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Modeling Fatigue-Induced Collision Relative Risk: Implications of Service Hours and Fatigue Management Policies on Transit Bus Operators in Florida

by Enock Mtoi, Ren Moses, and Thobias Sando

This research explores the association between fatigue-induced crash risk, transit operator hours of service and fatigue management policies in the state of Florida. Data used in this study include incident data archived by transit agencies and bus driver schedules. The results show a decreasing trend of collision risks when drivers start their schedules late morning or afternoon compared with early morning. The effect of time on task shows increasing collision risk as drivers drive long hours without enough off duty periods.

INTRODUCTION

Driver fatigue has been identified as a high-priority commercial vehicle safety issue by the Federal Motor Carrier Safety Administration (FMCSA), the commercial motor vehicle industry, highway safety advocates, researchers, and the public (Barr et al. 2005). Different sources reported that driver fatigue and fatigue-related accidents are affected by a variety of variables, such as time of day effect due to circadian rhythm, sleep debt, monotonous driving environments, length of driving, weather conditions, use of alcohol and drugs, heat, vibration, and noise (Wyle et al. 1996). Agencies such as the Florida Department of Transportation (FDOT) that deal with regulating transit systems have established rules that limit operator duty periods to reduce fatigue. Although there are many reasons why managing service hours is a challenging task, the most perplexing is the inconsistency in research findings concerning the effect of driving schedules on driver performance and safety (Park et al. 2005). Operating rules are created to promote safe, efficient, timely, and customer-oriented transit operations. Most states have adopted intrastate regulations that 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 hours compared with 10 and 11 hours for interstate carriers carrying passengers and commercial motor vehicles). The 16-hour on-duty limit in Florida is higher than the 15-hour limit for interstate passenger-carrying commercial motor vehicles' drivers.

FDOT's Bus Transit Draft Rule 14-90.006 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 (Florida Administrative Register and Administrative Code 2008). The rule allows the 12 hours of driving time to be spread out provided they do not exceed 16 hours of on-duty time in any one 24-hour period. For example, in the worst case scenario, a driver might be on duty driving for eight hours and then take four hours break and return to on duty status for an additional eight hours (i.e., four hours driving and four hours non-driving). This would be considered as a maximum driving time of 12 hours and 16 hours on duty time in a 24-hour period, although the driver may not have had any rest for 20 hours. Rule 14-90.006 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 (Florida Administrative Register and Administrative Code 2008).

Table 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 15-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.

Source: Federal Motor Carrier Safety Administration (2010)

Notably, the minimum eight consecutive hours of off-duty time stipulated in Rule 14-90.006 is not the net resting time. Part of the eight hours 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 sleeping. Regarding the split schedule, it is presumed that operators would use the break time for resting to rejuvenate their bodies 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.

The preponderance of scientific literature strongly shows that long hours of work lead to fatigue that can degrade performance, alertness, and concentration, which increase safety risk. Several studies on the influence of operator schedule on accident occurrence have been conducted for the aviation, rail, and trucking industries (McCart et al. 2000, Williamson et al. 1995, Coplen and Sussman 2000). The search of literature did not reveal similar research efforts for bus operators despite a concern that bus operators' spread-hour schedules can lead to fatigue and hence increase the chance of crash occurrence. A thorough understanding of the correlation between transit accident occurrence and long duty hours caused by split schedules, together with the minimum eight consecutive hours of off-duty time, is crucial in setting transit operating rules.

The objective of this study is to analyze operator hours-of-duty policies in Florida and determine if there are safety impacts that may prompt changes to these policies. The study uses incident reports and operator schedule data archived by transit agencies to determine the relationship between crash involvement and operator schedules. Factors of interest in this study, as found in the existing hours of service policies, are the influence of shift pattern (start and end time), schedule pattern (split or straight time schedule), time spent on driving, and time off duty on fatigue and safety.

LITERATURE REVIEW

The concepts of "fatigue," "sleepiness," and "drowsiness" are sometimes used interchangeably. Sleepiness can be defined as the neurobiological need to sleep resulting from physiological wake and sleep drives (Johns 2000). Fatigue has, from the beginning, been associated with physical labor, or, in modern terms, task performance. Although the causes of fatigue and sleepiness may be different, their effects are very much the same, namely a decrease in mental and physical performance capacity.

