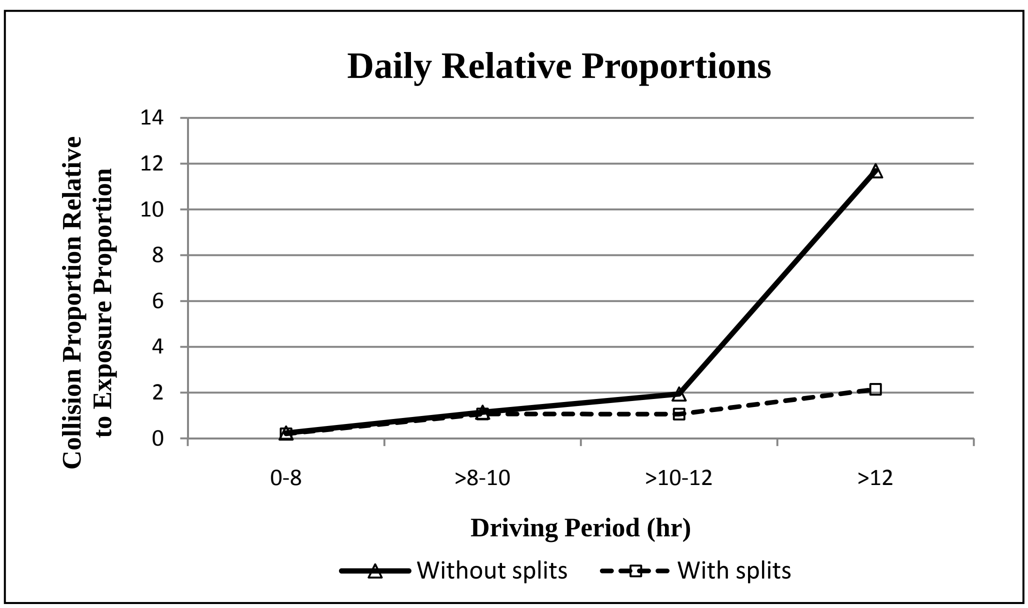

FIGURE 5.7 Daily Proportions of Preventable Collisions Relative to Exposure by Driving Period

5.2.5.1 Neglecting Split Times

Figure 5.8 depicts the comparison between the schedules of operators who were involved in preventable collisions and the schedules of the entire operator population that participated in the study. Unlike Figure 5.5, split-times were not included. It is clear from the two graphs presented in Figure 5.5 that the propensity of being involved in collisions increased as the number of driving hours increased.

