2016

Safety Implications of Transit Operator Schedule Policies

Hung Hoang
University of North Florida, hoangahung1305@gmail.com

Safety Implications of Transit Operator Schedule Policies

by

Hung Anh Hoang

A thesis submitted to the School of Engineering

in partial fulfillment of the requirements for the degree of

Master of Science in Civil Engineering

UNIVERSITY OF NORTH FLORIDA

COLLEGE OF COMPUTING, ENGINEERING, AND CONSTRUCTION

April, 2016

This thesis titled Safety Implications of Transit Operator Schedule Policies is approved:

Dr. Thobias Sando, Committee Chair

Dr. Christopher Brown, Committee Member

Dr. Patrick Kreidl, Committee Member

Dr. Beyza Aslan, Committee Member

Accepted for the School of Engineering:

Dr. Murat Tiryakioglu,
Director

Accepted for the College of Computing, Engineering and Construction:

Dr. Mark Tumeo
Dean

Accepted for the University of North Florida:

Dr. John Kantner
Dean of the Graduate School

ACKNOWLEDGMENTS

Firstly, I would like to express my sincere gratitude to my advisor, Dr. Thobias Sando, for his support and dedication to my academic endeavors. I am greatly thankful for all the opportunities on transportation research projects that I have worked with him over the years. Without his guidance and mentorship, I would have not accomplished my educational goal.

My sincere thanks also go to Dr. Beyza Aslan, Dr. Chris Brown, and Dr. Patrick Kreidl for their time and energy as thesis committee members as well as for their insightful comments and encouragement. Also, special thanks go to Michelle Angel for assisting me with feedback on the thesis.

I would like to thank Dr. Mark Tumeo and Dr. Murat Tiryakioglu for their helpful review and recommendations, and to the College of Computing, Engineering, and Construction for providing an inviting and engaging learning environment.

Special thanks to bus transit agencies including Jacksonville Transportation Authority (JTA), Central Florida Regional Transportation Authority (LYNX), Hillsborough Area Regional Transit Authority (HART), Miami Dade Transit (MDT) and StarMetro at Tallahassee for cooperating and assisting me in data collection for the study.

Special thanks also go to England, Thims & Miller, Inc. for financial assistance, and allowing me to flex my working schedule to attend school.

Last but not least, I would like to thank my family, including my aunt's family, for supporting and motivating me throughout my college years as well as my life in general.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

ABSTRACT

In the bus transit community, driving long hours or spending extra hours at work are very common. This is true in the State of Florida, where bus transit is a very popular mode of public transportation. Although the correlation between a bus driver's schedule and a crash event appears intuitive, further study regarding the effects of operator driving schedules on accident rates is needed to evaluate safety measures. The focus of this research is on the examination of bus driver schedules, and the effects of scheduling on accident rates in Florida. Data were collected at five bus transit agencies including Jacksonville Transportation Authority (JTA), Central Florida Regional Transportation Authority (LYNX), Hillsborough Area Regional Transit Authority (HART), Miami-Dade Transit (MDT) and StarMetro in Tallahassee. Data collected included bus operator work schedules, accident data, and a voluntary questionnaire survey. The results indicate that the number of working hours significantly affect driving quality and increase the likelihood of driver involvement in a bus crash. Based upon 410 surveys obtained from operators, over 21% of drivers were concerned about the effects of split-time on fatigue. In addition to split-time considerations, the study revealed that nearly 15% of operators who completed the survey had a secondary driving job. The review of operator schedules also indicated that drivers involved in preventable accidents spent longer hours at work than on actual driving duty, primarily due to extended split-time. Consequently, drivers who had more than two hours of break had a higher probability of being involved in a preventable collision compared to drivers with less than two hours of split-time.

Keywords: fatigue; transit; operator schedule; accidents

CHAPTER 1: INTRODUCTION

The Florida Department of Transportation (FDOT) sponsored a study that analyzed the safety impacts of transit operator schedule policies (Chimba et al., 2010). It was discovered from the study that some operators have more than one job. Some drivers indicated that they drive school buses before starting their transit routes. It was also noted that some operators drive other modes of transportation such as taxi cabs and UPS trucks/vans during their off-duty time. Currently, transit agencies are not required to track hours bus operators spend driving those other modes of transportation as a second job. The main concern with this practice is the additional driving hours worked outside the transit agency causing a reduction in the amount of time available to the operator for rest. An operator can appear to have met the on-duty maximum of 16 hours within a 24-hour period and the 12 hours driving requirement within a 24-hour period as outlined in Rule 14-90.006, Florida Administrative Code in one job, but actually have exceeded these limits due to time spent driving for another company during their off-duty time.

In addition to tracking internal and external hours of driving, FDOT perceived a need to examine the importance of transit operator rest breaks during and in-between shifts extending beyond eight hours within a 24-hour period. It is a known fact that driving performance (e.g., the ability to control, navigate, and guide) deteriorates after driving continuously for many hours (Chimba et al., 2010). There is paucity of literature on the length of time deemed appropriate for rest breaks and intervals between breaks. This study explores the bus operator break issue and provides recommendations on how long the breaks should be for optimal safety and efficiency.

Statement of Problem

Bus transit is one of the most popular public transportation modes in Florida (Sapper, 2004). Many studies and projects have been performed to improve the bus industry in the State

including routing design improvement, constructing bus-only lanes on high-capacity roadways, as well as transit and enhancement projects to improve bus stops. In recent years, crash rates related to bus transit have noticeably increased. As a result, scholars and engineers have been inspired to provide more comprehensive research on this matter. The consequences of bus accidents can be severe, involving not only the driver, but also the numerous riders that depend on bus transportation. When discussing vehicle crashes, many tend to gravitate toward roadway characteristics, mechanical issues, and driver condition as probable causes. Transit operators' schedules, on the other hand, may also be an important aspect regarding bus transit safety. Available research on this concept is considerably limited and serves as the motivation for the current study.

Significance of Study

Studying and developing transit safety is a principle consideration in the bus transit industry. However, operational characteristics have not drawn much attention from scholars. Accordingly, the current research on bus transit operator schedules will provide additional and useful analyses to more effectively improve the safety of this popular transportation mode in Florida and nationwide. Furthermore, the study is designed to identify an optimized and practical set of schedules to cover all bus routes so as to utilize the manpower resource efficiently without violating labor regulations.

CHAPTER 2: REVIEW OF LITERATURE

According to Brown (1994, p.229), fatigue for drivers is defined as "when an individual cannot meet self-imposed or externally imposed performance goals but is forced to continue working under adverse conditions by a sense of duty and/or the need to safeguard the lives of others." Brown (1994) also suggested that continuous durations of working and duty periods are the leading contributors to driver fatigue. Long work periods effect driving safety and potentially lead to accidents or physical violence (Bültmann et al., 2000). Literature on the effects of fatigue on transit safety is limited. However, there is a broad knowledge related to the effects of fatigue on safety, due to long work schedules, for other transportation modes such as trucking, rail, and the aviation industry.

Effects of Fatigue in Trucking Industry

Commercial vehicle drivers encounter an overload of health and safety risks due to long hours on the road and exposure to multiple work stressors. A study by Hege et al. (2015) indicated that long working hours and irregular work shifts had a significant influence on drivers' sleep patterns. Of the study participants, findings revealed that truck drivers with the highest rate of working hours (at least 48 hours/week) either nearly missed (53.2%) or caused (7.5%) an accident due to sleepiness. Similarly, drivers who had irregular work schedules experienced shorter sleep times and more sleep disturbance than drivers with fixed schedules. According to Hege et al. (2015), work hours and varying work schedules are the primary cause of fatigue and lead to health and roadway safety risks in commercial vehicle drivers.

An earlier study of long distance heavy-vehicle drivers in Australia found that 20% of drivers reported at least one accident related to fatigue on their last trip (Williamson et al., 2001).

The study also indicated that nearly 33% of these drivers were not adhering to regulations on nearly half of their trips.

A study by Gander et al. (2006) investigated the proportion of truck crashes involving fatigue for 130 truck drivers in New Zealand, who were also involved in a total of 511 reported crashes. Drivers were asked to complete anonymous questionnaires related to their sleep history 72 hours prior to the crash occurrence. By using statistical analysis, findings revealed that approximately 11% of the drivers were associated with two risk factors for fatigue: either having less than 6 hours of sleep or being continuously awake for more than 12 hours in a 24-hour day. Additionally, out of the 102 crashes with sufficient data on physiological risk factors, 17.6% were related to at least one fatigue characteristic. However, due to the low response rate from the questionnaire, it was recommended that further questions about sleep habits be added to more effectively evaluate the influence of fatigue on truck crash rates.

Effects of Fatigue in Railroad Industry

Baysari et al. (2008) conducted a study on human factors contributing to railway accidents and incidents in Australia, and found that nearly 50%, of the 40 rail accident investigation reports reviewed, resulted from equipment failures. The lack of maintenance activities and monitoring programs resulted in technical breakdowns and caused crashes. The remaining 50% of reported accidents were associated with physical fatigue and an inadequate level of alertness while driving.

In Germany (Metzger, 2005) and the United States (Molitoris, 2007), analyses of rail accidents in terms of error types indicate that a reasonable number of rail accidents/incidents in are related to human error. Jolene Molitoris, the Administrator of the Federal Railroad

Administration (FRA), stated that approximately 33% of train incidents are caused by human factors, mostly influenced by fatigue.

An interesting study conducted by Lamond et al. (2005) in Australia surveyed 15 operators on relay trips. The study found that operators working the early roster had 11.6 hours of sleep during their 42-hour relay trip while drivers working the late roster had 8.4 hours of sleep. As a result, train drivers tend to sleep less when working late shifts, and consequently, have more fatigue.

Effects of Fatigue in Aviation Industry

A project by the National Research Council titled “Effects of Commuting on Pilot Fatigue” outlined the correlation between fatigue and aviation accidents (Dawson et al., 2012). A total of 863 accidents were recorded from 1982 to 2010 with about 11% of accidents involving fatigue, either as a probable cause or a contributing factor. However, due to the inadequate data about the effectiveness of regulations regarding pilot commutes, further research was recommended to harness more scientific tools and techniques to demonstrate the influence of fatigue on aviation safety. Even in military or emergency aviation services, where fatigue appeared obvious, observing information on “fatigue-proofing” strategies was difficult or impractical (Dawson et al., 2012). A recently available analysis by Dawson et al. (2015) after interviewing 18 pilots and air-crewman from aviation trades revealed that there were almost 150 informal ways to reduce the fatigue-related errors. Even though these behaviors were not typical safety procedures in aviation management systems, the level of fatigue during long-shift work was significant.

Effects of Fatigue in Transit Industry

A research report by Tse et al. (2006) identified many health illnesses related to bus drivers in the United Kingdom (UK). The report reviewed 10,781 accident records occurring in 2002, both fatal and non-fatal, and included buses, coaches, and minibuses (Department for Transport, 2003). While several factors were considered in bus accidents, including age (Greiner et al., 1998), and driver's experience (Blom et al., 1987), the element of time pressure was an essential influence in bus collisions. Dorn (2003) pointed out, bus drivers stated that risky behavior was often result of insufficient time to maintain running schedules. Moreover, irregular shift patterns caused fatigue on-the-job and increased crash risks for bus drivers (Dom, 2003).

Bus transit safety is also a substantial concern in many developing countries including India, Nepal, Tanzania, Zimbabwe, Pakistan, Chile, Sri Lanka and Bangladesh (Barua et al., 2010). In the United States, approximately 63,000 buses are involved in traffic collisions each year (Blower and Green, 2010). Of this total, 22.2% included at least one injury, and nearly 1% resulted in a fatality. Although the observed numbers appear significant, considerably few studies focused on safety solutions. Moreover, according to Federal Transit Administration (FTA), while accounting for only 42.8% of transit passenger miles in 2007, buses were engaged in 51.9% of the industry's safety incidents, 77.8% of all collisions, and 62.3% of all injuries. Although 31.2% of incidents involved fatalities, this value is more than likely under-represented since bus collision rates have increased in recent years. Strathman et al. (2010) reviewed 4,628 safety incidents from TriMet's Accident and Incident Tracking System for 2006 to 2009. Surprisingly, the collision rate was 13.4% lower between 4pm and 7pm compared to other time blocks. The study indicated that maintaining schedules placed pressure on the drivers, and

caused significant stress. The authors also noted that the collision and non-collision risk was greater during overtime shift hours.

Hours of Service Regulations

Phase I of the safety study on bus transit operators indicated that Florida has higher daily driving limits for intrastate commercial motor vehicles. Table 2.1 shows the details of driving-hour limitations between federal and Florida regulations. Bus drivers in Florida are allowed to drive a maximum of 12 hours in one 24-hour period. Under federal regulations, however, the limits are 11 hours and 10 hours for property-carrying commercial motor vehicle (CMV) drivers and interstate passenger-carrying CMV drivers, respectively. Florida bus drivers are also allowed to have an on-duty maximum of 16 hours in a 24-hour period while federal regulations allow just 14-hour and 15-hour on-duty limits for property-carrying CMV drivers and passenger-carrying CMV drivers, respectively.

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 14-90.006(3))
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.

CHAPTER 3: METHODOLOGY

The research approach included two main instruments – questionnaire surveys and operator schedules coupled with accident reports. Data were collected at five selected agencies in Florida including: Jacksonville Transportation Authority (JTA), Central Florida Regional Transportation Authority (LYNX), Hillsborough Area Regional Transit Authority (HART), Miami-Dade Transit, and StarMetro in Tallahassee. After developing a list of operators involved in preventable accidents, schedules for a two-week period containing the day of the accident were collected. Along with this schedule data, a random two-week period schedule of all operators was obtained for comparison purposes.

A questionnaires survey was delivered to all drivers at each agency. The survey consisted of multiple questions such as full-time/part-time, a secondary driving job, type of transportation for the second job, different shift, split-time, etc. (see Appendix A). The survey was geared toward collecting information on external driving hours while the operator schedule data were used to determine the amount of split-time that allows minimal effects on crash occurrence. Both descriptive and statistical analyses were applied to examine the data.

A chi-square test was also performed to determine whether or not effects of split-time schedules exist. Effects in a contingency table are defined as relationships between the row and column variables. Significance in this type of statistical test means that further analysis should be examined. Non-significance means that any difference in cell frequency could be explained by chance. The procedure used to test the significance of contingency tables is similar to all other hypothesis tests. That is, a statistic is computed and then compared to a model representative of what the result would look like if the experiment was repeated an infinite number of times when there were no significant relationships between the factors in the rows and the columns. For this

study, the chi-square test was applied for the statistical analyses on split schedules. A heuristics algorithm (Chen et al., 2012) was used to optimize the split-time of bus operators to determine the most effective period based on the outcomes of both descriptive and statistical analyses. Additionally, using the Tabu Search algorithm method (Chen et al. 2012), MATLAB software was used to optimize the split-times. The results from these analyses were then evaluated to determine the efficiency of minimizing the total idle time between driving shifts.

Questionnaire Survey

A survey of bus operator activities was conducted. The questionnaire was designed to gather information concerning operator activities performed during on- and off-duty hours. The objective of the questionnaire was to assess the adequacy of the minimum off-duty period of eight 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 on 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 to potentially establish the relationship between the length of the break and type of typical activities performed during the break.

Operator Schedule

First, incident reports archived electronically by transit agencies were collected. Only collisions coded as “preventable” were examined (National Center for Transit Research, 2013). Pertinent collision attributes such as operator information, time of crash, date of crash, and type

of crash were collected to enable further analysis. Secondly, schedules of operators who were involved in preventable collisions were collected. Each record included total days worked, on-duty hours, driving hours, and time of reporting on- and off-duty. Further analyses were conducted and are presented in subsequent chapters. Sample operator schedules from JTA, LYNX, HART, and Miami-Dade Transit are shown in Appendix C.