It is comprehensible from everyday experience that fatigue has different causes; the most common is intensity and duration of physical work. To maintain health and efficiency, the recuperative processes must cancel out accumulated fatigue. Recuperation takes place not only during night-time sleep, but free periods during the day, and all kinds of pauses during work, also make their contributions.

Various studies have been conducted to develop relationships between fatigue and performance decreases in different industries. Particular significance is attached to studies of fatigue in traffic, because it is reasonable to suppose that fatigue plays an important part in mistakes and crashes. For the driver, the main effect of fatigue is progressive withdrawal of attention from road and traffic conditions leading to impaired performance behind the wheel. Fatigue influences driving behavior in various ways such as slower reaction time, reduced vigilance, unsafe car following behavior, speed choice, and reduced information processing. Several authors have shown indisputably that about four hours of continuous driving is enough to bring on a distinct reduction in the level of alertness, and thereby increase the risk of accidents (Feyer and Williamson 1995; Williamson et al. 1995; Knipling and Wang 1994). Fatigue and sleep are causal factors in thousands of crashes, injuries and fatalities annually (Knipling and Wang 1994). At the 1995 National Truck and Bus Safety Summit, driver fatigue was identified as the leading safety issue in the industry (U. S. Department of Transportation 1998) and the National Transportation Safety Board (NTSB) estimated 31% of all truck-driver fatalities and 58% of all single-truck crashes were fatigue related (Schultz 1998).

In an effort to identify factors affecting long-haul truck drivers' performance, McCart et al. (2000) performed face-to-face interviews with 593 long-distance truck drivers at rest areas and inspection points. They found six factors influence drivers falling asleep at the wheel. They are greater daytime sleepiness; more arduous schedules with more hours of work and fewer hours off-duty; older, more experienced drivers; short, poorer sleep on road; symptoms of sleep disorder; and greater tendency toward nighttime drowsy driving. The study further suggested that limiting drivers' work hours would enable them to get adequate sleep to reduce sleep-related crashes.

Using a different technique, Williamson et al. (1995) carried out a controlled experiment whereby they examined 27 professional truck drivers who completed a 12-hour, 900 kilometer trip under three different settings – a relay trip, a working-hour regulated one-way single trip, and a one-way (flexible) trip with no work-hour constraints. The results of the study indicated no difference in fatigue for the three different experimental settings. However, the study suggested that fatigue patterns were more related to pre-trip fatigue levels.

The review of literature thus far indicates that most studies' focus is more on other modes of transportation than on bus transit. Very few studies have examined the influence of fatigue specifically on city bus drivers. Santos et al. (2004) evaluated daytime and nighttime sleep, as well as daytime and nighttime drowsiness of professional shift-working bus drivers in Brazil. The study revealed that the sleep time of shift-working bus drivers was shorter and more fragmented when it occurred during the day than at night. Howarth (2002) investigated differences in self-reported sleep length and aspects of fatigue for a sample of bus transit 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, whereby fatigue levels increased with decreasing sleep length.

It is important to recognize that the operational characteristics of city buses differ from those of other modes of mass transportation and trucking. Feyer and Williamson (1995) pointed out that although fatigue is a problem for coach drivers, it is not of the same importance for truck drivers. They argue that operationally, bus drivers are not as free as truck drivers to take rest on a need basis. Unlike trucks for example, bus routes are scheduled during peak hours because that is the time when buses get more riders. Also, unlike truck drivers, bus drivers have less flexibility in choosing their schedules based on what time of the day they feel more energetic to perform a task. City buses use mostly city streets while trucks use mostly highways. Buses stop more frequently than trucks. In addition to driving, bus operators in most agencies perform other tasks such as collecting fares and validating identity cards.

In order to reduce fatigue and fatigue-related accidents, management of driver hours-of-service for bus transit operators has been a continual safety challenge. One study found that the principal factor associated with decline in driver performance was time of day (Wyle et al. 1996). Furthermore, the study found that the number of driving hours and the cumulative number of days driving were not strong or consistent predictors of decline in driver performance. This study therefore examines operator hours-of-duty policies in Florida and determines if there are safety impacts that may prompt changes to these policies.