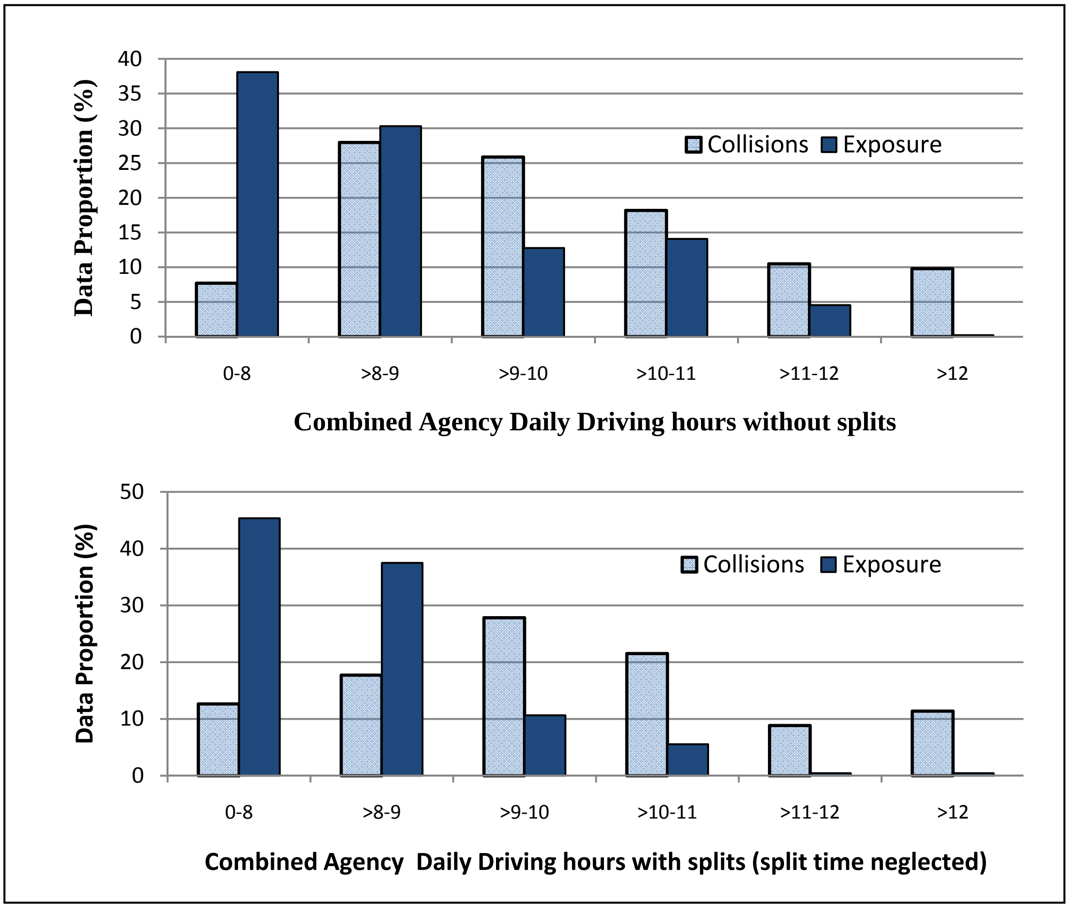

FIGURE 5.8 Comparative Analyses for Combined Daily Hours Neglecting Split Time

The implications of longer driving hours can be easily discerned by examining a supplemental graph, Figure 5.9, which shows the relative proportions of the percentage of collisions versus exposure percentage for drivers with and without splits. It is revealing to observe that for 10 driving hours or less, no difference is observed between drivers with and without splits. After 10 hours of driving, drivers with splits seem to have a higher ratio of accident proportion to exposure. This is probably caused by the fact that operators who drive more than 10 hours with splits may be driving 13 hours after reporting to work. If time between waking up and starting driving is taken in account, it is possible that this category of operators could be driving up to the 15th hour after waking up.

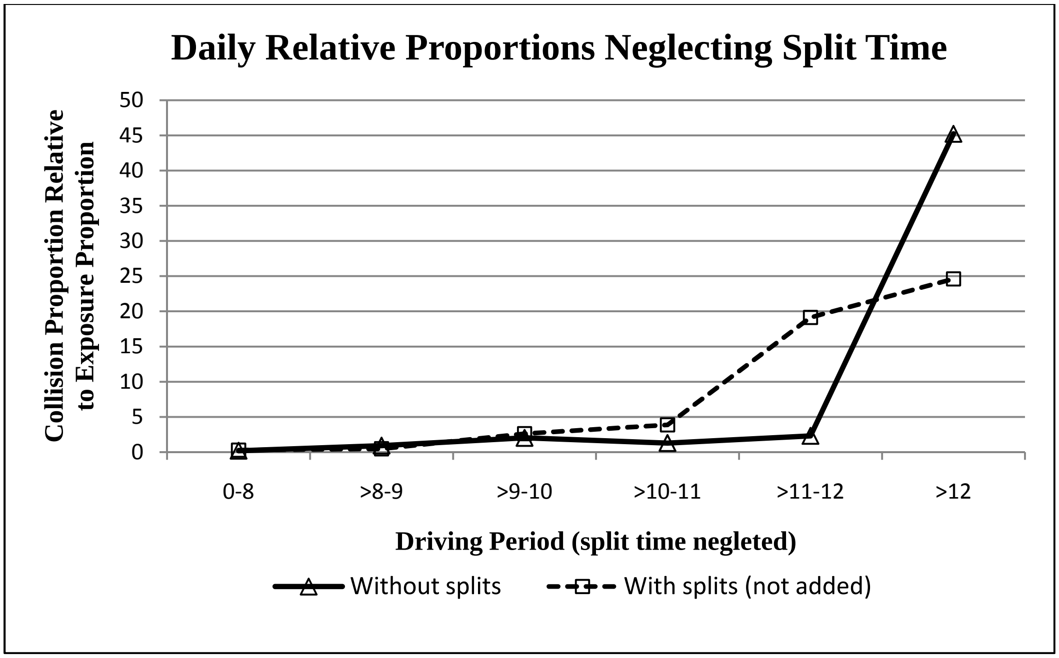

FIGURE 5.9 Daily Proportions of Preventable Collisions Relative to Exposure by Driving Period Neglecting Split-Time