CHAPTER 4: DATA ANALYSIS: QUESTIONAIRE SURVEY

Split-time

A total of 410 questionnaires were collected from bus agencies. Of the responding surveys from all selected agencies, it was observed that about 21% of drivers complained about split-time. Most of the concerns revolved around having too long of a split, which extended the work day resulting in fatigue. Short splits would allow drivers to have enough time for resting before resuming driving duty. Alternatively, extensive split-times, presented opportunities for operators to perform other activities, such as running errands, with resting less likely. Split-time activities were a common reason for driver fatigue when returning to duty after the break. As a result, operators shared the preference of either minimizing or possibly eliminating the split time from their schedules. Table 4.1 shows the percentages of drivers surveyed who commented on split-time.

Table 4.1

Total surveyed drivers and number of drivers concerned about split-time

Agency	Drivers Surveyed	Split-time Comments	Percentage (%)
Jacksonville (JTA)	49	12	24.5
Orlando (LYNX)	58	22	37.3
Tampa (HART)	97	27	27.8
Miami Dade (MDT)	144	14	9.7
Tallahassee (StarMetro)	62	12	19.0
Total	410	87	21.1 (Average)

Figure 4.1 represents the proportions of drivers concerned about split-time. When considering operators with split schedules independently, the mean split-time was about 2.5 hours. The minimum split was 0.5 hours, while the maximum split-time duration was five hours. Despite the fact that the majority of drivers did not prefer split-time between shifts, results from

the Miami-Dade Transit agency indicate fewer drivers were concerned with split-time schedules. One possible explanation for this discrepancy may be that drivers were paid for split-time greater than 90 minutes (see Appendix B). Operators from other agencies, in contrast, were not paid during the break periods.

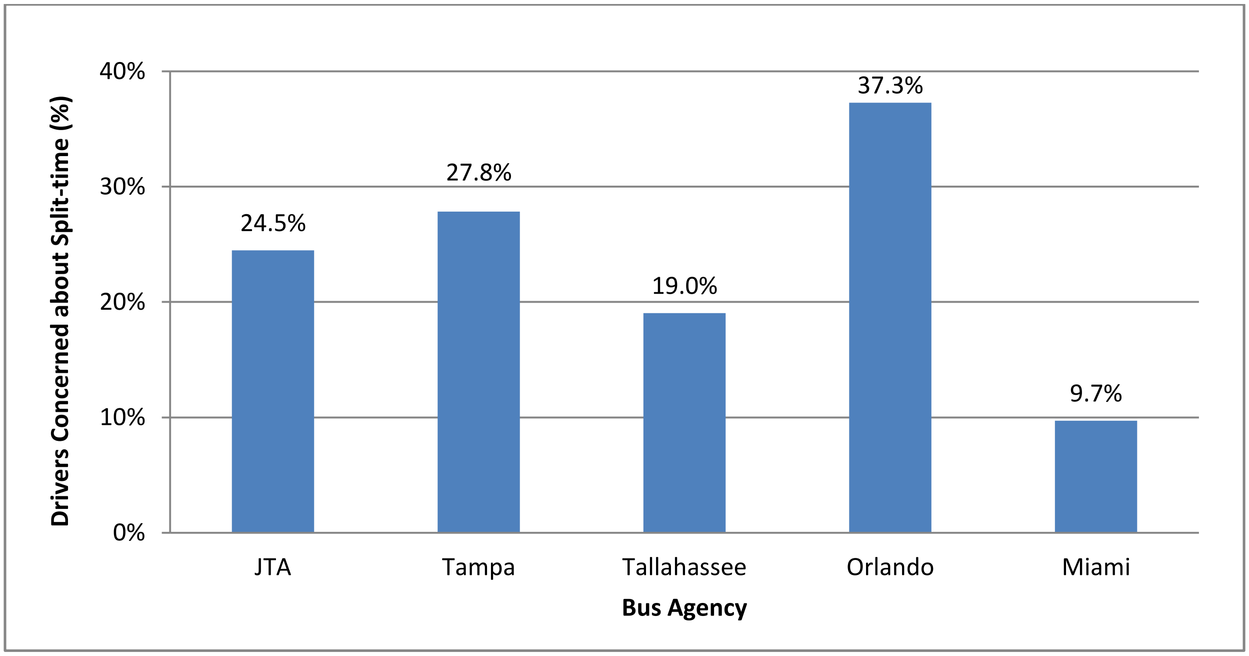

Figure 4.1. Percentage of drivers concerned about split-time.

Operators with a secondary driving job

Operators were questioned in the survey about external driving jobs not related to work duty. Secondary driving jobs result in less actual recovery time before returning to driving duty. Consequently, driving quality could be significantly affected and increase the probability of preventable accidents. Although voluntary, due to the sensitive of this matter, it was expected that some drivers would not truthfully answer questions on the survey relating to secondary driving activities. Despite this fact, the observed results qualified for inclusion in the study.

The survey results summarized in Table 4.2 indicate the number of drivers involved in secondary driving jobs vary by agency. Overall, approximately 15% of operators who completed the survey had an external driving job, and 2.4% of these drivers were part-time operators at their bus agencies. Interestingly, almost one-third of the operators surveyed at StarMetro in Tallahassee engaged in secondary driving work. Although the overall percentage of operators involved in external driving activities is comparatively low, it is a valuable observation in study of operator schedules.

Table 4.2

Number of drivers with a secondary driving job

Agency	Total Surveyed	Drivers with 2nd driving job	Percentage (%)	Part-time (drivers)	Percentage of Part-time (%)
Jacksonville (JTA)	49	3	6.1	0	0.0
Orlando (LYNX)	58	11	19.0	1	1.7
Tampa (HART)	97	9	9.3	0	0.0
Miami Dade (MDT)	144	20	13.9	5	3.5
Tallahassee (StarMetro)	62	17	27.4	4	6.5
Total	410	60	14.6 (average)	10	2.4 (average)

Operators that engaged in external driving jobs were also asked to indicate other types of transportation vehicles commonly used in the secondary driving job. Table 4.3 summarizes the findings among the operators surveyed, and reveals that other bus transportation, such as driving a school bus, church bus, or county bus, were favored for secondary job work. Additionally, driving UPS/FEDEX vans, limousines, and taxis were also reported by operators.

Over 38% of the operators listed “other” as a secondary driving mode, which may indicate a reluctance to identify the external driving job, or the secondary job involved driving delivery or heavy-duty trucks. An illustration of the findings is presented in Figure 4.2.

Table 4.3

Secondary driving jobs, type and proportion

Type of Transportation	Secondary driving job (drivers)	Proportion (%)
Taxi	1	1.7
Bus	24	40.0
Limousine	3	5.0
UPS/FEDEX Vans	8	13.3
StarMetro	1	1.7
Other	23	38.3
Total	60	100

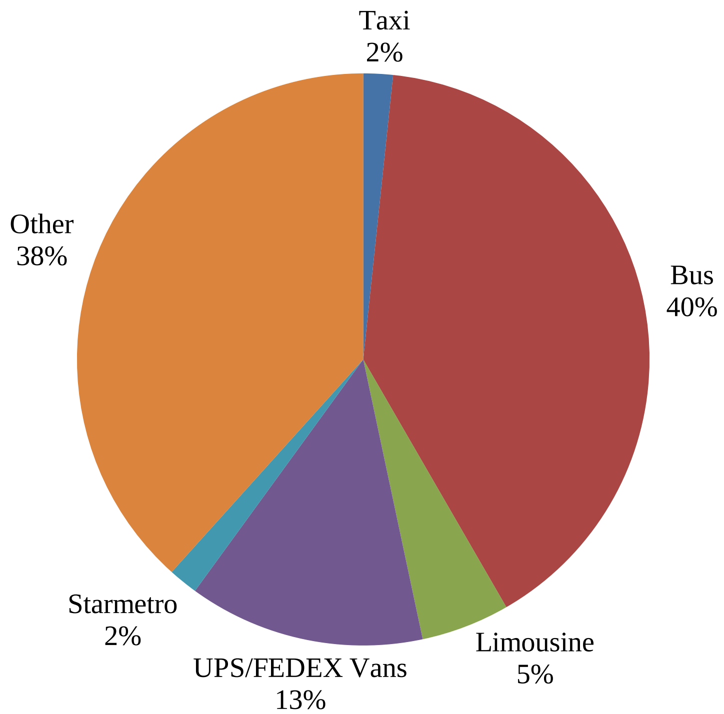

Figure 4.2. Secondary driving jobs, type and proportion.

As with any questionnaire, the possibility exists that respondents may interpret the questions incorrectly when answering them. Therefore, each completed questionnaire was examined during the data analysis process, and removed from the data set if evidence of

misunderstanding of the questions was present. For example, if an operator indicated that he/she worked 8 hours per week, and at the same time worked 5 days a week, the response was considered to be inconsistent. Overall, very few surveys were rejected.

Driving time and time spent at work

Schedules of operators that had secondary driving jobs were further analyzed on the basis of total on-duty driving time and time spent at work. As shown in Table 4.4, the data were categorized by six groups representing hourly time blocks. More than 53% of drivers surveyed drove eight hours or less each day, while nearly 42% of the operators actually spent eight hours or less at the bus facility. Operators on driving duty for at least 10 hours consisted of approximately 10%, while more than 38% of drivers had to stay longer than 10 hours at work. The results indicate that the majority of operators spent more time at work than actual time on driving duty.

Table 4.4

Daily driving time and time spent at work of operators with the secondary job

Daily hours	No. Drivers Driving	Proportion of Total (%)	No. Drivers for Time spent at work	Proportion of Total (%)
0-8	32	53.3	25	41.7
8.1-9	11	18.3	6	10.0
9.1-10	11	18.3	6	10.0
10.1-11	2	3.3	2	3.3
11.1-12	1	1.7	8	13.3
> 12	3	5.0	13	21.7

Figure 4.3 graphically presents the percentages of bus operators with secondary driving jobs relative to daily hours of on-duty driving time and time spent at work. The proportion of drivers relative to on-duty drive time shows a decreasing trend as the number of scheduled work

hours increased. For example, the proportion of operators that drove for eight hours or less, from nine to 10 hours, and more than 11 hours were 53.3%, 18.3%, and 6.7 %, respectively. The proportion of drivers relative to time spent at work showed a similar trend for operators with less than 10 hours on-duty per day. However, the proportion of operators with more than 10 hours scheduled spent considerably less time driving over the duration of the shifts, allowing opportunity for other activities between on-duty drive times. These results confirmed the effect of split-time on bus operator schedules by extending the drivers' day, thus reducing available recovery time.

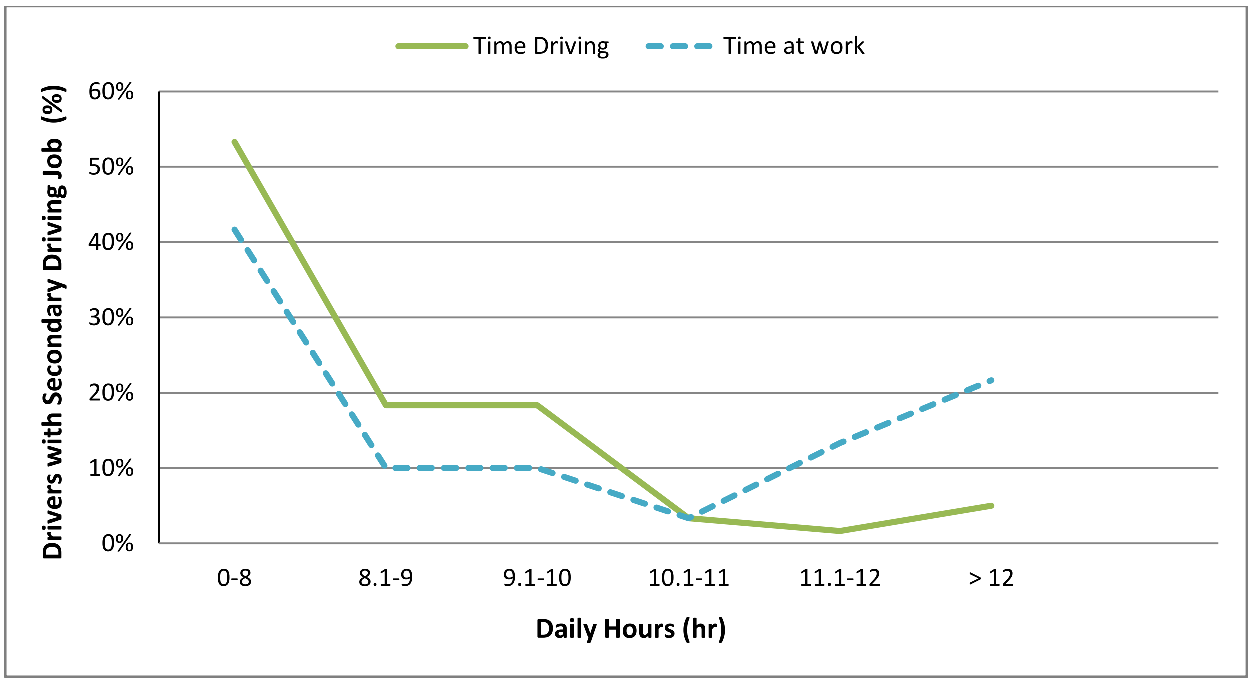

Figure 4.3. Daily driving time vs. time spent at work of drivers with secondary driving job.

CHAPTER 5: DATA ANALYSIS: OPERATOR SCHEDULE AND COLLISION

Split-time

Collision data were collected from four large-size bus agencies: JTA, LYNX, HART, and Miami-Dade Transit. A total of 569 drivers involved in preventable accidents were included in the data set. Table 5.1 lists the fleet sizes of each bus agency, as well as the number of drivers with and without split-time schedules on the day the accidents occurred. Approximately 63% of drivers had straight-shifts, while about 37% of operators had split schedules. These findings suggests that drivers with straight-shifts are more likely to be involved in an accident than drivers with split schedules. However, the durations of split-time can result in driver fatigue and also lead to accident occurrences.

Table 5.1

Number of drivers involved in preventable accidents with/without split-time

Agency	Drivers involved in accidents				
	Fleet size	Without split	Proportion (%)	With split	Proportion (%)
Jacksonville (JTA)	127	84	66.1	43	33.9
Orlando (LYNX)	137	88	64.2	49	35.8
Tampa (HART)	100	45	45.0	55	55.0
Miami Dade (MDT)	205	142	69.3	63	30.7
Total	569	359	63.1	210	36.9

Figure 5.1 illustrates the comparison between operators involved in preventable collisions with straight-time and split-time schedules. Although the data from HART revealed a slightly opposite result from the other agencies, the overall data notably depict the influence of split-time schedules on preventable accident occurrence.