RESEARCH APPROACH

Data Collection

Data from four Florida transit agencies were acquired. Until 2009, there were 35 fixed-route transit systems operating in Florida. Data collected for this study were from 2007 to 2009. Due to difficulties in acquiring the data, and the requirements to deliver results on time, the research team categorized the agencies into two. Agencies operating a fleet of less than 200 buses were grouped as small size agencies and those operating a fleet of more than 200 buses were categorized as large size agencies. Appendix A shows that two large and two small agencies were selected for the study. The selection was based on agency willingness to provide the data. Jacksonville Transit Authority (JTA) and Lynx (the transit agency in Orlando) are the large size agencies while StarMetro and Regional Transit System (RTS) in Tallahassee and Gainesville, respectively, are the small size agencies. These agencies require bus operators to report all incidents including collisions with other vehicles and fixed objects.

From the incidents' databases of these agencies, data on bus crashes and operator schedules were extracted. The crash reports were then reviewed to identify bus crashes with other vehicles, bicycles, pedestrians, or fixed objects. Further examination was done to eliminate any preventable accident that was 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.

Model Formulation and Variable Design

A regression model is formulated to relate crashes to fatigue and other variables. In this model, the response variable takes two distinct values: Y = 1 if a crash occurred and Y = 0 if a crash did not occur. Because the responses are binary, the most common techniques to analyze them are logistic and probit regressions and they have been used in many crash studies (Hours et al. 2010, Robertson and Vanlaar 2008, Schiff et al. 2008). Because both models give similar results, the choice between which to use depends upon assumptions regarding the distribution of the responses. In this paper it is assumed that the responses follow logistic distribution leading to the choice of logistic regression with crashes as the dependent variable. The data collected from the agencies showed that there are two types of schedules; split- and straight-runs. A split-run schedule is where a person's normal work day is split into two or more segments while in a straight-run schedule, each operator has its own set of continuous work hours that do not change. The data also showed that there are three different work-starting times for drivers: early morning, late morning, and afternoon. Therefore, the variables were categorized by schedule types and work starting times. The predictors of relative collision risk are schedule types (split = SPL or straight = CON), time on task (TOT), off duty hours (OFF), and start time (ST). Appendix B shows descriptions of these predictors. The model does not include driver and vehicle characteristics. Although important, for privacy and personnel policy reasons, the agencies could not provide them.

Unlike ordinary linear regression, which can be solved explicitly, logistic regression equations are solved iteratively until a solution is reached (Hosmer 2000). The logistic regression model is:

$$(1)\quad \pi(x) = \Pr(Y = 1|X_i) = \frac{e^{[g(X_i,\beta)]}}{1 + e^{[g(X_i,\beta)]}}$$

Where, Y is a response variable representing crash occurrence (Y = 1) or nonoccurrence (Y = 0) for an individual driver *i*. X_i is a multivariate attribute vector for schedule characteristics of this driver, some arbitrary function of X_i, β a parameter vector, and $\pi(x)$ the probability that a crash occurs. Taking the logarithm of Eq. (1) and solving gives,

$$(2)\quad \boldsymbol{g}(x) = ln\left[\frac{\Pr(Y = 1|X_i)}{1 - \Pr(Y = 1|X_i)}\right] = ln\left[\frac{\Pr(Y = 1|X_i)}{\Pr(Y = 0|X_i)}\right] = \alpha + \beta_1 x_1 + \beta_2 x_2 + \cdots \beta_i x_i$$

From this equation, the coefficients represent changes in the log odds of the responses per unit changes in the predictors. Therefore, to predict the relative collision risk of each driver, exponentials are applied to each log odd. That is, if the log odd is *m*, the corresponding relative collision risk would be e^m.