6 FATIGUE ANALYSIS

6.1 Fatigue Analysis Using Fatigue Audit Interdynamics (FAID®)

This section discusses the use of Fatigue Audit Interdynamics (FAID®) as fatigue assessment tool. FAID® is a product designed to assist in the assessment of risks associated with workplace fatigue. FAID® is focused on fatigue related to hours of work only. As a risk assessment tool, FAID® fundamentally focuses on three basic elements which in combination create a potentially high risk of causing an accident. These three elements are hours of work (time on task), inadequate sleep (inadequate off duty period), and fatigue related hazards. Estimates of work-related fatigue are based on statistical modelling of the amount of sleep likely to be obtained by individuals based on the time of day and duration of work and non-work periods over a seven-day period. Indicative fatigue is inferred from estimated sleep obtained. These estimates are based on a formula developed by the Centre for Sleep Research at the University of South Australia and published in international peer-reviewed journals.

FAID® produces a number of outputs ranging from Key Risk Indicators (KRI) to Sleep Estimates (SE). The key outputs of interest for this study were: (1) FAID® Condition (FC); if Fatigue Tolerance Levels (FTL) is set, then in the Outputs, the work periods FAID® Score is compared to FTL. There are three levels of FAID® Conditions – Red (FAID® Score greater than FTL), Yellow (FAID® Score between –10 and 0 of the FTL) and Green (less than –10 of the FTL). (2) Compliance (used to describe the percentage of time individuals have worked when their indicative fatigue is below the Fatigue Tolerance Level (FTL)). (3) FAID® Score (FS); A relative index of work-related fatigue. (4) Fatigue Hazard; defined as a known characteristic, inherent property, vulnerability, condition or unintended action that represents a potential threat to people, property, the environment or business profitability that can be triggered by fatigued individuals.

6.2 Assessment of fatigue accumulation

FAID® Scores are indicators of the impact of work schedules leading to sleep deprivation and hence fatigue. As they are based on a statistical analysis of research performed into fatigue levels over a broad sample of population, they provide guidance on the fatigue of an individual. The FAID® Scores can be obtained in tabular format (Table 6.1) or plot (Figure 6.1). The tabular outputs make it easier to conduct further statistical analyses to develop or investigate the association between the FAID scores and crash occurrences. It is easier to verify the pattern of fatigue accumulation by using FAID® Scores Plot. Figure 6.1 shows fatigue conditions (FAID® Scores) for a particular operator from 9^{th} – 31^{st} August, 2009. Essentially, FAID® gives such plots for every operator whose work schedules were entered into a system database.