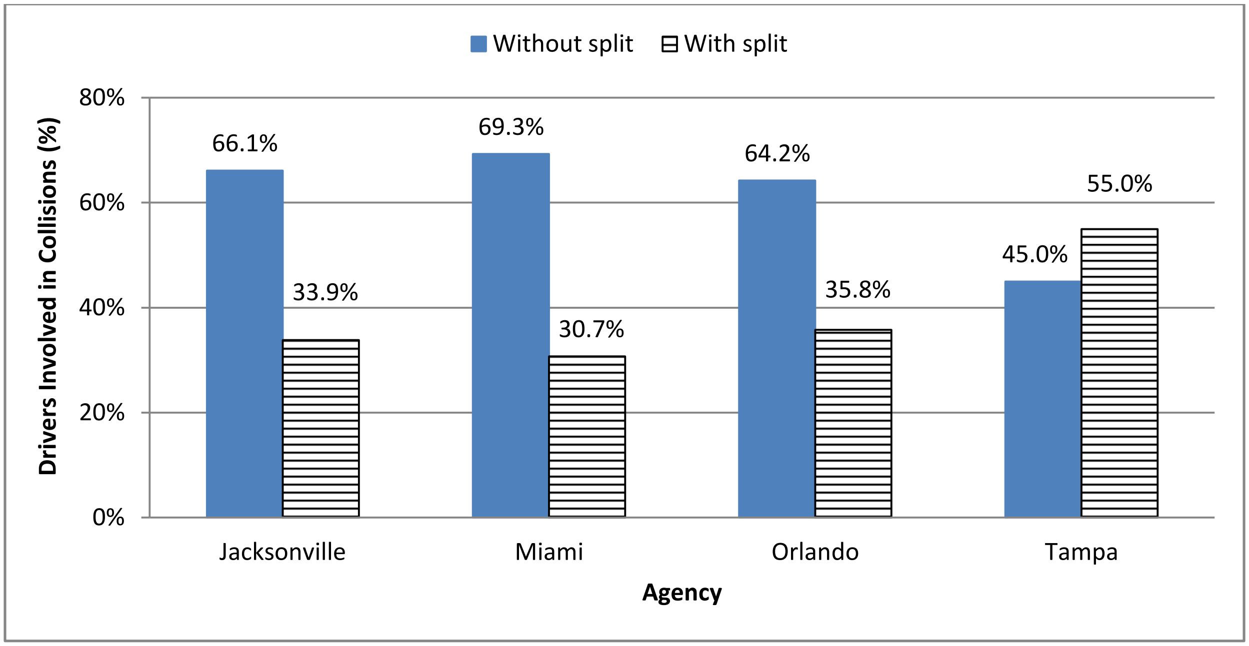

Figure 5.1. A comparison of drivers involved in accidents with and without split-time.

A statistical analysis on split-time

The data summarized in Table 5.1 were further analyzed using a chi-square hypothesis test to determine the effects of split-time on collision occurrence. The null-hypothesis test was defined as following:

H_o: the number of accidents and split-time are not correlated.

H_1: the number of accidents and split-time are correlated.

The following formulas were applied to calculate the degree of freedom (*DF*), the expected value (*E*), and the chi-square value (χ^2), where *O* represents observed values (McClave el at. 2009):

$$DF = (\#row - 1) * (\#col - 1) \quad \text{(Eq. 1)}$$

$$E = \frac{(sumCol)*(sumRow)}{Total} \quad \text{(Eq. 2)}$$

$$\chi^2 = \sum \frac{(O-E)^2}{E} \quad \text{(Eq. 3)}$$

Table 5.2 shows a combined chi-square value for the two groups, split-time and straight-shift schedule drivers of 18. A 99.5% confidence interval with three degrees of freedom, resulted in a critical value of 12.838 (see Appendix E), considerably less than the calculated total chi-square value of 18. Hence, the null hypothesis was rejected, indicating that there was enough statistical evidence to support the claim that the occurrence of bus accidents is correlated to split-time schedules.

Table 5.2

Calculations of χ^2 value for drivers with and without split-time schedules

Without split time	E	80.1	86.4	63.1	129.3
	O-E	3.9	1.6	-18.1	12.7
	$(O-E)^2$	14.99	2.44	327.36	160.25
	$(O-E)^2/E$	0.2	0.0	5.2	1.2
Total χ^2 value					**6.6**
With split time	E	46.87	50.56	36.91	75.66
	O-E	-3.87	-1.56	18.09	-12.66
	$(O-E)^2$	14.99	2.44	327.36	160.25
	$(O-E)^2/E$	0.32	0.05	8.87	2.12
Total χ^2 value					**11.4**

The chi-square test was also applied to determine the effects of different split-time durations on the number of preventable accidents. Bus driver schedules at the four selected agencies in terms of split-time are summarized in Table 5.3. Split-time durations were divided into six categories in ascending order from zero hours to greater than four hours. As shown in Table 5.3, just over 63% (359) of the drivers had straight-shift schedules, and nearly 23% of drivers had longer than two-hour split-times on the day of accident occurrence.

Table 5.3

Bus driver schedules in term of split-time duration

Split time (hr)	City				Total
	Jacksonville	Orlando	Tampa	Miami-Dade	
0	84	88	45	142	359
0-1	2	8	5	17	32
1-2	10	18	10	10	48
2-3	23	15	9	8	55
3-4	7	7	17	10	41
>4	1	1	14	18	34
Total	127	137	100	205	569

For the statistical analysis of the effects of split-time durations, the same null-hypothesis as above was used. Similar calculations, using equations 1-3, were performed for this analysis resulting in a total chi-square value of 78.43, summarized in Table 5.4. A 99.5% confidence interval, with 15 degrees of freedom, resulted in a critical value of 32.801 (see Appendix E). Since the calculated chi-square value was greater than the critical value, the null hypothesis was rejected, and enough evidence exists to support the claim that crash occurrence is correlated to split-time durations. The chi-square analyses clearly indicate that split-time duration impacts the preventable collision rates of bus drivers.

Other aspects of driver schedules, including daily driving time, time spent at work, time-of-day and day-of-week of accident occurrence, as well as split-time hours the week before the collision, were also examined to determine the correlations between driver schedules and preventable accidents.

Table 5.4

Calculations of χ^2 value for drivers with different split-time durations schedule

Items	Split-time (hr)	Jacksonville	Orlando	Tampa	Miami-Dade	Total
O	0	84	88	45	142	359
E		80.1	86.4	63.1	129.3	
O-E		3.9	1.6	-18.1	12.7	
$(O-E)^2$		15.0	2.4	327.4	160.3	
$(O-E)^2/E$		0.2	0.0	5.2	1.2	**6.64**
O	0-1	2	8	5	17	32
E		7.14	7.70	5.62	11.53	
O-E		-5.14	0.30	-0.62	5.47	
$(O-E)^2$		26.44	0.09	0.39	29.93	
$(O-E)^2/E$		3.70	0.01	0.07	2.60	**6.38**
O	1-2	10	18	10	10	48
E		10.71	11.56	8.44	17.29	
O-E		-0.71	6.44	1.56	-7.29	
$(O-E)^2$		0.51	41.51	2.45	53.20	
$(O-E)^2/E$		0.05	3.59	0.29	3.08	**7.01**
O	2-3	23	15	9	8	55
E		12.28	13.24	9.67	19.82	
O-E		10.72	1.76	-0.67	-11.82	
$(O-E)^2$		115.01	3.09	0.44	139.61	
$(O-E)^2/E$		9.37	0.23	0.05	7.05	**16.69**
O	3-4	7	7	17	10	41
E		9.15	9.87	7.21	14.77	
O-E		-2.15	-2.87	9.79	-4.77	
$(O-E)^2$		4.63	8.25	95.93	22.77	
$(O-E)^2/E$		0.51	0.84	13.31	1.54	**16.20**
O	>4	1	1	14	18	34
E		7.59	8.19	5.98	12.25	
O-E		-6.59	-7.19	8.02	5.75	
$(O-E)^2$		43.41	51.64	64.39	33.07	
$(O-E)^2/E$		5.72	6.31	10.78	2.70	**25.51**

Daily driving time and time spent at work

The actual schedules of operators involved in preventable collisions were reviewed to determine the daily hours spent driving and the total time spent at work on the day of collision occurrence. A comparison between the two factors, illustrated in Figure 5.2, is consistent with results shown in Figure 4.3. Almost 30% of operators drove for eight hours or less each day, while nearly 24% of operators actually spent a similar amount of time at work. As the time duration increased, the percentage of drivers involved in preventable collisions dropped. However, the proportion of operators that drove more than 10 hours a day, although reasonably low (16.5%), more than 39% had spent at least 10 hours a day at work. This variation further confirms the effect of split-time on increasing the possibility of being involved in a bus collision.

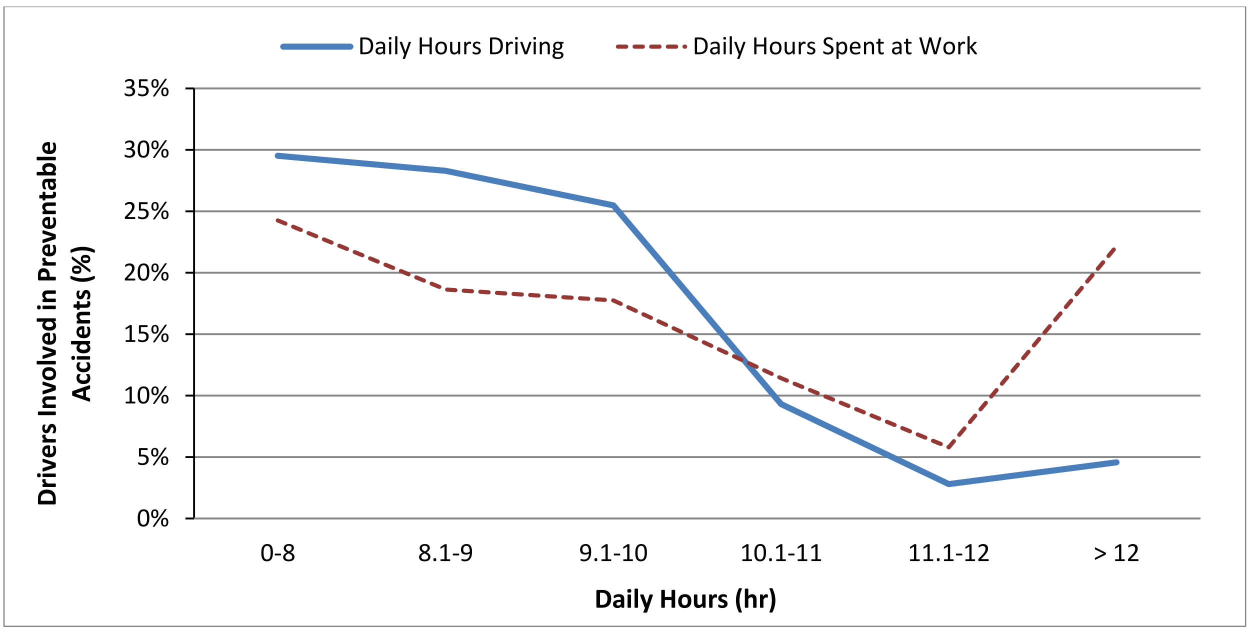

Figure 5.2. Daily working hours vs. total daily time spent at work of bus drivers.

Time of day

Related to the concept of driver fatigue, accident occurrences were classified by time of day, in four-hour increments. Figure 5.3 depicts the outcome of preventable collisions happening

during a day. The highest frequency of collisions (28.3%) occurred between 4pm to 8pm, while the lowest rate (2.1%) occurred from midnight to 4am. A possible explanation for this phenomenon is that drivers tend to be tired later in the day, and lose their focus while driving. Also, it is important to note that peak hours lie between from 4pm to 8pm for most roadways. Hence, a combination of high traffic and driver fatigue may contribute to high crash occurrences during this time block.

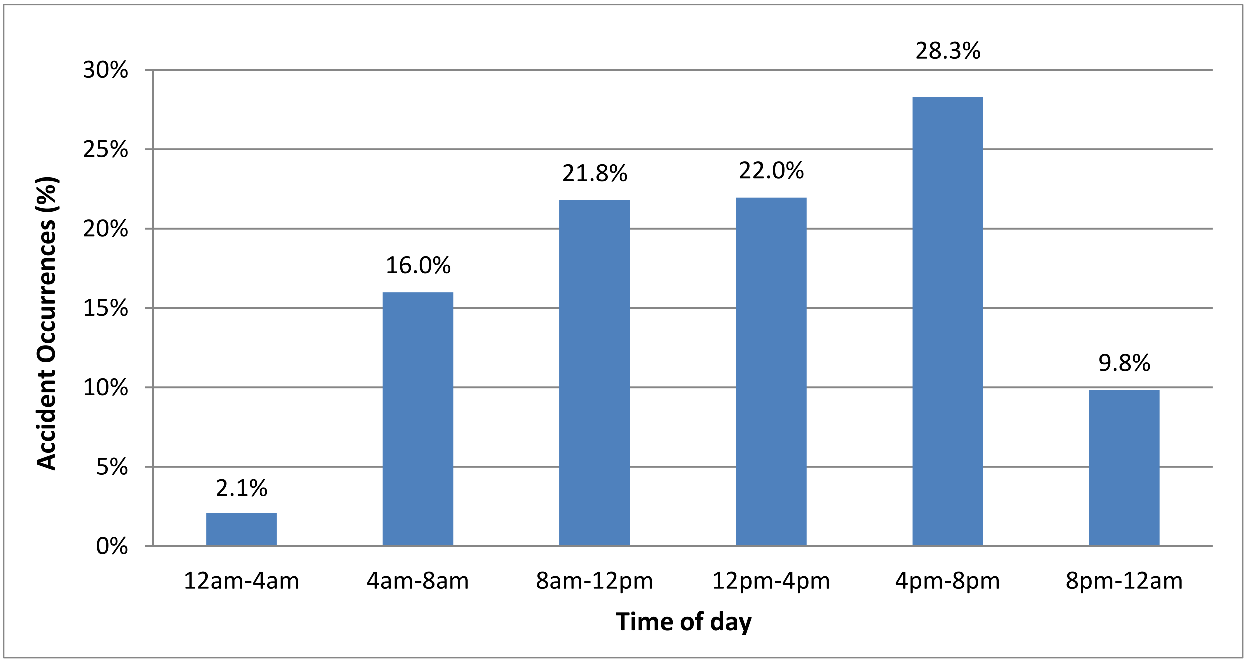

Figure 5.3. Accident occurrences by time of day.

Day of week

The data were also analyzed in terms of day-of-week of accident occurrence, and the results are presented in Figure 5.4. The highest frequency of collisions occurred on a Monday (19.5%), followed closely by Friday (18.1%). Over 19% of accidents occurred on weekends, which reflects the reduction of exposure. However, the frequency of Sunday crashes nearly equal

the percentage of collisions that occurred on a Tuesday. This result is most likely due to Sunday events where bus travel is often utilized.