Descriptive Statistics of Operator Schedules

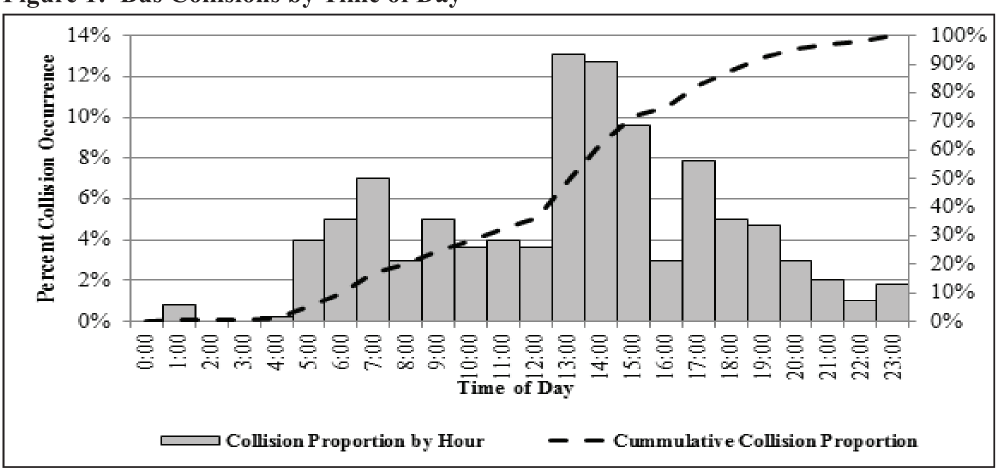
A total of 222 collisions were examined and descriptive statistics calculated. These statistics are in Table 2, and show a combined mean driving time of 49.8 hours for driving periods containing no split runs, with a 95% confidence interval of 48.7 hours to 50.9 hours. For operator weekly driving times containing split-run intervals, the combined mean driving time is 53.7 hours with a 95% confidence interval of 52.3 hours to 55.0 hours was calculated. The 95% confidence interval for the combined mean daily driving time for operators involved in collisions was also calculated. The statistics show a combined mean driving time is 9.8 hours for straight runs with a 95% confidence interval of 8.8 hours to 11.5 hours. For operator daily driving times containing split runs, the combined mean driving time is 11 hours with a 95% confidence interval of 10.2 hours to 11.9 hours.

The distribution of collisions by time of day is depicted in Figure 1. The smallest proportion of collisions occurred between midnight and 4:00 a.m., a reflection of both reduced routes and exposure late at night. It was also observed that collisions happened more often between 1:00 p.m. and 7:00 p.m. (56%) when traffic volumes are high with the largest proportion occurring between 1:00 p.m. and 3:00 p.m. (26%).

Table 2: Average Driving Hours of Operators Involved in Collisions and All Operators

Location	Average		Std. Deviation		Minimum		Maximum	
	Involved	All Drivers	Involved	All Drivers	Involved	All Drivers	Involved	All Drivers
Weekly average driving hours without split runs								
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 split runs								
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
Daily average driving hours without split runs								
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 split runs								
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

Figure 1: Bus Collisions by Time of Day



Inferential Statistics to Compare Driving Hours

A one-tailed, two-sample *t*-test was used to determine whether the population of operators involved in collisions predominantly work longer hours or if driving schedules with split runs played a role in collision occurrences compared with the overall population sampled with similar schedules. The *t*-test statistics for weekly driving hours without splits and with splits are summarized in Table 3. The statistics show that, on average, drivers who were involved in collisions drove more than 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 the combined data. It is therefore statistically evident that operators who are involved in collisions drive more hours compared with the population of all drivers. Additionally, the one-tailed, two-sample *t*-test was performed to examine if the population of operators involved in collisions worked longer hours or if daily scheduled split runs influenced the likelihood of collisions compared with the general population of operators. The one-tailed, two-sample *t*-test statistics for daily driving hours are in Table 3. The results show a statistically significant difference between the operators

Table 3: Test Statistics –Daily and Weekly Driving Hours

Test Results - Collisions for driving periods without split runs						
Location	**Sample size**		**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
Test Results - Collisions for driving periods with split runs						
Location	**N Sample size**		**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

Test Results – Collisions for daily driving periods without split runs						
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
Test Results – Collisions for daily driving periods with split runs						
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

driving longer hours per day, or with split runs during the day, were more likely to be involved in a preventable collision.

Selection of Variables for the Model

Four variables were selected for inclusion in the model (i.e., start time, hours on a task, off-duty hours, and schedule type) because the study focuses on hours of service policies for transit bus operators in the state of Florida. Impacts of schedule type, off-duty hours, and hours spent on driving were presumed to be significant contributors to fatigue.

Table 4 summarizes likelihood ratio test for the variable. The Chi-square value of the start time is 33.766 with two degrees of freedom. The start time probability value of 0.000 indicates high significance as do the values for hours on task and off-duty hours. However, the probability value of 0.72 for schedule type indicates that this variable is not significant at the 0.05 probability level. Using a forward elimination method, schedule type was omitted and the model re-estimated. The remaining variables were all statistically significant after the second attempt.