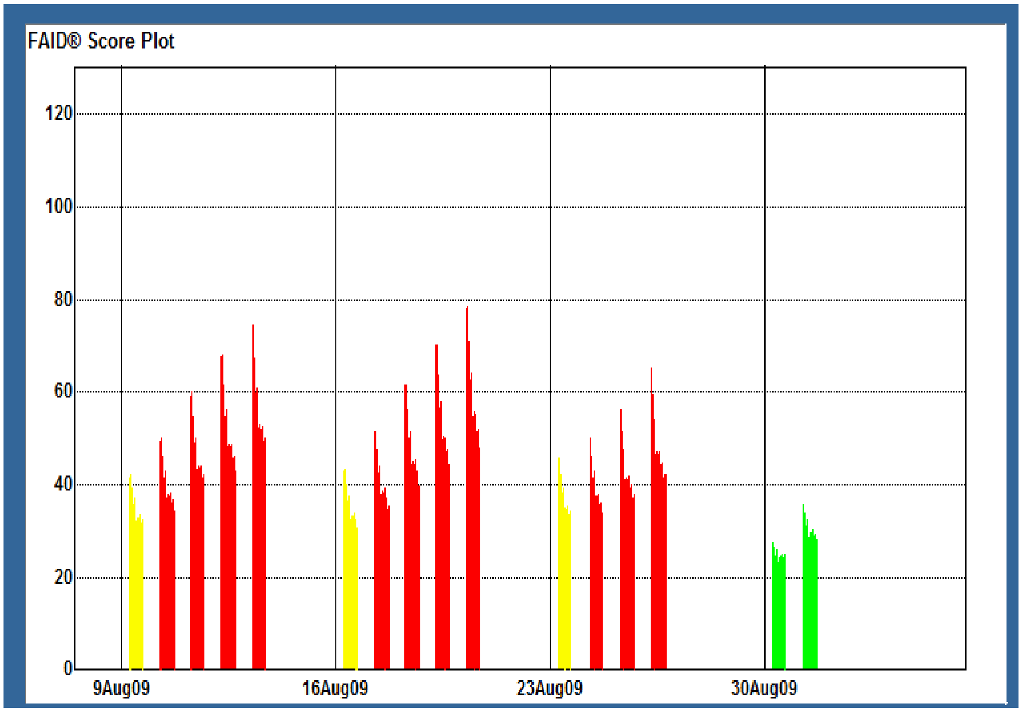

FIGURE 6.1 Fatigue score plot

The yellow FAID® condition in the first day of the schedule indicates the effects of early start and long hours on task. The early start leads to reduced sleep which is among significant factors which cause fatigue. The effect seems to accumulate more in the next day shifting the fatigue condition into red which is the critical fatigue condition. We can clearly observe from every schedule that peak FAID® conditions increase cumulatively every worked day. The importance of adequate off-duty period and a well managed schedule can be observed by noticing the difference in FAID® condition in 16th August, 2009 (after 2 days of rest) and 30th August, 2009 (after 3 days off duty). The schedule of starting on August 30, 2009 shows FAID® condition green which means the fatigue that was accumulated all over the previous schedules was completely dissipated within the off duty period. In other schedules prior to that starting on August 30, 2009, just on the first day of the schedule the operator is exposed to yellow FAID® condition implying that the off duty period wasn't enough to dissipate the accumulated fatigue in the previous schedules.

The phenomenon of cumulative nature of fatigue calls a need for a strong move toward developing different approaches to ensure an adequate average off duty period and opportunity to obtain sleep for fatigue risk management. Broadly speaking these can be divided into two groups: modified prescription; and fatigue modeling. The most common control process has been compliance with prescriptive hours of service (HOS) rule sets. In spite of the frequent use of prescriptive rule sets, there is an emerging agreement that they are an ineffective hazard control, based on poor scientific defensibility and lack of operational flexibility (Dawson *et al*., 2005). In investigating potential alternatives the proposed approach is to shift from prescriptive HOS limitations toward a broader Safety Management System (SMS) approach which assesses individual's fitness for duty.

6.3 Investigation of the association between FAID® conditions and crashes.

To conduct the accident analysis the fatigue conditions output for all operators from FAID® were obtained (see sample output in Table 6.1) and the operators who were involved in preventable accidents were identified and categorized in three FAID® conditions (green, yellow and red) ; similarly, operators who were not involved in preventable accidents were categorized in three FAID® conditions.

TABLE 6.1 FAID® score for operator monthly schedule

Non-Work	Start	Work	Task	FAID® Condition Green	FAID® Condition Yellow	FAID® Condition Red	Peak FAID® Score	Peak FAID® Cond
61.8	9 Aug 09 0630	9.7	Moderate	8hr 19min	1hr 23min		43	-7
14.3	10 Aug 09 0630	10.8	Moderate	6hr 47min	3hr 27min	35min	51	1
13.2	11 Aug 09 0630	10.2	Moderate	2min	7hr 22min	2hr 46min	60	10
13.8	12 Aug 09 0630	10.6	Moderate		6hr 19min	4hr 17min	68	18
13.9	13 Aug 09 0700	9.0	Moderate		1hr 2min	7hr 58min	75	25
62.5	16 Aug 09 0630	10.5	Moderate	8hr 54min	1hr 36min		43	-7
13.5	17 Aug 09 0630	11.4	Moderate	7hr 13min	3hr 12min	59min	52	2
12.6	18 Aug 09 0630	10.7	Moderate	17min	6hr 42min	3hr 45min	62	12
13.3	19 Aug 09 0630	10.4	Moderate		3hr 58min	6hr 29min	71	21
13.6	20 Aug 09 0630	10.5	Moderate		29min	10hr 2min	79	29
61.6	23 Aug 09 0635	9.6	Moderate	7hr 36min	2hr 1min		46	-4
14.8	24 Aug 09 0700	10.1	Moderate	6hr 37min	3hr 25min	5min	50	0
13.9	25 Aug 09 0700	11.1	Moderate	2hr 51min	6hr 54min	1hr 21min	57	7
12.9	26 Aug 09 0700	11.4	Moderate		7hr 51min	3hr 33min	65	15
84.6	30 Aug 09 0700	9.0	Moderate	9hr 0min			28	-22