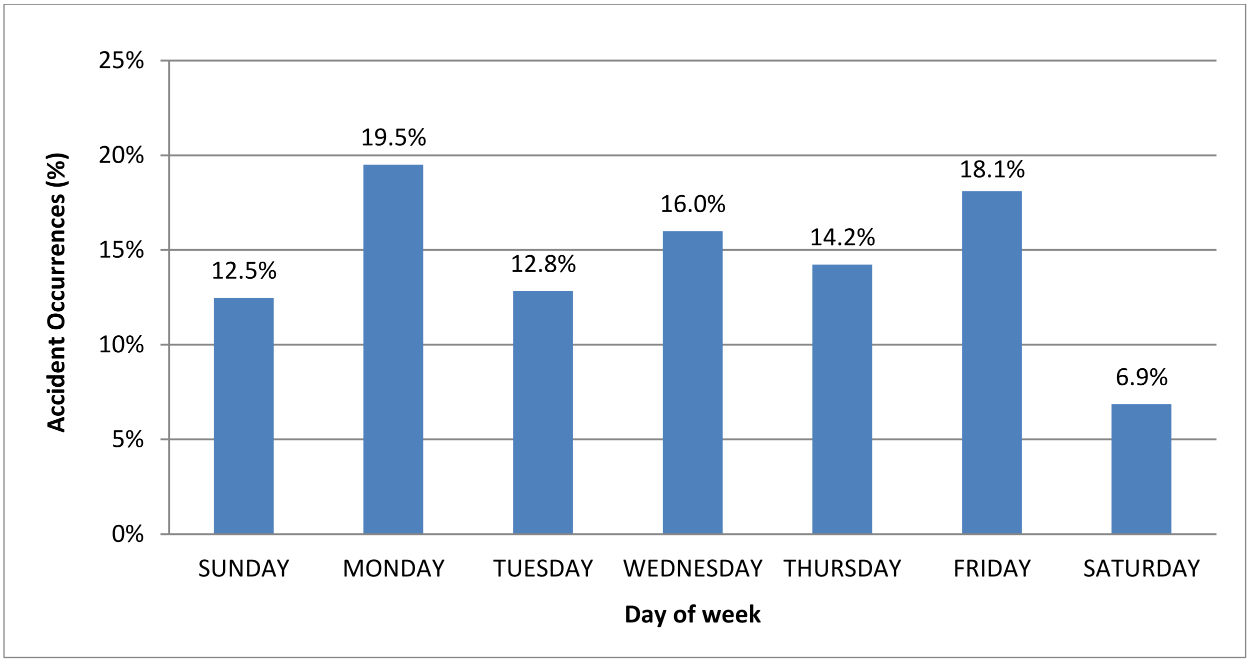

Figure 5.4. Accident occurrence by day of week.

Split-shifts

To measure the consistency of split-time in operator schedules, shift schedules for the week prior to the accident were also analyzed to determine the number and duration of split-times. As shown in Figure 5.5, nearly half (48.1%) of drivers involved in preventable collisions had no split-time during the week before the accident. Drivers that had either one or four splits during the prior week accounted for 12.4% of collisions, while only a small number (8.4%) of drivers had the same split-shift schedules each day.

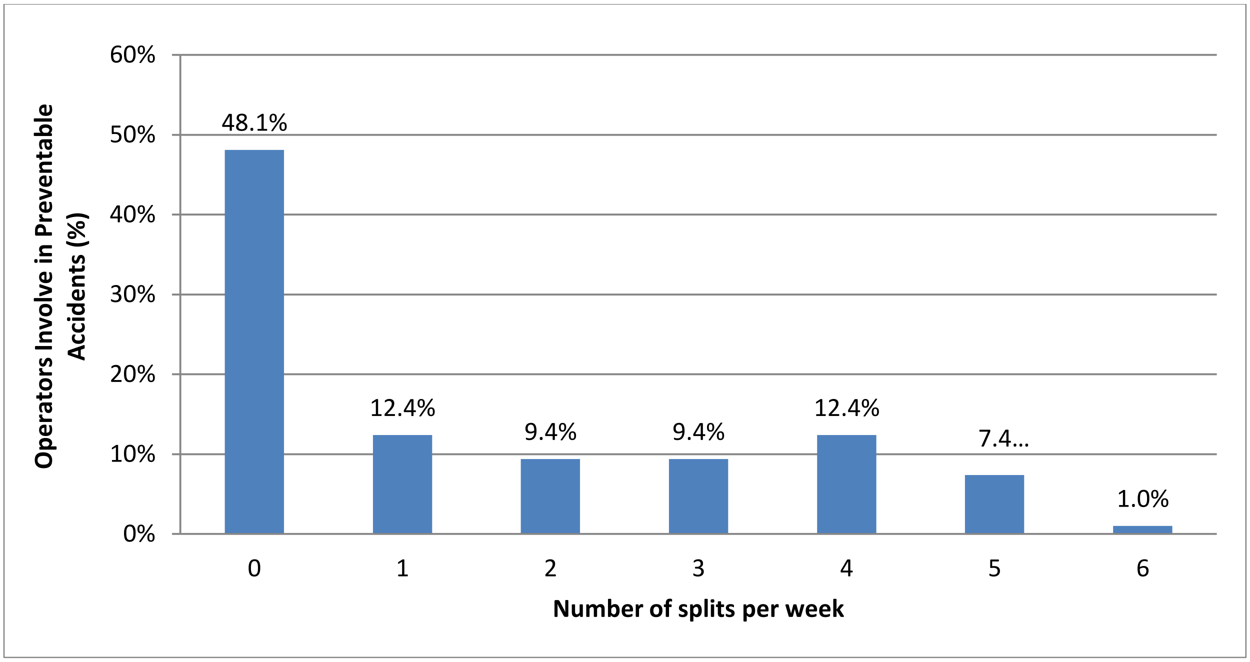

Figure 5.5. Split-shifts during week before accident.

Of the 569 reported collisions, 63.1 % of operators had straight-shift schedules and no split-time during the day of the accident, as shown in Figure 5.6. The distribution of drivers that had split-time schedules was moderately normal, with the highest frequency of collisions occurring with drivers that had a two to three hour break between driving duty. Interestingly, drivers with less than one hour or more than four hours of break time between driving duties experienced the fewest accidents of all operators with split-time schedules.

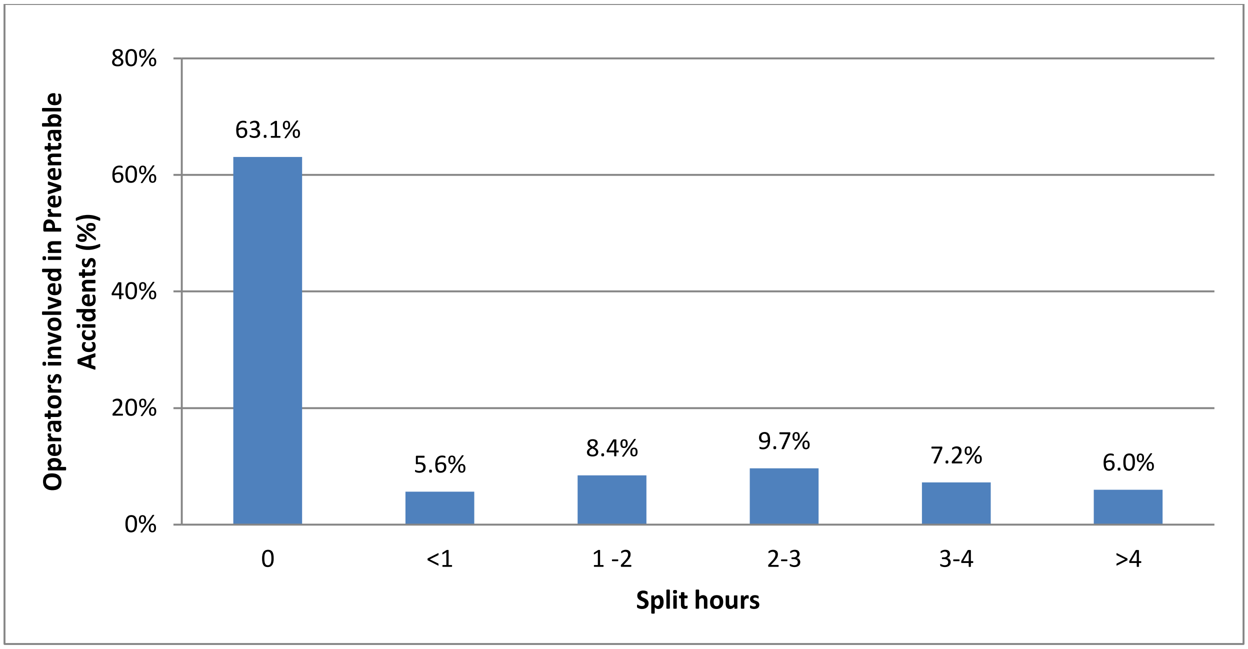

Figure 5.6. Split hours during the day of accident.

Overrepresentation Analysis

From the results shown in Figures 5.5 and 5.6, operators that did not have split schedules experienced the most number of accidents; however, does this imply that split-shifts are better and safer than straight-shift schedules? To answer this question, an overrepresentation analysis was performed to determine the ratio of collisions between selected occurrences and total operator driving time at all four agencies.

The proportions used in the analysis are listed in Table 5.5. The accident proportion relative to driving time proportion generally increased as split-time increased with ratios of 0.74, 1.81, and 0.94 for split-times of zero hours, up to one hour, and one to two hours, respectively. For long split periods of 2-3 hours, 3-4 hours, and greater than four hours, the collision ratio significantly increased to 4.21, 9.64, and 53.82, respectively. This suggests that schedules consisting of longer split-time durations have a negative impact on bus driver safety while on duty.

Table 5.5

Accident proportion relative to driving time proportion

Split-time (hr)	Number of accidents	Accident Proportion	Driving time	Time proportion	Accident proportion relative to driving time proportion
0	359	0.63	8959.6	0.85	0.74
0-1	32	0.06	329.1	0.03	1.81
1-2	48	0.08	943.3	0.09	0.94
2-3	55	0.10	242.6	0.02	4.21
3-4	41	0.07	79.0	0.01	9.64
>4	34	0.06	11.7	0.00	53.82
Total	569	1.00	10565	1.00	

Figure 5.7 graphically displays the analysis results showing the trend of collision proportion relative to total driving time proportion. As split-time duration increased, the accident proportion also increased. For operators with more than two hours of split-time, the percentage involved in preventable accidents increased considerably. Additionally, these findings also suggest that the safest split interval should be minimized with no more than a two-hour period.

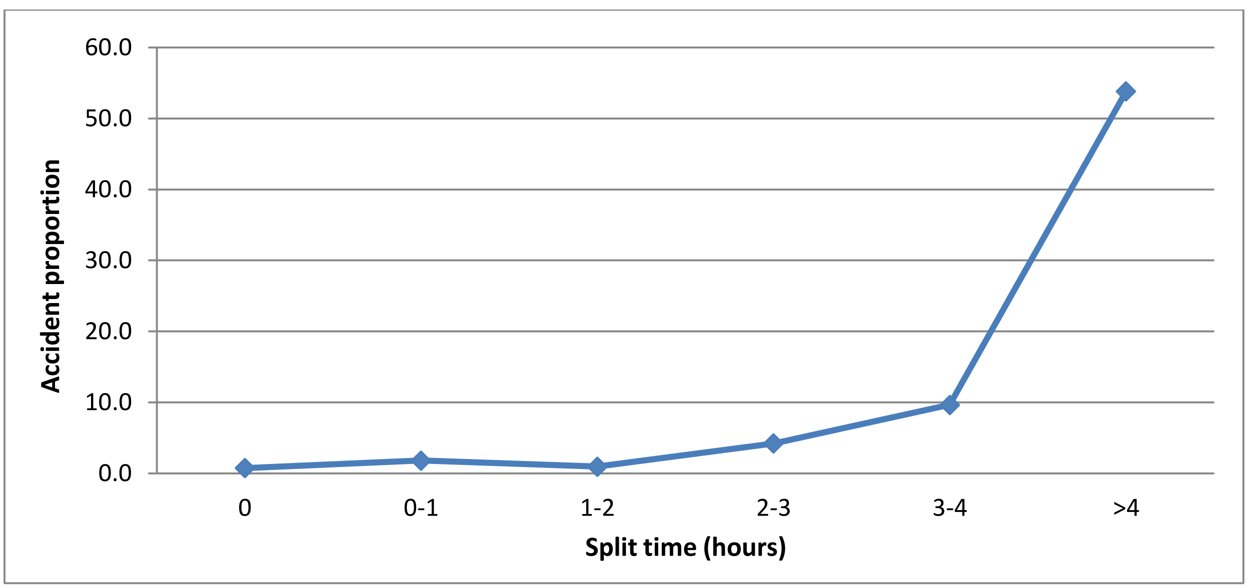

Figure 5.7. Accident proportion relative to exposure to daily split-time.

Varying shifts

An interesting detail of bus operator schedules was the variation of driving shifts. It was observed that drivers involved in preventable accidents had a considerably high rate of unstable shifts (72.6%), illustrated in Figure 5.8. Their schedules consistently changed during the week leading up to the crash. This observation could serve as a potentially attractive subject for future study relating to bus transit operator shifts and routing.

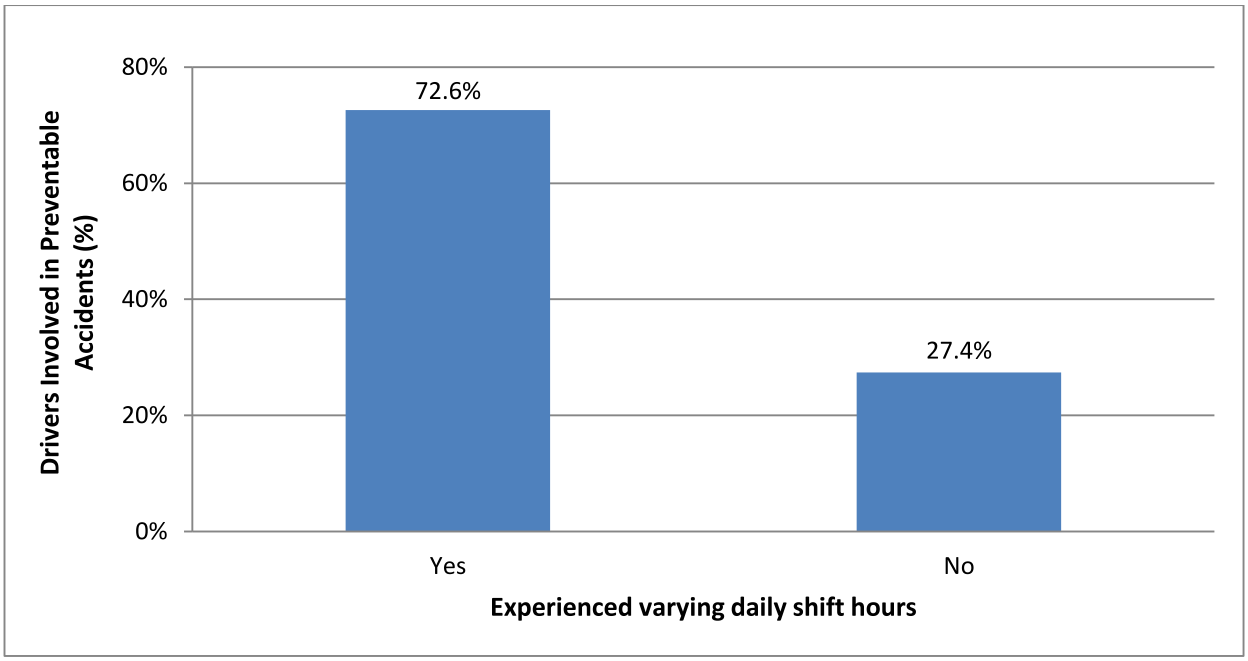

Figure 5.8. Operator with varying daily shift hours.

CHAPTER 6: OPTIMIZATION OF SPLIT-TIME

Method

Minimizing the total split time between bus driver shifts is a primary objective. Chen et al. (2012) presented a paper about establishing a crew scheduling model with impartiality constraint relating to this subject. To adhere to working regulations including maximum number of daily working hours, longest time spent at work, and rest periods, the optimization model was built to minimize the idle time for bus drivers. The procedure was designed using a Tabu Search algorithm (Chen et al. 2012), a mathematical optimization method, and a Heuristic algorithm with a set of shifts. The model then generated the initial solution and a search method using exchange and insert strategy based on proposed order of sequences. The process was repeated to move from one potential solution to an improved solution. The final combinations of shifts was presented when all shifts were generated to minimize split-time. Examples of the exchange and insert strategy presented by Chen et al. are illustrated in Figures 6.1 and 6.2.