Table 4: Likelihood Ratio Test for Each Variable

	First attempt			**Second attempt**		
Variable	Chi-square	DF	*p*-value	Chi-square	DF	P-value
Start Time (ST)	33.766	2	0.000	33.766	2	0.000
Hours on Task(TOT)	49.670	3	0.000	49.670	3	0.000
Off Duty Hours(OFF)	43.444	3	0.000	48.524	3	0.000
Schedule Type(CON, SPL)	5.234	1	0.72	Omitted	Omitted	Omitted
Overall Variables	132.117	9	0.000	131.960	8	0.000

Note: CON means continuous run; SPL refers to split run

Discussion of the Model

The accident risk of each variable was checked first by using its odd ratio. In keeping with the views in other safety studies (Hauer 2004), the discussion of each parameter is conducted using a null hypothesis test of significance; probability level of 0.05 is used to screen variables and identify those of particular interest. Table 5 shows the coefficient for each variable. The last column quantifies the size of the effects on collision odds relative to other variables. The results show that drivers starting work in the morning between 3:00 a.m. and 7:00 a.m. had higher collision odds (2.017) compared with drivers starting between 7:00 a.m. and 11:00 a.m. (1.262), and those starting between 11:00 a.m. and 3:00 p.m. (0.943). This might be due to the fact that work start times between 3:00 a.m. and 7:00 a.m. interfere with circadian low points which occur from 2:00 a.m. to 6:00 a.m. (Howarth 2002). Comparatively, based on the collision odds, the collision risk for drivers driving more than 16 hours within a 24-hour period (6.462) is higher than that of drivers driving less than eight hours (1.400), or driving between eight and 12 hours (1.406), and 13-16 hours (1.565). This is expected because fatigue and weariness increase with increases in exposure on the job. The importance of having enough off-duty time to sleep and release accumulated fatigue is shown by the collision odds for different off-duty hours. Drivers with less than eight hours off duty have higher collision odds (4.323), compared with those who are off duty eight to 16 (2.226) and more than 16 hours (1.822). These results suggest that there is a need for transit managers to design schedules with optimal balance between time on task and off-duty periods for safer operations.

Table 5: Parameter Estimates for Variables and Interaction Terms in the Model Equation

Variables		Coefficient	S.E	P-value	Collision Odds
Start Time	ST1	0.702	0.190	0.000	2.017
	ST2	0.232	0.203	0.252	1.262
	ST3	0.058	0.204	0.774	0.943
Hours on Task	TOT1	0.337	0.484	0.486	1.400
	TOT2	0.341	0.420	0.417	1.406
	TOT3	0.448	1.055	0.671	1.565
	TOT4	1.866	0.597	0.002	6.462
Off-duty Hours	OFF1	1.464	0.374	0.000	4.323
	OFF2	0.800	0.367	0.020	2.226
	OFF3	0.146	0.515	0.776	1.158
	OFF4	0.600	0.458	0.019	1.822
	Constant	-3.562	0.277	0.000	0.028
Interaction Terms		**Coefficient**	**S.E.**	**P-value**	**Collision Odds**
ST1 by CON		0.721	0.469	0.124	2.056
ST1 by SPL		0.862	0.336	0.010	2.367
ST# by SPL		0.725	0.294	0.014	2.064
ST4 by SPL		0.768	0.319	0.016	2.156
TOT2 by ST4		1.682	0.639	0.008	5.376
TOT4 by STe		3.222	1.002	0.001	25.087
OFF1 by ST1		2.306	0.839	0.006	10.035
OFF1 by ST4		1.276	1.071	0.233	3.584
OFF2 by ST1		1.756	0.643	0.006	5.789
OFF2 by ST4		0.971	0.745	0.193	2.641
OFF4 by ST1		1.518	0.771	0.049	4.561

Note: ST1 = 3:00 a.m to 7:00 a.m; ST2 = 7:00 a.m to11:00 a.m; ST3 = 11:00 a.m to 3:00 p.m; ST4 = later than 3.00 p.m;
TOT1 = Less than 8 hours; TOT2 = 8 to 12 hours; TOT3 = 13 to 16 hours; TOT4 = More than 16 hours;
OFF1 = Less than 8 hours; OFF2 = 8 to 12 hours; OFF3 = 13 to 16 hours; OFF4 = More than 16 hours;

Model Interaction Terms

The interactions among the variables were also examined to identify the effects of schedules with multiple characteristics. The analysis of variable interactions enables the identification of desirable balances between schedule characteristics. Two-, three-, and four-way interactions were performed and it was noted that three- and four-way interactions were statistically insignificant; therefore only two-way interactions were retained in the model. The results of this test are summarized in Table 5.