For analysis simplicity the variables for crash occurrence and non-occurrence are coded as Y=1 and Y=0 respectively. The fatigue condition an operator is exposed to and crash frequencies data are structured as a 2x3 contingency table (Table 6.2) to pose the question: Is there an association between crash occurrence and a particular fatigue condition? The null and alternative hypotheses to test for independence between crash occurrence and FAID® condition variables are written as:

$H_0 : \prod_{ij} = \prod_{i.} \cdot \prod_{.j};$ (Row and column variables are independent)
$H_a : \prod_{ij} \neq \prod_{i.} \cdot \prod_{.j}$ (Row and column variables are dependent) $i = 1, 2; j = 1,2,3$

The test statistic is (distributed as chi-square with degree of freedom $(n_i-1)(n_j-1)$):

$$F = \sum_{i=1}^{3}\sum_{j=1}^{3} \frac{(O_{ij} - e_{ij})^2}{e_{ij}} \text{ , Where; } e_{ij} = \frac{n_{i.}n_{.j}}{n_{ij}}$$

It compares the observed frequencies (O_{ij}) in the table with the expected frequencies(e_{ij}) when H_0 is true .

TABLE 6.2 FAID® Conditions and Frequencies *of Accident Occurrence and Non-occurrence*

Crash response	FAID® conditions						Total ($n_{.j}$)	$n_{.j}$ /n
	Green		Yellow		Red			
		e_{ij}	O_{ij}	e_{ij}	O_{ij}	e_{ij}		
Y =1	20	33.096	27	27.290	61	47.613	108	0.581
Y =0	37	23.903	20	19.709	21	34.387	78	0.419
Total ($n_{i.}$)	57		47		82		186	
$n_{i.}$ /n	0.306		0.253		0.441			

$$F = \sum_{i=1}^{2}\sum_{j=1}^{3}\frac{(O_{ij} - e_{ij})^2}{e_{ij}} = 21.343, \quad df = 2, \quad p - value < .0001$$

As indicated in Table 4.1 the FAID® condition and the crash occurrence are significantly associated (*p*-value <0.001). The calculated Chi-square of 21.343 is highly significant exceeding the 5% significance threshold as shown in the bottom of the Table 6.2. Most of the accidents (56.48%) occur when the operators are exposed to red fatigue conditions. The proportion of accidents seems to decrease as the fatigue condition changes from red towards green.

According to Table 6.3, operators who were in green fatigue conditions show good driving history as indicated by the nonoccurrence proportion (47.8%). Yellow condition shows most interesting results; having about the same proportions for both occurrence and nonoccurrence (25% and 25.64% respectively). In our opinion, we could choose this fatigue condition as an optimum fatigue condition for the establishment of fatigue management framework.

TABLE 6.3 FAID® conditions and proportions of accident occurrence and nonoccurrence

Crash response	FAID® condition		
	Green	Yellow	Red
Y =1	18.52%	25.00%	56.48%
Y =0	47.77%	25.64%	26.92%

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

This study was conducted to examine the relationship between the number of driving hours of bus operators and the occurrence of preventable collisions. The study utilized incident and schedule data from four Florida transit agencies. Weekly schedules of transit operators were examined using several analysis methods including descriptive statistics, *t*-test inferential statistics, and graphical comparative analysis.

The main objective of this study was to evaluate the relationship between the number of driving hours of bus operators and the occurrence of preventable collisions. The research team conducted a comprehensive analysis of the influence of operator schedules on transit safety using a combination of three methods. The three methods employed were: (1) Questionnaire Survey, (2) Operator Schedule and Collision Analysis, and, (3) Fatigue Analysis. The results pertaining to each of the five methods are summarized below.