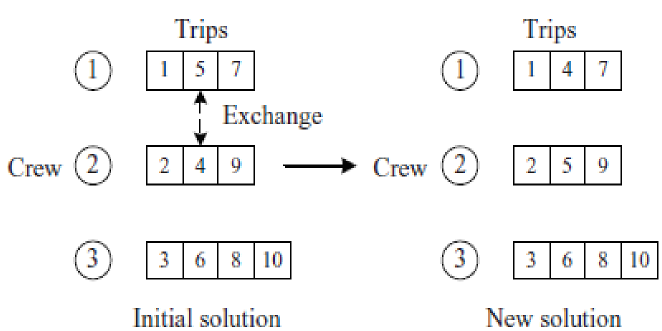

Figure 6.1. Trips exchange strategy.

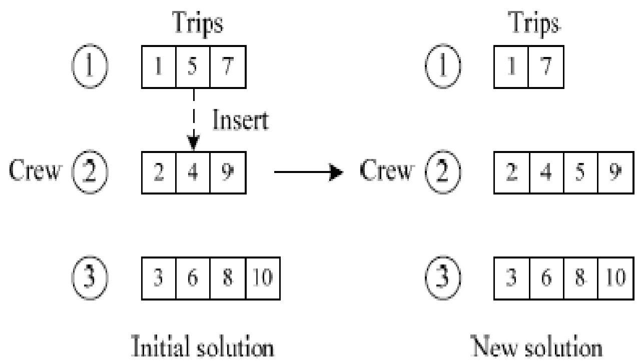

Figure 6.2. Trips insert strategy.

The model assumes all drivers are equally familiar with every bus route. In other words, each bus agency has only one crew, in which each driver can be assigned duty on every route. To express the minimizing split-time as an objective function, the following notations were used: *n* is the number of trips in a day; *i* represents the index of the shift; t_f is the finished driving time of shift *i*; t_i is the starting driving time of shift *i* in the same day. A binary zero-one x_{ij} takes two values: $x_{ij} = 1$, if shift *j* is the next shift after shift *i*; otherwise, $x_{ij} = 0$. The optimization formula is expressed in equation 4 as follows:

$$\sum_{i=1}^{n} x_{ij}(t_f - t_i) \qquad \text{(Eq. 4)}$$

Examining the two-duty period scheduling problem, Shepardson et al. (1980) used Lagrangean relaxation and subgradient optimization. Bus crew schedules at Helsinki City Transport (Finland) were used for the study. Each driver's schedule was categorized in either a single-duty shift or a double-duty shift. A general matrix was constructed to show the overall schedules of all drivers with their assigned shifts at each station (Figure 6.3). The rows represent the operational hours of each station, where each column corresponds to an assigned bus operator.

		X_1	X_2	X_3	$\cdots$	X_N	RHS
Station 1	8 am–9 am	1	0	0		0	b_1
	9 am–10 am	1	0	0		0	b_2
	$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$
	4 pm–5 pm	0	0	1		0	b_p
Station 2	8 am–9 am	0	0	0		1	b_{p+1}
	$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$
	4 pm–5 pm	0	0	0		0	b_q
	$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$
Station Q	8 am–9 am	0	0	1		0	b_r
	$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$
	4 pm–5 pm	0	0	0		1	b_M

$X_j \geqslant 0$, Integer $\quad j = 1, \ldots, N$

Figure 6.3. A sample of overall bus crew schedules (Shepardson et al. 1980).

To minimize the split-time between shifts, the following formula (Eq. 5) was generated:

$$Min \sum_{j=1}^{N} C_j X_j \qquad \text{(Eq. 5)}$$

The two-duty period scheduling problem was simplified to calculate the following formula (Eq. 6):

$$Min \quad CX \qquad \text{(Eq. 6)}$$
$$\text{Where} \quad AX = b, \text{ and } X \in S$$

In equation 6 (Eq. 6), matrix $A = [a_{ij}]$ $(representing\ all\ rows), i = 1, \ldots, M; j = 1, \ldots, N$, where C, X, and b are corresponding dimensioned vectors. S is a set of nonnegative integer N-vectors. Also, each row a_{ij} takes three values: 0, -1, and 1. Each column of the

constraint matrix have either one or two segments of ones, where a segment of ones is a column element a_{ij}, $i = k, k+1, \ldots, k+p-1, k+p$ such that:

$$a_{ij} = 1, \qquad i = k, \ldots, k+p, \text{ or}$$

$$a_{ij} = -1, \qquad i = k, \ldots, k+p,$$

$$\text{and,} \qquad a_{k-1,j} = 0 \text{ } if \text{ } k > 1, \;\; a_{k+p+1,j} = 0 \text{ } if \text{ } k+p < M$$

The algorithm for the two-duty period problem was based on substituting each variable X_j by two variables, X_j^1 and X_j^2. By adding the constraint, $X_j^1 = X_j^2$, Lagrangean relaxation and subgradient optimization can be applied to solve this problem.

Algorithm Design

Since the split-time schedules are the initial solution, the following procedure presents the steps to optimize the drivers' existing working schedules:

Step 1: Let *A* be a matrix of split-shift periods. Calculate this matrix to determine all possible gaps between first shifts and second shifts.

Step 2: For each row *i*, choose *j* such that *A*(*i*,*j*) meets the assigned minimum allowable split-time.

Step 3: Verify the shift time constraint. If $t_f - t_i > 16$, or the total work time $Z_k > 12$, go to step 2.

Step 4: Pair shift *i* and shift *j*, and remove trip *j* from the list by setting $A(:j) = 0$.

Optimizing Split-time Using MATLAB

Figure 6.5 displays existing schedules of all drivers with split schedules. Before performing the optimizing analysis, existing drivers' schedules shown in Figure 6.3 were tested

for population normality. A probability plot was generated (Figure 6.4) after applying the Kolmogorov-Smirnov method (Minitab 2013). At a 95% level of confidence, the *p*-value of .01 was less than the α-value of .05. As a result, the conclusion was that the population is non-normal (Minitab 2013). Using the data set presented in Figure 6.5, an optimizing analysis on split periods was performed to compare improved schedules with the drivers' existing schedules.

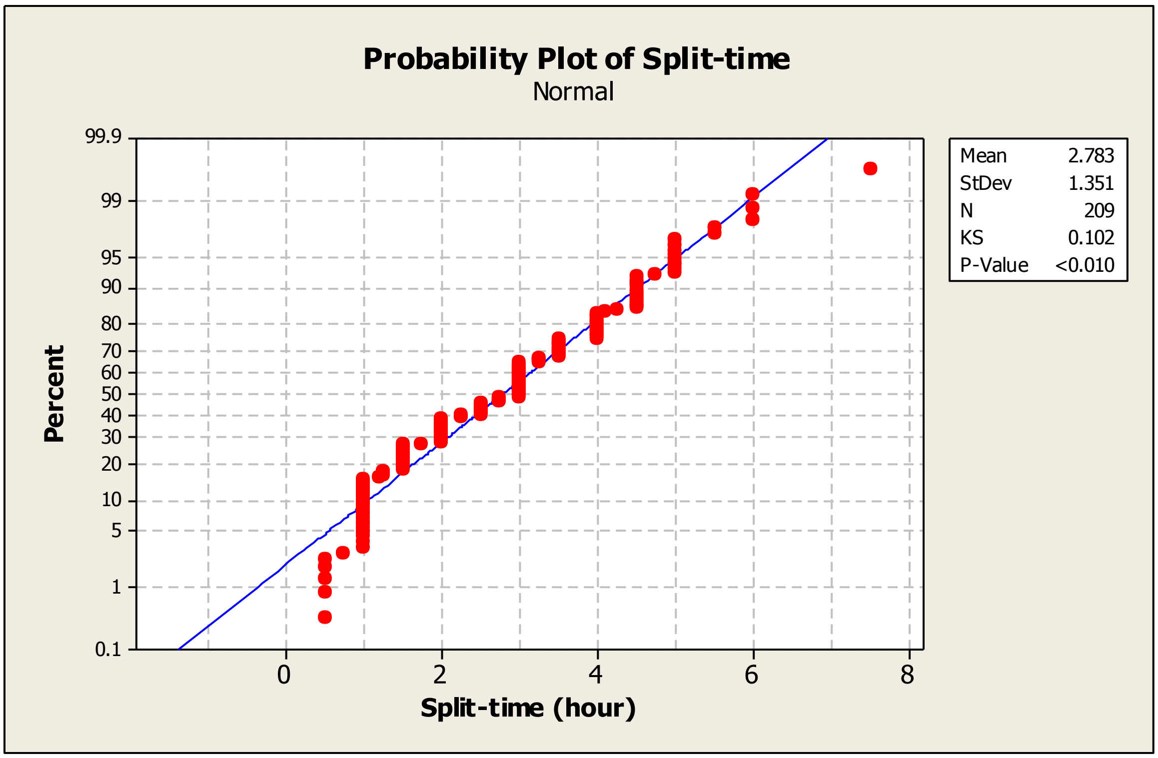

Figure 6.4. Probability plot of split-time schedules.

Table 6.1 lists the results from the MATLAB optimization showing the split-time between shifts was reduced after the minimizing process. For example, when the minimum break time between shifts was set to zero (hour), the total split-time was decreased by 170 hours, a reduction of almost 71% from the total split-time of the existing data. As the minimum allowable split-time increased to 0.5 and 1.0 hours, the total split-time reductions were nearly 63% and

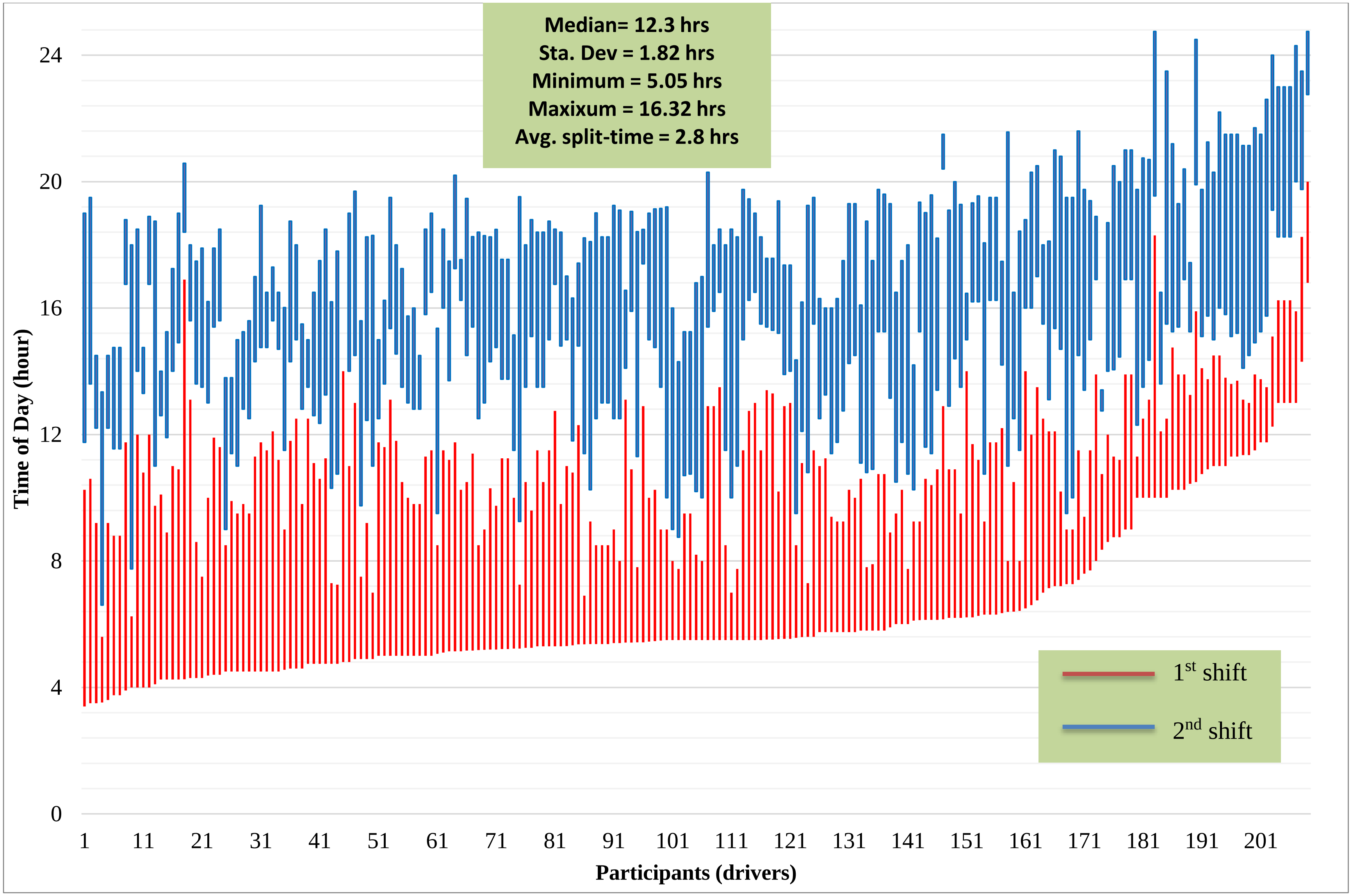

Figure 6.5. Drivers' existing schedules with split-time.

55.3%, respectively, from the existing data. The analysis shows that the extension of a minimum break time to two hours, reduced the total split-time by 24.6%. The programming code developed for the MATLAB optimization analyses is listed in Appendix F.

Table 6.1.

Split-time reduction after optimization

Minimum allowed time between shifts (hours)	Minimum (hours)	Maximum (hours)	Total split-time (hours)	Total split-time reduction (%)
Existing data	0.5	7.5	582	N/A
0	0	3.6	170	70.7%
0.5	0.5	4.2	216	62.9%
1	1	3.5	260	55.3%
1.5	1.5	3.2	341	41.3%
2	2	3.6	438	24.6%

The total split-time reduction for each different allowable break time after optimization is illustrated in Figure 6.6. As the minimum allowable split-time increased, the total split-time reduction decreased. The optimization process was stopped at the two-hour minimum split-time to correspond to the result shown Figure 5.7 indicating that drivers with more than a two-hour break between shifts had a higher probability of being involved in a preventable accident.

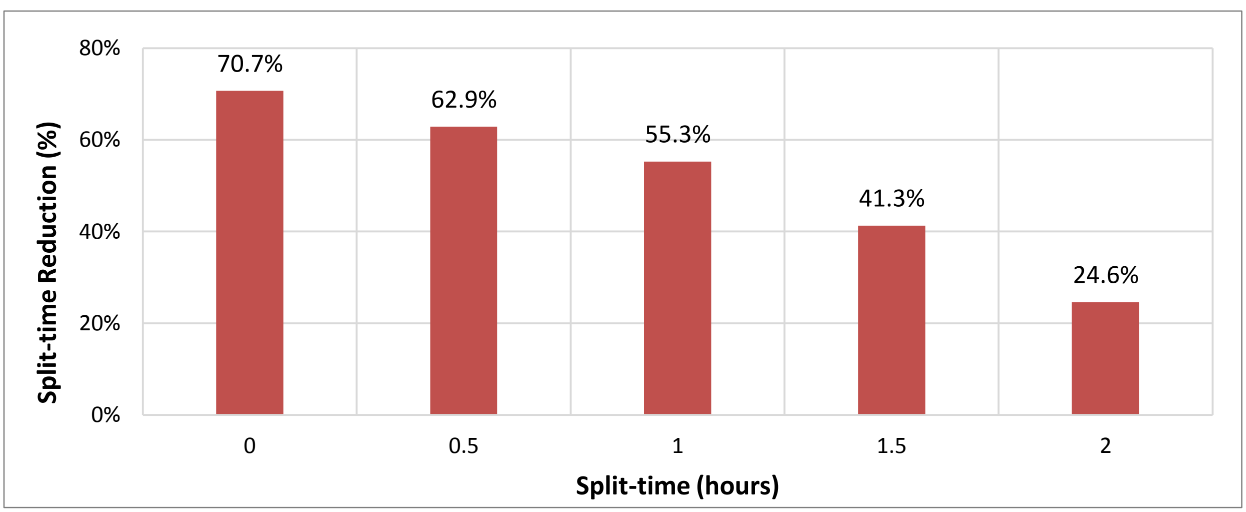

Figure 6.6. Split-time reduction after optimization.