The interpretation of the interaction terms can be well understood by comparing the odd ratios (OR). For instance, among the drivers starting their schedules at 3:00 a.m. to 7:00 a.m. (ST1), a relative collision risk of drivers who work split runs (SPL) versus those who work straight runs (CON) is. This gives an estimated odds ratio of 2.367, i.e., ($e^{0.862}$). Therefore, among the drivers with work start time of 3:00 a.m. to 7:00 a.m., those who work split runs have higher collision odds (2.367) than (1) those working split-runs but starting work between 11:00 a.m. to 3:00 p.m. (2.064), and (2) others working split runs and starting later than 3:00 p.m. (2.156). Drivers starting work between 1:00 a.m. to 3:00 p.m. and working more than 16 hours a day, have much higher collision odds (25.087) compared with those who start work later than 3:00 p.m. and work eight to 12 hours a day (5.376). The effects of the interaction between off-duty hours and work start times indicate higher collision odds (10.035) for drivers who have been off duty less than eight hours compared with those who have been off duty more than eight hours off and starting work between 3:00 a.m. to 7:00 a.m. For transit managers and fatigue management policy makers, these results suggest that, if in a particular day, drivers finish their shifts late at night, the next shift should start late afternoon to allow enough time to release fatigue. Likewise, the number of working hours between shifts should be balanced to avoid long working hours, which is one of the main causes of fatigue. Shift rotations among drivers could be one of the best practices while maintaining efficient transit operations.

CONCLUSIONS AND RECOMMENDATIONS

This research explored the association between relative crash risk and existing transit operator hours of service policies in the state of Florida. Descriptive and logistic regression was used in the analysis. The logistic regression revealed a decreasing trend of collision risks when drivers start their schedules late morning or in the afternoon compared with early morning. This was expected because early starting schedules, such as from 3:00 a.m. to 6:59 a.m., interferes with circadian low points that occur from 2:00 a.m. to 6:00 a.m. This is consistent with the findings that drivers may not be fully refreshed and awake when they begin their workdays (Barr et al. 2005). The effects of time on the job showed increasing collision risk for driving longer hours without enough off-duty time. In addition, the results showed that drivers who work split runs have higher relative crash risks than the drivers who work straight runs. The group of operators working split runs has long driving hours and early start and late ending times. These are the characteristics of work schedules that lead to fatigue. It is obvious that split runs cannot be avoided. This study recommends that schedules be optimized with an objective of minimizing the length of split runs. Based on the results of this study, FDOT may further investigate reductions of the maximum driving hours of transit operators. The current Florida limits are higher compared with federal limits that govern trucks and interstate buses. Further research is needed to study the influence of the factors that were not included in this study, such as route length, vehicle characteristics, and driver characteristics, among other factors.

APPENDIX A: Transit Agencies Used in the Study

Agency Name	Location	Fleet size	Number of drivers
Jacksonville Transit Authority (JTA)	Jacksonville	129	268
Lynx	Orlando	274	396
Regional Transit System (RTS)	Gainesville	80	148
StarMetro	Tallahassee	105	160

APPENDIX B: Description of Variables

Variable	Dummy variable	Abbreviation	Range	Description
Schedule Start Time (ST)	Start Time Category 1	ST 1	3:00 a.m-7:00 a.m	1 if ST 1
	Start Time Category 2	ST2	7:00 a.m-11:00 a.m	2 if ST 2
	Start Time Category 3	ST 3	11:00 a.m-3.00 p.m	3 if ST 3
	Start Time Category 4	ST4	Later than 3.00 p.m	4 if ST 4
Total Off Duty Hours (OFF)	Off Duty Category 1	OFF 1	Less than 8 hours	1 if OFF 1
	Off Duty Category 2	OFF 2	8 – 12 hours	2 if OFF 2
	Off Duty Category 3	OFF 3	13 – 16 hours	3 if OFF 3
	Off Duty Category 4	OFF 4	More than 16 hours	4 if OFF 4
Total Hours on Task (TOT)	Total Time on Task Category 1	TOT 1	Less than 8 hours	1 if TOT 1
	Total Time on Task Category 2	TOT 2	8 – 12 hours	2 if TOT 2
	Total Time on Task Category 3	TOT 3	13 – 16 hours	3 if TOT 3
	Total Time on Task Category 4	TOT 4	More than 16 hours	4 if TOT 4
Schedule Type	Continuous Schedule	CON	Varies	0 if CON
	Split Schedule	SPL	Varies	1 if SPL

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