7.1.1 Questionnaire survey

On average, the surveyed drivers reported to sleep for about six hours per day. It was observed that the amount of sleep decreases with the increase in the number of hours on duty with a drastic decrease after spending more than 16 hours on duty. A regression model that was developed to describe the influence of reported factors on the amount of sleep revealed that the amount of sleep that transit operators get is influenced by several factors including arrival time to work, leave time from work, time of driving duty, and the number of days worked per week. As for the splits, responses from drivers who worked split shifts indicated that just about half of the drivers used split time for resting activities, i.e., napping and relaxing. When considering net resting time, it is clear from the results of the survey that most split time is used for activities other than resting.

7.1.2 Operator Schedule and Collision Analysis

The results show an overall average of 49.8 hours for driving periods containing no split-time intervals, with a 95% confidence interval of 48.7-hr to 50.9-hr. For operator weekly driving times containing split-time intervals, a combined mean driving time of 53.7 hours with a 95% confidence interval of 52.3-hr to 55.0-hr was computed indicating a 95% chance that a collision would occur when an operator's total hours, including split-times, exceeds 50 hours. The results of the t-test analysis indicate that drivers who are involved in preventable collisions drive more than six hours per week than the general driver population. The results were statistically significant.

The results of the comparative analysis suggest that preventable collisions occur predominantly to drivers with long driving schedules. The overrepresentation analysis further indicated that relatively, drivers driving over sixty hours per week without splits have higher propensity of being involved in a preventable collision. Based on the findings of this study, a discernible pattern was observed that shows that there is a correlation between preventable collisions and the length of transit operator driving hours. Present regulation limits bus operators to drive a maximum of seventy two hours per week. In light of the findings of this study, a lower limit might be more desirable as the overrepresentation ratio was observed to spike after sixty hours of driving per week.

7.1.3 Fatigue Analysis

The peak fatigue scores for a particular day in a schedule were observed to be higher than the previous day for the same schedule. This is the evidence of cumulative nature of fatigue. The results from the fatigue analysis also indicates that, after the accumulation of fatigue the operator needs enough off duty period to recover from critical fatigue condition. To start with a green fatigue condition (full recovery) the results indicated that, in a weekly schedule the operator needs at least two days off duty. In addition, the study revealed that, there is a statistically strong association between fatigue condition and crash occurrence (with *p*-value less than 0.001); a large proportion (56.48%) of accidents associated with operators who were in red fatigue conditions.

7.2 Recommendations for Transit Operator Schedules

7.2.1 Minimum Daily Off-Duty Period

Individuals should be afforded the opportunity to obtain eight hours of sleep per twenty-four hour period. The current regulation allows for a minimum of eight hours of off-duty time which does not translate to eight hours of sleep. Based on the findings of the survey, on average drivers spend 52.36 minutes to travel to and from work and 41.47 minutes to prepare to go to work after waking up. That does not account for the time they need to spend with family and perform other after and/or before work activities. Clearly, the current minimum off-duty period of eight hours is insufficient, if the objective is to afford operators with a minimum eight hour sleep time. Based on the findings of this study, it is recommended that FDOT consider increasing the minimum off-duty time.

7.2.2 Split-Time

Typically, agencies run more routes during peak hours, namely the morning and evening peak hours and operate fewer buses during non-peak hours. Operators with split shifts are therefore not needed during off-peak hours hence do not get paid for the time off in between driving periods. The questionnaire analysis indicates that drivers with split shifts stay longer hours at work and get less amount of sleep. Responses from questionnaires show that nearly 50% of drivers do not use split-time for resting. The analysis of actual schedules and collisions show that proportionally, operators with split schedules are more involved in preventable collisions. This study recommends that schedules be optimized with an objective of minimizing the length of splits.

7.2.3 Maximum Daily Driving Hours

Currently, Florida drivers are permitted to drive up to 12 hours in any one 24-hour period. The rule also allows drivers to work for a maximum of 16 hours (without counting the split-time) if four hours are non-driving activities. If non-driving work and splits are involved, drivers who drive buses for 12 hours per day could spend more than 16 hours at work per day.