The maximum split-time period for each minimum allowable split-time is displayed in Figure 6.7. Results show that the maximum splits at 1-hour and 1.5 hour allowable split-time, were 3.5 and 3.2 hours, respectively, and were the lowest maximum break times between shifts (Table 6.1).

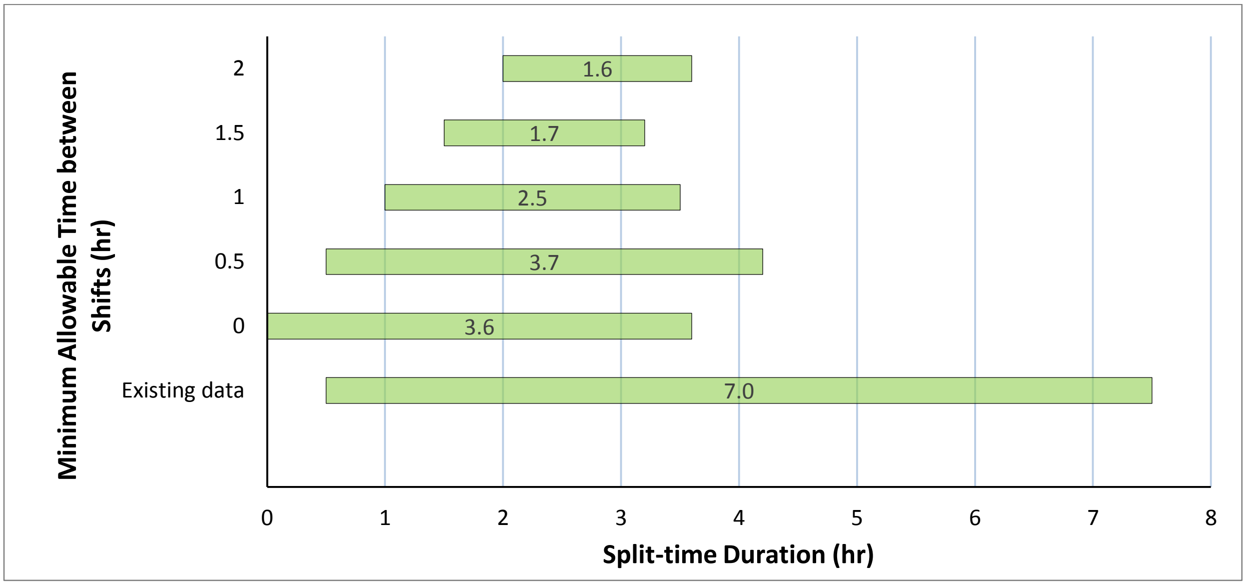

Figure 6.7. Minimum and maximum split-time duration of existing and optimizing data.

The optimized data were also categorized into half-hour split-time periods. Table 6.2 lists both the existing and improved results. Existing schedule data consisted of almost 46% of drivers having more than two hours of split-time, while the 0-hour and 0.5 hour minimum allowable break reduced the number of drivers in this group to about 15% and 13%, respectively. When the minimum split-time was set to one hour and 1.5 hours, the percentages of drivers who had greater than two hours of split-time significantly reduced to 8.2% and 7.8%, respectively. However, the two-hour minimum break time did not reduce the number of drivers with long split-times.

Table 6.2.

Proportions of split-time before and after optimization.

Minimum time allow between shifts (hours)	Split-time (hours)				
	0-1	1-2	2-3	3-4	>4
Existing data	15.2%	22.9%	26.2%	19.5%	16.2%
0	69.7%	15.4%	11.5%	3.4%	0.0%
0.5	69.7%	17.3%	10.1%	2.9%	0.0%
1	46.9%	44.9%	7.7%	0.5%	0.0%
1.5	0.0%	92.2%	7.3%	0.5%	0.0%
2	0.0%	55.3%	43.2%	1.5%	0.0%

Figure 6.8 shows the distribution of split-time periods for existing and optimized data at the 0-hour, 1-hour, and 2-hour minimum allowable split-times. Maintaining the minimum split-time at zero and one hour helped to reduce the percentage of drivers whose schedules contained more than a 2-hour break between shifts.

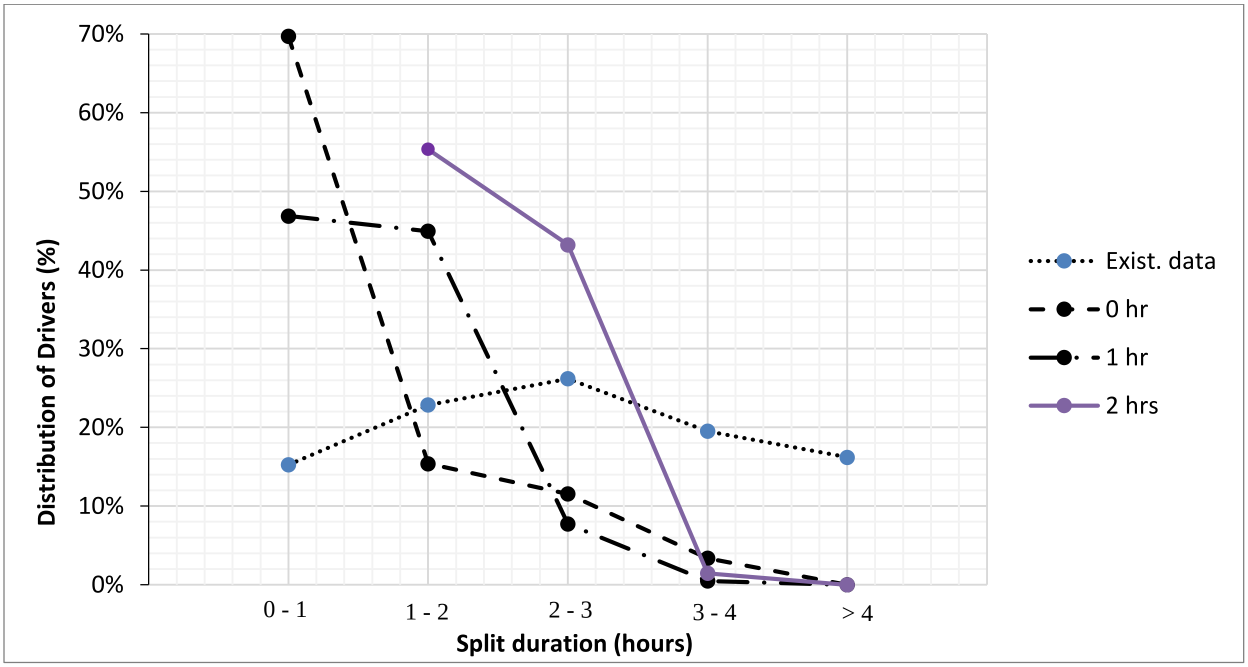

Figure 6.8. Distribution of drivers before and after optimizing schedules data.

From the improved data, 1-hour minimum allowable split-times appeared to present the optimal schedule for bus drivers. The existing data shown in Figure 5.7 also indicated a lower accident proportion for split-times between one and two hours compared to other split periods. Moreover, when optimizing drivers' split-time, maintaining a minimum break of 1-hour between shifts not only helped to reduce the total split-time by 55.3%, it also decreased the maximum split from 7.5 hours from existing data to 3.5 hours. Furthermore, it effectively reduced the number of drivers who had long breaks (more than 2-hours) as shown in Table 6.2. Based on the optimized results, optimum driver schedules are represented in Figure 6.9. Additionally, the maximum time that drivers spent at work reduced from 16.32 hours (existing data) to 14.8 hours.

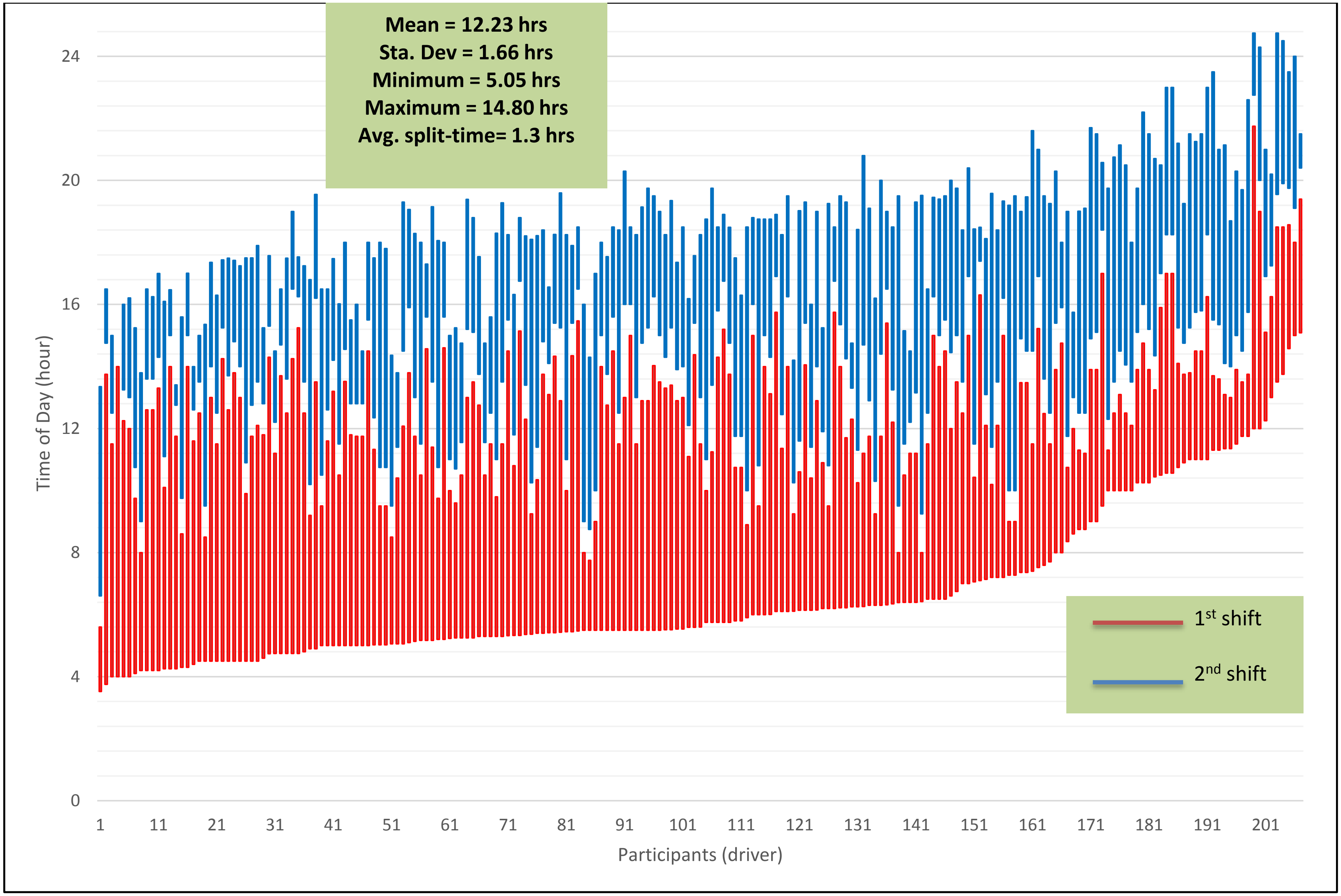

Figure 6.9. Optimal drivers' schedules with split-time.

CHAPTER 7: RESULTS AND DISCUSSION

This study revealed different aspects and correlations between bus driver schedules and the occurrence of preventable collisions in Florida. Based on responses obtained from questionnaire surveys, there were a noticeable number of bus drivers who also had a second driving job. Most of the drivers were also current fulltime operators at their bus agencies. This fact resulted in longer driving times over a 24-hour period, and possibly resulted in driver fatigue while on duty driving for the agency. A considerable numbers of drivers were also concerned about long split-times between shifts, creating longer work days without proper rest time between shifts. Since most of bus agencies did not pay employees during split-time, it potentially increased the stress level of drivers, perhaps contributing to preventable accidents. Split-times also created a sense of unfairness among the drivers when some had longer work hours while others had a more stable schedule. This phenomenon could result in reduced work efficiency and quality of bus service. In addition to safety reasons, long split periods need to be minimized to optimize manpower with minimal cost.at bus agencies that pay drivers during breaks between shifts.

Results from operator schedules and collision analyses strongly indicated the correlations between split schedules and preventable collision occurrence. The chi-square test showed that there was enough evidence to conclude that the preventable crash rates were related on split-time durations between driving shifts. Additionally, the overrepresentation analysis showed that as split duration increased, accident proportions also increased. The optimization analyses suggest that bus agencies should minimize split-time to a one-hour period for drivers. This change would further reduce the percentage of drivers spending long durations of time at work with improper time for rest and recovery for the next day.

CONCLUSIONS

Focusing on several aspects of bus operator schedules, this research examined relationship between driver schedules and occurrence of preventable accidents. Data were collected from five bus transit agencies located in Florida, consisting of driver schedule and collision data, and voluntary survey questionnaire responses. Multiple analyses were applied to evaluate the influence of driving hours and split-time on operator preventable accidents. This study focused on three main objectives: the effects of additional driving jobs outside the transit agency, the effects of split-time schedules on operator fatigue, and the estimation of optimal daily split-time durations. The results are summarized as follows:

Questionnaire survey

Of the 410 surveys obtained from operators, 21.1% of drivers were concerned about the effects of split-time on fatigue. The comments regarding split-times reflected a strong dislike by the drivers of having split hours in their schedules. The extra hours extended the work day, and meant less time for resting before the next work day. In addition to split-time concerns, the study revealed that nearly 15% of operators who completed the survey had a secondary driving job. The types of external modes of transportation driving consisted of public buses, UPS/FEDEX vans, limousines, and taxis. The two most common types of external driving modes included public buses (40%) and UPS/FEDEX vans (13.3%). The on-duty driving hours of these operators were further analyzed to determine the correlations between daily agency driving time and time spent at work. The results indicate that many drivers spend longer periods at work than actual driving time. With the influence of split-time plus the time spent at a secondary driving job, the time for rest and recovery was greatly reduced. As a result, driver fatigue increased during operating times, and possibility contributed to preventable accident occurrence.

Operator schedules and collision analysis

Similarly to the survey data results, operator schedules also indicated that drivers involved in preventable accidents spent longer hours at work than actual driving shifts. The outcome also revealed that longer driving shifts increased accident rates. From the overrepresentation analyses, a split-time period between one to two hours was found to be the most favorable split-time duration. This period of break allowed drivers to perform personal activities between shifts such as having lunch, resting, and napping. Additionally, preventable accidents mostly occurred from 4-PM and 8-PM (28.3%) with the highest frequency of accidents occurring on a Monday (19.5%) and Friday (18.1%). An analysis on the variation of shifts also showed a greater propensity for preventable accidents with varying shift schedules during the week.