The questionnaire analysis shows that drivers who work long hours obtain fewer hours of sleep. The operator schedules and collision analysis indicates that longer hours are associated with higher occurrence of preventable collisions. The fatigue analysis confirms that drivers who worked longer hours were overrepresented in the highest fatigue score (red condition). The current daily limits used in the state of Florida are higher compared to the federal limits that govern trucks and interstate buses (see Table 2.1). Based on the results of this study, FDOT is advised to consider reducing the maximum driving hours.

7.2.4 Maximum Weekly Driving Hours

According to Draft Rule 14-90.006(3-6) for Florida transit operators, a driver shall not be permitted or required to be on duty more than 72 hours in any period of seven consecutive days. In comparison, the maximum driving federal regulation for interstate truck and interstate passenger-carrying commercial motor vehicle drivers is 60/70 hours on duty in 7/8 consecutive days. The overrepresentation analysis presented in Chapter 5 indicated a spike in crash occurences for operators who drove more than 60 hours per week. It is advised that FDOT consider reducing the maximum weekly driving hours to allow more off-duty time for drivers to regenerate before resuming transit driving task.

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Appendix A

A Blank Questionnaire Survey

Anonymous Questionnaire to solicit information on typical transit operator activities on a normal work day
Survey guide for transit operators

The Florida Department of Transportation is sponsoring a research project to evaluate the safety implications of transit operator schedule policies. The main objective of this research is to evaluate the adequacy of a minimum 8-hour off-duty time as a mandatory rest period for bus operators. More information about the project is available from the project manager and the principal investigator who can be reached using the following email addresses and phone numbers.

FDOT Project Manager: Victor Wiley; Contact Info: victor.wiley@dot.state.fl.us; (850) 414-4525
Principal Investigator: Thobias Sando; Contact Info: t.sando@unf.edu; (904) 620-1142

This questionnaire is designed to guide a bus operator to provide his/her best knowledge on how he/she uses her time on a typical work day.

1. What time do you normally arrive at work? ___________; leave from work? ___________
2. How many days during your 7-day work week are you on duty? ________________; days on duty not driving? _____________________.
3. How many hours during your 7-day work week do you normally drive? _________________; hours on duty not driving? _______________.
4. How many hours during a 24 hours period do you normally drive? ___; hours on duty not driving? ________
5. Is your schedule fairly the same throughout the week? Yes_____ No_______
6. Do you work different shifts? Yes_____ No______
7. Do you work split schedule? Yes_____ No_______
8. On average, how long is your split time? ______hours
9. How do you use your split time? Check all that apply.
   Running errands: shopping, doctor's appt, etc. [ ]
   Eating: [ ] at work site [ ] or at home [ ]
   Relaxing - not sleeping: [ ] at work site [ ] or at home [ ]
   Taking a nap: [ ] at work site [ ] or at home [ ]
   Performing non-driving duties in the office [ ] Reading [ ]
   *Other (list)*____
10. How far from work do you live? _____ Miles
11. On average, how long does it take for you to travel from home to work? ____ Min/Hours
12. On average, how long does it take for you to travel from work to home? ____ Min/Hours
13. On average, how long do you prepare to get ready to leave for work? _____ Minutes
14. Do you regularly run personal errands on your way home from work? Yes_____ No_____
15. On average, how long does it take from the time you get home to the time you go to sleep? ___ hours
16. On average, what time do you go to sleep? _____
17. On average what time do you get up? ____

18. Any Comments/Remarks

____

____

____

____

Thank you for your participation in this important research aimed at enhancing safety and improving transit operations in the state of Florida.

Rule 14.90 F.A.C.-Definitions
"On Duty" means the status of the driver from the time he or she begins work, or is required to be in readiness to work, until the time the driver is relieved from work and all responsibility for performing work. "On Duty" includes all time spent by the driver as follows:

a) Waiting to be dispatched at bus transit system terminals, facilities, or other private or public property, unless the driver has been completely relieved from duty by the bus transit system.
b) Inspecting, servicing, or conditioning any vehicle.
c) Driving.
d) Remaining in readiness to operate a vehicle (stand-by).
e) Repairing, obtaining assistance, or remaining in attendance in or about a disabled vehicle.

"Drive" or "Operate" are terms which include all time spent at the controls of a bus in operation.