Split-time Optimization analysis

MATLAB software was utilized to optimize split-time periods between driver shifts. A total of 210 split schedules were generated with two constraints, including the maximum allowable daily driving time of 12 hours, and a daily on-duty restriction of no more than 16 hours. The results indicate that the optimal break time between two driving shifts is a minimum of one-hour. The total split-time reduced by 55.3% compared to the existing data. Also, the maximum split-time of drivers decreased from 7.5 hours to 3.5 hours, and the longest on-duty day decreased from 16.32 hours to 14.8 hours. Additionally, the percentages of drivers who have more than two-hour split-times reduced to from 46% (existing data) of drivers to 8%.

LIMITATIONS AND RECOMMENDATIONS

A portion of this study involved data generated from questionnaire survey responses. As a result, some bus drivers may not have been sincere with their responses. Though the purpose of this study was carefully explained, some drivers did not fully understand some questions and gave incorrect information. However, the data were thoroughly reviewed before performing analyses. Incomplete and incoherent surveys were eliminated from the data set.

Previous studies have found that nearly 50% of bus operators did not use split-time periods for resting purposes. Thus, long split durations provide drivers with opportunity to perform personal errands or engage in secondary driving activities. The findings from this study suggests that bus operators should have at least a one-hour break between shifts. Driver schedules studied that had this split duration experience the lowest preventable accident rate, overall.

Additionally, with the effects of having an external driving job, operators possibly exceeded the maximum allowable daily driving time. Furthermore, recovery time was undoubtedly affected by the additional driving activity. Although the results relating to secondary driving jobs were significant, it was understood that some drivers may have been reluctant to disclose such information. Therefore, it is recommended that each bus agency develop a system that allows operators to declare secondary driving jobs, (example shown in Appendix D), and further determine appropriate bus shifts using a special bidding process.

As a final point, the optimization of split-time between shifts provides drivers with more reasonable work schedules, and promotes efficiency. However, the optimization procedure assumed all drivers were familiar with all routes and types of buses, an ideal scenario. Therefore, a detailed classification of drivers is recommended for future study to yield a more practical and inclusive outcome.

REFERENCES

Barua, U., Tay, R. (2010). *Severity of urban transit bus crashes in Bangladesh*. Journal of Advanced Transportation, 44, 34-41.

Baysari, M. T., McIntosh, A. S., Wilson, J. R. (2008). *Understanding the human factors contribution to railway accidents and incidents in Australia.* Accident Analysis & Prevention, 40 (5), 1750-1757.

Blom, D. H. J., Pokorny, M. L. I., & van Leeuwen, P. (1987). *The role of age and experience in bus drivers accidents*. International Journal of Epidemiology, 16, 35–43.

Blower, D., Green, P.E. (2010). *Type of motor carrier and driver history in fatal bus crashes.* Transportation Research Record, 2194, 37-43.

Brown, I. D. (1994). *Driver fatigue. Human Factors*. 36, 298–314.

Bültmann, U., de Vries, M., Beurskens, A. J. H. M., Bleijenberg, G., Vercoulen, J. H. M. M., & Kant, I. (2000). *Measurement of prolonged fatigue in the working population: Determination of a cut-off point for the checklist individual strength*. Journal of Occupational Health Psychology, 5, 411–416.

Chen, M., Niu H. (2012). *Research on the scheduling problem of urban bus crew based on impartiality.* Social and Behavioral Sciences, 43, 503-511.

Chimba D., Sando T., Kwigizile V. (2010). *Effect of bus size and operation to crash occurrences.* Accident Analysis and Prevention, 42 (6), 2063-2067.

Dawson, D., Cleggett, C., Thompson, K., Thomas, M. J. W. (2015). *Fatigue proofing: the role of protective behaviours in medating fatigue-related risk in a defence aviation environment.* Accident Analysis & Prevention.

Department for Transport. (2003). *Transport statistics Great Britain*. London: TSO.

Dorn, L. (2003). *Reducing the risk of bus crashes. Paper presented at the 68th Road Safety Congress: Safer driving—reducing risks, crashes & casualties*. Blackpool, UK.

Estache, A., Gómez-Lobo, A. (2005). *Limits to competition in urban bus services in developing countries*. Transport Reviews, 25, 139-158.

Gimeno, P. T., Cerezuela, G. P., & Montanes, M. C. (2006). *On the concept and measurement of driver drowsiness, fatigue and inattention: Implications for countermeasures*. International Journal of Vehicle Design, 42(1/2), 67–86.

Greiner, B. A., Krause, N., Ragland, D. R., & Fisher, J. M. (1998). *Objective stress factors, accidents, and absenteeism in transit operators: A theoretical framework and empirical evidence*. Journal of Occupational Health Psychology, 3, 130–146.

Hartenbaum, N.P., Zee P.C. (2011). *Shift work and sleep optimizing health, safety, and performance.* J Occup Environ Med, 53, pp. S1–S10.

Hege, A., Perko, M., Johnson A., Yu C. H., Sönmez, S., Apostolopoulos, Y. (2015). *Surveying the impact of work hours and schedules on commercial motor vehicle driver sleep.* Safety and Health at Work, 6(2), 104-113.

Howarth, H.D. (2002). *An Investigation of Sleep and Fatigue in Transit Bus Operators on Different Work Schedules*. Doctor of Philosophy Dissertation, University of Connecticut.

Jayatilleke, A.U., Nakahara S, Dharmaratne, S.D., Jayatilleke, A.C., Poudel, K.C., Jimba1, M. (2009). *Working conditions of bus drivers in the private sector and bus crashes in Kandy district, Sri Lanka: a case-control study*. Injury Prevention, 15, 80-86.

Jovanis, P. P., Wu, K., Chen, C. (2012). *Effect of hours of service and driving patterns on motor carrier crashes*. Journal of the Transportation Research Board, No. 2281.

Kaplan S., Prato C. (2012). *Risk factors associated with bus accident severity in the United States: A generalized ordered logit model.* Journal of Safety Research, 43, 171-180.

Lamond .N, Darwent .D, Dawson .D. (2005). *Train drivers' sleep and alertness during short relay operations.*

May, J. F., Baldwin, C. L., (2009). *Driver fatigue: The importance of identifying causal factors of fatigue when considering detection and countermeasure technologies.*

McClave, T.J, Sincich, T., (2009). *Statistics* (11th ed.). Upper Saddle River, New Jersey, United States of America.

Metzger, U. (2005). *Investigation of rail-specific human error*. In: Paper Presented at the Second European Conference on Rail Human Factors.

Minitab, Inc. (2013). Minitab 16: Statistical Software (Version 16.2.4) [Software]. Available from http://www.minitab.com/en-us/

Mirza, S., Mirza M., Chotani H., Luby S. (1999). *Risky behavior of bus commuters and bus drivers in Karachi, Pakistan*. Accident Analysis and Prevention, 31, 329-333.

Monson R., (2015). *What you should know from yesterday's Miami transit summit*.

National Center for Transit Research. (2013). *A qualitative analysis of bus simulator training on transit incidents – a case study in Florida*. Center for Urban Transportation Research, FL.

National Sleep Foundation. (2008). *Sleep in America poll. Sleep, performance, and the workplace.* National Sleep Foundation, Arlington, VA.

Pearce, T., D.A.C. Maunder, T.C. Mbara, D.M. Babu, and T. Rwebangira. (2000). *Bus accidents in India, Nepal, Tanzania, and Zimbabwe*. Transportation Research Record, 1726, 16-23.

Philippa .G, Marshall .N, James .I, Le .Q. (2006). *Investigating driver fatigue in truck crashes: Trial of a systematic methodolog*y.

Salmon, P. M. (2011). *Human Factors Methods and Accident Analysis: Practical Guidance and Case Study Applications.*

Santos, E. H. R., de Mello M. T, Pradella-Hallian,M., Luchesi, L., Pires, M. L. N., Tufik, S. (2004). *Sleep and Sleepiness among Brazilian Shift-Working Bus Drivers*. Chronobiology International: The Journal of Biological and Medical Rhythm Research.

Sapper D., Page O. (2004). *Analysis of Florida Transit Bus Accidents.*

Sapper D., Reep A. (2007). *Toolbox for transit event investigation.*

Shepardson, F., Marsten R. E. (1980). *A lagrangean relaxation algorithm for the two duty period scheduling problem.* Management Science, 26 (3), 274-281.

Strathman J., Wachana .P, Callas .S. (2010). *Analysis of bus collision and non-collision incidents using transit ITS and other archived operations data*.

Sussman D, Coplen M. (2000). *Fatigue and Alertness in the United States Railroad Industry part I: the Nature of the Problem*.

Transportation Research Board. (2001). *The effects of Commuting on Pilot Fatigue.* Washington, D.C.: The National Academies Press.

Tse, J. L. M., Flin R., Mearns, K. (2006). *Bus driver well-being review: 50 years of research.* Transportation Research Part F, 89-114.

Williamson A, Sadural S, Feyer A, Friswell R. (2001). *Driver fatigue: a survey of long distance heavy vehicle drivers in Australia. Information Paper CR 198, National Road Transport Commission*.

APPENDIX A: A BLANK QUESTIONNAIRE SURVEY

Questionnaire to solicit information on external hours - Hours working outside the transit agency

Survey guide for transit operators

The Florida Department of Transportation is sponsoring a follow up research project to evaluate the safety implications of transit operator schedule policies. The main objective of this study is to examine bus operator schedules to determine their duration length, length between split shifts, and layover durations to assess their impacts on transit vehicle accidents. Also, this research will evaluate the influence of external driving hours on transit safety.

FDOT Project Manager: Victor Wiley; Contact Info:

Principal Investigator: Thobias Sando; Contact Info:

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/week.

1. Are you a full time or part time employee? Full time ___Part time ___
2. How many hours during a 7-day work week are you on duty at the transit agency? ________________;
3. How long is your average scheduled work day at the transit agency? (total hours from driving schedule)
4. How many hours, on average, do you spend at the transit agency? (include all time spent at the transit agency; route schedule, breaks, splits, layovers)
5. How many days during a 7-day work week are you on duty at the transit agency? ________________;
6. How many hours per day do you perform other (employment related) driving duties outside the transit agency? ________________. (2nd employment info; does not include personal driving time)
7. How many days per week do you perform other driving duties outside the transit agency? ________________.
8. What type of external driving do you perform? Taxi [ ] School bus [ ] Limousine [ ] UPS/FEDEX Vans [ ] Other [ ] ____________________________
9. Is your schedule fairly the same throughout the week? Yes_____ No_______
10. Do you work different shifts? Yes_____ No______
11. Do you work split schedule? Yes_____ No_______
12. On average, how long is your split time between shifts? ______hours
13. How far from work do you live? _____ Miles (information requested in #5)
14. On average, how long does it take for you to travel from home to work? ____ Min/Hours (#5)
15. On average, how long does it take for you to travel from work to home? ____ Min/Hours
16. 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.

INFORMED CONSENT FORM

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 influence of external driving hours on transit safety. Also, this study will examine bus operator schedules to determine their duration length, length between split shifts, and layover durations to assess their impacts on transit vehicle accidents. The outcome of this study will be used by transportation officials from state to local transit agencies in determining how best to schedule bus operator hours in order to improve highway safety. Please complete a short survey which should take less than 5 minutes.

The University of North Florida (UNF) is the source of this research. Participation is voluntary. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are entitled. The information you are providing is anonymous. 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:

Principal Investigator: Thobias Sando; Contact Info:

For questions regarding the rights of research subjects feel free to contact the chair of the UNF Institutional Review Board, (904) 620-2498. There are no reasonably foreseeable risks or discomforts to the subject. Your participation will potentially contribute to a body of knowledge. No monetary or other compensation or inducements will be awarded. By participating in this survey you certify that you are over 18 years old.

If you wish to participate, please tell the researcher or please take a survey and put it in the box when you are done.

APPENDIX B: MIAMI-DADE SPLIT-TIME PAY DESCRIPTION

From: Perez, Joel (MDT)
Sent: Thursday, October 17, 2013 12:20 PM
To: Smerling, Barry (MDT)
Cc: Thobias Sando
Subject: RE: Question on Split schedules

Below is the portion of the contract that explains the difference between a split and a combination. We pay for the time in between a split if the intervene time is greater than 90 minutes

A **split run** consists of two parts and each part may be on a different route. On split runs, intervening time in excess of 90 minutes will be paid at straight time. The minimum unpaid intervening time will be 30 minutes.

Wait and travel on a split run where each part is on a different route will be based on last available bus plus wait time at relief point for next bus.

Eighty (80) per cent of the regular runs shall be straight runs and twenty (20) per cent may be splits.

(o) **Combination Runs** --It is the expressed intend of the parties to develop additional work schedule procedures which will result in pre-assigning as much work as practical on a daily or weekly basis.

M.D.T. will develop, in addition to the regular runs heretofore described, a group of Combination Runs. These runs shall be scheduled and paid as follows:

Runs shall include fifteen (15) minutes bus preparation time for each piece of work comprising the combination plus a maximum of eight and one-half (8 ½) platform hours within a total elapsed time of twelve hours.

Work beyond the twelfth hour will be at overtime in all cases.

When platform time within the 12 hour spread exceeds 8 hours, daily overtime guarantee applies. Pay for combination runs will be a minimum of 45 hours of pay at straight time rate.

For example, the pay for a week could be made up of the following:

(1)	41.25	Hours of work time
	2.50	Hours of report time
	1.25	Hours overtime premium pay
	45.00	Hours at straight time rate
(2)	37.00	Hours of work time
	2.50	Hours of report time
	5.50	Hours of paid unassigned time
	45.00	Hours of straight time rate

Should an operator with paid unassigned time in his/her daily work schedule desire to work during the intervening period of his/her combination run, overtime or added pay will begin after paid unassigned time for that day is made up by work time. Any work performed at either end of the combination run will come under the daily overtime provision of this Agreement.

If an operator with a combination run, which has paid unassigned time, works an assignment which is authorized by the Dispatcher, a Supervisor or Starter during his/her intervening period, payment for such work will be above his/her run pay at the applicable rate of pay. If an operator is late returning to the garage at the end of his/her combination, he shall be paid above his/her run pay at the applicable rate of pay.

APPENDIX C: SAMPLE OPERATOR SCHEDULE FORMAT

```
05/17/2011 Tuesday  FT  FT5  Scheduled to work

     204     127 12702  09:45M 11:28M      1.63  0.08  0.00  0.00  1.72

     204     027 02706  14:33M 21:38M      6.83  0.25  0.00  0.00  7.08

                                   ----- ----- ----- ----- -----

                                   8.47  0.33  0.00  0.00  8.80

Piece Details:  Platform:   8.47  Report:   0.25  Travel :   0.08

Run Totals: Overtime:   0.40 (  0.80)

                                      Total Work Pay:  9.20


--> Total of time entries using (whole) times:  9.60
```

Figure C.1. Operator driving schedule at JTA sample.

Division	Work Type	Run Type	Work Name	Piece Num	Sign On	From Time	To Time	Sign Off	Date	Work Time	Platform Time	Report Time	Comments		
	Day Off		Day Off						2010-10-10						
			UnAssigned						2010-10-11	0	0				
			UnAssigned						2010-10-12	0	0				
A	Run	AM STR	17	1	4:17a	4:27a	11:46a	11:46a	2010-10-13	7h29	7h19	10		Bid	
			Total						2010-10-13	7h29	7h19	10			
A	Run	AM STR	17	1	4:17a	4:27a	11:46a	11:46a	2010-10-14	7h29	7h19	10		Bid	
			Total						2010-10-14	7h29	7h19	10			
A	Run	10 AM STR	229	1	5:08a	5:18a	3:21p	3:21p	2010-10-15	10h13	10h03	10		Bid	
A	ExtraPay		HT	1		3:21p	3:27p		2010-10-15	6	6		Heavy Traffic		
			Total						2010-10-15	10h19	10h09	10			
	Day Off		Day Off						2010-10-16						
	Day Off		Day Off						2010-10-17						
A	Run	AM STR	19	1	4:18a	4:28a	12:01p	12:01p	2010-10-18	7h43	7h33	10		Bid	
A	ExtraPay		OTHER	1		12:01p	12:07p		2010-10-18	6	6		Other Time		
			Total						2010-10-18	7h49	7h39	10			
A	Run	AM STR	17	1	4:17a	4:27a	11:46a	11:46a	2010-10-19	7h29	7h19	10		Bid	
			Total						2010-10-19	7h29	7h19	10			
A	Run	AM STR	17	1	4:17a	4:27a	11:46a	11:46a	2010-10-20	7h29	7h19	10		Bid	
			Total						2010-10-20	7h29	7h19	10			
A	Run	AM STR	17	1	4:17a	4:27a	11:46a	11:46a	2010-10-21	7h29	7h19	10		Bid	
A	ExtraPay		ACRT	1		11:46a	12:01p		2010-10-21	15			Accident ReportTime		
			Total						2010-10-21	7h44	7h19	10			
A	Run	10 AM STR	229	1	5:08a	5:18a	3:21p	3:21p	2010-10-22	10h13	10h03	10		Bid	
			Total						2010-10-22	10h13	10h03	10			
	Day Off		Day Off						2010-10-23						

Figure C.2. Operator driving schedule at LYNX sample.

```
02/21/2010 Sunday  FT  FTXB  Regular Day Off
(Extraboard)
Daily P/R Totals not created for this employee on this day
------------------------------------------------------------------------------
02/22/2010 Monday  FT  FTXB  Scheduled to work
(Extraboard)
A    A0  305   11       1104 01:05P 04:15P        3:00  0:00  0:10  0:00  3:10
A D A0  305   30       3020 06:15P 11:00P        4:30  0:15  0:00  0:00  4:45
 -->Actual where different:                                        0:30  5:15


                                                ----- ----- ----- ----- -----
                                                 7:30  0:15  0:10  0:30  8:25
Piece Details:  Accident/Incident:   0:30  Platform:   7:30  Report:   0:15
      Travel:   0:10
Run Totals: Make Up (Pad):   0:05
Calculated Totals: Accident/Incident OT:  00:15.00 ( 0:30)
                                                       Total Work Pay:  8:45
```

Figure C.3. Operator driving schedule at HART sample.

Dispatch Date	Garage Nbr	Badge Nbr	Route Nbr		Run Nbr	Run Type	Start Time	End Time	Finished Time	Report Time	Micl Time
26-Apr-12	NE	2041	75	05183-01	03	5.32	14.47	14.57	5.17	-	9966
27-Apr-12	NE	2041	75	05183-01	03	5.32	14.47	14.57	5.17	-	9966
28-Apr-12	NE	2041	3	05966-02	05	12.38	16.19	16.19	12.23	-	2136
28-Apr-12	NE	2041	H	05966-01	05	6.14	11.06	11.06	5.59	-	2136
29-Apr-12	NE	2041	17	06257-01	05	6.42	12.33	12.33	6.27	-	9966
1-May-12	NE	2041	75	05183-01	03	5.32	14.47	14.57	5.17	-	9967
2-May-12	NE	2041	75	05183-01	03	5.32	14.47	14.57	5.17	-	9966
3-May-12	NE	2041	75	05183-01	03	5.32	14.47	14.57	5.17	-	9966
4-May-12	NE	2041	75	05183-01	03	5.32	14.47	14.57	5.17	-	2137
5-May-12	NE	2041	77	05952-02	05	16.52	19.09	19.09	16.37	-	0
5-May-12	NE	2041	3	05966-02	05	12.38	16.19	16.19	12.23	-	9977
5-May-12	NE	2041	H	05966-01	05	6.14	11.06	11.06	5.59	-	9977
8-May-12	NE	2041	75	05183-01	03	5.32	14.47	14.57	5.17	-	9966
9-May-12	NE	2041	75	05183-01	03	5.32	14.47	14.57	5.17	-	9966
10-May-12	NE	2041	75	05183-	03	11.06	14.47	14.57	11.06	-	9966
10-May-12	NE	2041	75	05183-01	03	5.32	11.06	11.06	5.17	-	9966

Records Count: 16

Figure C.4. Operator driving schedule at Miami-Dade Transit sample.

APPENDIX D: BROWARD EXTERNAL WORK FORM

Board of County Commissioners, Broward County, Florida
HUMAN RESOURCES DIVISION

OUTSIDE EMPLOYMENT REQUEST FORM

TO: ____________________
DIVISION/OFFICE/DEPARTMENT DIRECTOR

FROM: ____________________
NAME OF EMPLOYEE TITLE DIVISION/OFFICE/DEPARTMENT

ALL EMPLOYEES MUST COMPLETE THIS FORM, WHETHER OR NOT THEY SEEK TO ENGAGE IN OUTSIDE EMPLOYMENT.

County employees who seek to engage in outside employment may do so upon completing this form and obtaining the written approval of their division, department, or office director (as applicable). For purposes of this form, "outside employment" means:

1. Any compensated employment performed by a County employee aside from his or her employment with the County, including any part-time employment, self-employment, or consultant-related employment; or

2. Serving as an officer, director, or registered agent, or in any similar capacity, with or without compensation, for any for-profit or not-for-profit business entity that:
   a. Is a County vendor under contract with the County, or a prospective vendor seeking to do business with the County; or
   b. Receives, directly or indirectly, any grants, loans, or other County funds that are made available through any agency of the County, or is an applicant for any such County funds.

Please place a checkmark next to the applicable provision below:

○ (1) I am not engaged in any outside employment as defined above. Should I wish to engage in any outside employment at any time in the future, I will complete and submit an updated Outside Employment Request Form to my supervisor prior to engaging in such outside employment.

○ (2) I request permission to engage in outside employment as defined above.

If you checked provision (1), please proceed to the back of this form and sign on the "employee signature' line. If you checked provision (2), you must provide the following information (attach additional sheets if necessary), proceed to the back of this page and sign.

Name of Firm: ____________________

Location of Outside Employment: ____________________

Outside Employment Contact Telephone Number: ____________________

Type of Outside Employment:

☐ Compensated or ☐ Uncompensated

Period of Outside Employment: Start: __________ End: __________

My Hours of Outside Work: ____________________

Brief Statement of Outside Duties: ____________________

Outside Employment Position/Title:
____

Form 102-113 (rev 5/11) Page 1 of 2

The undersigned understands that the following provisions relate to outside employment and conflicts of interest of County employees:

1. Florida Statutes, Sections 112.311 to 112.326, Code of Ethics for Public Officers and Employees.
2. Broward County Code of Ordinances, Sections 26-67 through 26.80.
3. Broward County Administrative Code, Section 14.249 through 14.253, Ethics and Conflict of Interest for the County Civil Service Rules and Regulations.
4. Broward County Administrative Code, Section 1.11(v).
5. Administrative Order #400, Human Resources Internal Control Handbook.

The undersigned represents and acknowledges that:

1. Any proposed outside employment will not interfere with the efficient performance of the undersigned's regular County duties, and will not occur during regular or assigned working hours unless applicable leave is requested and approved to cover the absence.
2. Any proposed outside employment will not involve a conflict of interest or otherwise conflict with any of the undersigned's responsibilities as a County employee.
3. Any proposed outside employment will not involve the performance of maintenance or other work to the personal or real property of a managerial-level County employee or County elected official or anyone in the employee's chain of command.
4. Any proposed outside employment does not involve the undersigned lobbying, on behalf of an outside principal or employer for compensation, County Commissioners, members of any County Selection/Evaluation committee, or the governmental unit in which he or she is employed.
5. Approvals of any proposed outside employment are only for the specific employer and type of work disclosed by the undersigned. If any change in employer or type of work (including a change in hours) occurs, a new Outside Employment Request Form must be completed, submitted and approved. An employee wishing to engage in more than one form of outside employment must complete a separate Outside Employment Request Form for each form of outside employment being requested.
6. The County has the right to rescind outside employment approval at any time upon written notice.
7. Any violation of the above provisions, including any of the provisions of the laws or rules applicable to outside employment, is subject to appropriate corrective and/or disciplinary action including, where appropriate, discharge from County employment.

For further information or questions, please contact the Broward County Human Resources Division.

I represent that the information provided above is true and correct, and that I understand all applicable laws, rules, procedures, policies and other provisions governing outside employment. I also understand that any approval of this request for outside employment cancels all other approvals for outside employment unless expressly stated herein.

Employee Signature:____ **Date:** ______________________

Division/Office/Department Director: Check one of the three options below:

☐ Approved ☐ Approved with Restrictions ☐ Denied

Signature:____ Date: ____________________

RESTRICTIONS OF APPROVAL (if any):

____

REASON FOR DENIAL (if applicable):

____

APPENDIX E: CRITICAL VALUES OF THE X^2 DISTRIBUTION

df \ p	0.995	0.975	0.9	0.5	0.1	0.05	0.025	0.01	0.005	df
1	.000	.000	0.016	0.455	2.706	3.841	5.024	6.635	7.879	1
2	0.010	0.051	0.211	1.386	4.605	5.991	7.378	9.210	10.597	2
3	0.072	0.216	0.584	2.366	6.251	7.815	9.348	11.345	12.838	3
4	0.207	0.484	1.064	3.357	7.779	9.488	11.143	13.277	14.860	4
5	0.412	0.831	1.610	4.351	9.236	11.070	12.832	15.086	16.750	5
6	0.676	1.237	2.204	5.348	10.645	12.592	14.449	16.812	18.548	6
7	0.989	1.690	2.833	6.346	12.017	14.067	16.013	18.475	20.278	7
8	1.344	2.180	3.490	7.344	13.362	15.507	17.535	20.090	21.955	8
9	1.735	2.700	4.168	8.343	14.684	16.919	19.023	21.666	23.589	9
10	2.156	3.247	4.865	9.342	15.987	18.307	20.483	23.209	25.188	10
11	2.603	3.816	5.578	10.341	17.275	19.675	21.920	24.725	26.757	11
12	3.074	4.404	6.304	11.340	18.549	21.026	23.337	26.217	28.300	12
13	3.565	5.009	7.042	12.340	19.812	22.362	24.736	27.688	29.819	13
14	4.075	5.629	7.790	13.339	21.064	23.685	26.119	29.141	31.319	14
15	4.601	6.262	8.547	14.339	22.307	24.996	27.488	30.578	32.801	15

APPENDIX F: MATLAB PROGRAMMING CODE FOR OPTIMIZATION ANALYSIS

```
clear;
SS = load('schedule.txt');
S = SS(350:end,:);
T1x = [SS(1:349,2)*60; S(:,2)*60];
T1y = [SS(1:349,5)*60; S(:,3)*60];
T1 = [T1x T1y];     %set of first trips
T2 = S(:,4:5)*60;   %set of second trips

m = length(T1);  %total number of first trips;
n = length(T2);  %total number of second trips;

h0 = 120;    %min gap minutes
h1 = 12*60; %max driving minutes
h2 = 16*60; %max working minutes

for k=1:n
    for j=1:m
        A(k,j) = T2(k,1) - T1(j,2);  %create the distance matrix
    end;
end;

test1 = sum(diag(A(:,350:m)));  %old total gap
l = diag(A(:,350:m));           %old gaps for each trip pairs

%x = contains the indices of the optimal second trips corresponding the first
trips
x = ones(1,n);

k = 1;
I = find(A(k,:) > 0);
[D t] = min(A(k,I));   %D:minimum gap, t: index that gives the minimum gap
total = T2(k,2) - T1(I(t),1);   %total length of the trips
totaldrive = (T2(k,2) - T2(k,1)) + (T1(I(t),2) - T1(I(t),1)); %total driving
time during the trips
for k=1:n
    k
    I = find(A(k,:) > 0);
    [D t] = min(A(k,I));
    total = T2(k,2) - T1(I(t),1);
    totaldrive = (T2(k,2) - T2(k,1)) + (T1(I(t),2) - T1(I(t),1))
    if ( (D >= h0) & (total <= h2) & (totaldrive <= h1) )
        x(k) = I(t)
        for s=1:n
            A(s,I(t)) = 0;
        end;
        k = k+1;
    elseif ( (D < h0) | ( (D >=h0) & (total > h2) ) | ( (D >=h0) & (total <=
h2) & (totaldrive > h1) ))
        while ( (D < h0) | ( (D >=h0) & (total > h2) ) | ( (D >=h0) & (total
<= h2) & (totaldrive > h1) ))
```

```
            A(k,I(t)) = 0;
            I = find(A(k,:) > 0);
            [D t] = min(A(k,I));
            total = T2(k,2) - T1(I(t),1);
            totaldrive = (T2(k,2) - T2(k,1)) + (T1(I(t),2) - T1(I(t),1));
        end;
        if ((D >= h0) & (total <= h2) & (totaldrive <= h1) )
            x(k) = I(t);
            for s=1:n
                A(s,I(t)) = 0;
            end;
            k = k + 1;
        end;
    end;
end;

for k=1:n
    for j=1:n
        B(k,j) = T2(k,1) - T1(x(j),2);  %create the distance matrix
    end;
end;

k = diag(B);

%find the single duty trips
for t=1:558
    if t~=x(:)
        y(t) = t;
    else
        y(t) = 0;
    end;
end;

Y = y';
K = find(Y(:)>0);
ftotaly = T1(Y(K),2) - T1(Y(K),1);  %trip total for single duty

test2 = sum(diag(B));           %new total gap
ftotal = T2(:,2) - T1(x(:),1);  %trip total for double duty
ftotaldrive = (T2(:,2) - T2(:,1)) + (T1(x(:),2) - T1(x(:),1));  %total
driving time for double duty trips

Snew_d = [x ; 1:n ; T1(x,1)' ; T1(x,2)' ; T2(:,1)' ; T2(:,2)' ; l' ; k' ;
ftotal' ; ftotaldrive']';
Snew_s = [y(K) ; T1(y(K),1)' ; T1(y(K),2)' ; ftotaly']';
ResultsFile_d = strcat ('NewSchedule_d') ;
ResultsFile_s = strcat ('NewSchedule_s') ;
save (ResultsFile_d, 'Snew_d') ;    %results for double duty saved in
NewSchedule_d
save (ResultsFile_s, 'Snew_s') ;    %results for single duty saved in
NewSchedule_s
```

VITA

EDUCATION

Master of Science – Civil Engineering (Transportation), Apr. 2016 Jacksonville, FL
University of North Florida

Bachelor of Science – Civil Engineering, Cum Laude, Apr.2012 Jacksonville, FL
University of North Florida

PROFESSIONAL EXPERIENCE

England, Thims, & Miller, Inc., Jacksonville, FL
Civil Engineer (Transportation) Jan 2015 – Present

England, Thims, & Miller, Inc., Jacksonville, FL
Civil Engineer (Land Development & CEI) Sep 2013 – Dec 2014

University of North Florida, Jacksonville, FL
Research Assistant Jun 2009 – Dec 2014

Florida State College at Jacksonville, Jacksonville, FL
Academic Tutor Dec 2011 – Dec 2013