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EVALUATING THE HOURS-OF-SERVICE RULE VIA GPS/GIS TRUCK TRIP DATA

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16. Abstract

Road safety has always been a constant issue for transportation networks. Commercial Motor Vehicles (CMV) operations have been a significant factor regarding crash rates increase due to the interaction of trucks with other vehicles. Federal Motor Carrier Administration, US-DOT suggested new Hours of Service (HOS) rules for CMV drivers as a measure of improving traffic safety. HOS rules define the driving and working hours of truck drivers and the corresponding rest periods on a daily and weekly basis. The potential effects of new regulation on truck operations are controversial. The major objective of this research is to investigate the potential impact of new HOS rules. The proposed methodology will focus on modeling the effects of new HOS rules on traffic conditions of road networks and mainly on the corresponding congestion levels during peak-hour periods.

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Executive Summary

Freight industry is a crucial sector of US economy. In 2011 the value of domestic shipments, imports and exports was estimated to approximately 16,804 billion of 2007 dollars (USDOT, 2012). Among the different modes of transportation, trucks accounted for 68% of total shipments tonnage distribution in 2011 (USDOT, 2012). However, extended truck operations which are included in the general category of Commercial Motor Vehicles (CMV) create issues regarding road safety.

Safety concerns refer to the interaction of CMVs with other modes of transportation. Statistics show that 276,000 trucks were involved in road crashes during 2009 and a corresponding increase in fatality levels of 9% was also observed (USDOT, 2012).

Driver fatigue is a primary cause of truck accidents. Transportation agencies, in order to reduce driver fatigue levels and improve road safety, developed Hours of Service (HOS) rules for CMV drivers. HOS rules define the maximum allowable driving and working hours and the corresponding required rest periods.

Currently, the Federal Motor Carrier Administration (FMSCA), US-DOT proposed new HOS rules for CMV drivers in the context of the continuous effort to improve safety standards. New rules suggest the reduction of the allowable working hours per week to 70 and require two rest periods between 1 a.m. to 5 a.m. to be included in the 34-hour off duty restart period (FMSCA, 2012). New regulation has created significant controversy regarding the potential effects on truck operations. The longer rest periods and the benefits regarding drivers' health are pointed out. However, various concerns are expressed regarding the impact of new rules on industry benefits/costs and also the effects on traffic and environmental conditions.

The major objective of this research was to investigate the potential effects of new HOS rules, focusing on the corresponding impact on traffic conditions and mainly congestion levels. Analysis included the selection of the case study area based on data availability and the identification of the existing truck trip patterns and characteristics using GPS/GIS truck data. Existing truck trip patterns were developed by statistically analyzing the provided data.

Then, research focused on developing a methodology to model the impact on traffic congestion. Congestion impact was identified by tracking the corresponding changes of the Level of Service (LOS) which described the traffic conditions of the case study road network. Analysis followed the suggested methodology by the Highway Capacity Manual (HCM, 2000); however, various adjustments to the related formulations had to take place. These adjustments mainly corresponded to the data characteristics and limitations.

Analysis outcomes from the applied case study revealed a significant impact of the new HOS regulations on traffic conditions during peak hours. Worse LOS values showed that congestion levels on the case study link could be significantly increased due to the application of the new HOS rules and their corresponding restrictions.

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1. INTRODUCTION

1.1 Problem Statement

The role of the freight industry in US economy is crucial. According to 2011 facts provided by the US Department of Transportation, total domestic shipments were 15,336 million tons. Exports were 895 million tons and imports were 1,390 million tons. The corresponding value of domestic shipments in 2011 was 13,200 billion of 2007 dollars. Value of exports was 1,285 billion of 2007 dollars and value of imports was 2,319 billion of 2007 dollars (USDOT, 2012).

Among the different modes of transportation, trucks were most significantly involved in freight movements, covering approximately 68% of total shipments tonnage distribution in 2011 (USDOT, 2012). Trucks are included in the general category of Commercial Motor Vehicles (CMV). CMV is defined by the USDOT (2013) as:

- Any vehicle which weighs 10,001 pounds or more
- Any vehicle or combination of vehicles with a gross weight rating (GCWR) of 10,001 pounds
- A vehicle that carries 16 or more passengers, including the driver not for compensation purposes
- A vehicle that carries 9 or more passengers, including the driver for compensation purposes
- Any vehicle that carries hazardous materials and requires placarding

CMV volumes significantly affect traffic conditions of road networks. Truck volumes' impact can be identified in various areas which include traffic congestion, safety levels and environmental concerns. Regarding road safety, trucks highly affect crash rates. Crash statistics show that 276,000 large trucks were involved in road accidents during 2010 in the US. A 9% increase in the fatality levels of truck involved crashes was also observed during this period since 2009 (USDOT, 2012). One of the major causes of truck involved crashes is driver fatigue due to the long distances and extended driving hours. Freight and transportation agencies in order to reduce crash rates introduced and applied approximately the last 76 years various regulation to ensure the ability of truck drivers to have efficient rest periods. Regulation was developed in the format of Hours of Service (HOS) for CMV drivers.

HOS rules define the maximum number of driving and working hours per day for a CMV driver before a rest period is enforced by law. Additionally, the maximum number of on duty hours per week and the length of the rest periods before a new weekly cycle restart are also described by HOS. Current HOS rules are presented in Table 1, provided by USDOT, 2013:

Table 1: Hours-of-Service Rules (USDOT, 2013)

Property-Carrying CMV Drivers (Valid Until July 1, 2013)	**Passenger-Carrying CMV Drivers**
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.
14-Hour 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
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.
Sleeper Berth Provision Drivers using the sleeper berth provision must take at least 8 consecutive hours in the sleeper berth, plus a separate 2 consecutive hours either in the sleeper berth, off duty, or any combination of the two.	**Sleeper Berth Provision** Drivers using a sleeper berth must take at least 8 hours in the sleeper berth, and may split the sleeper-berth time into two periods provided neither is less than 2 hours.

In the context of continuously improving HOS rules efficiency, the Federal Motor Carrier Safety Administration, US-DOT recently suggested a set of different changes regarding HOS regulation. Suggested changes are summarized in Table 2:

Table 2: SUMMARY OF 2011 HOS FINAL RULE PROVISIONS

Changes Compared to Current Rule (USDOT, 2013)

PROVISION	CURRENT RULE	FINAL RULE COMPLIANCE DATE JULY 1, 2013
Limitations on minimum "34-hour restarts"	None.	(1) Must include two periods between 1 a.m. – 5 a.m. home terminal time. (2) May only be used once per week.
Rest breaks	None except as limited by other rule provisions.	May drive only if 8 hours or less have passed since end of driver's last off-duty period of at least 30 minutes.[HM 397.5 mandatory "in attendance" time may be included in break if no other duties performed]
PROVISION	**CURRENT RULE**	**FINAL RULE COMPLIANCE DATE FEBRUARY 27, 2012**
On-duty time	Includes any time in CMV except sleeper-berth.	Does not include any time resting in a parked vehicle (also applies to passenger-carrying drivers). In a moving property-carrying CMV, does not include up to 2 hours in passenger seat immediately before or after 8 consecutive hours in sleeper-berth.
Penalties	"Egregious" hours of service violations not specifically defined.	Driving (or allowing a driver to drive) 3 or more hours beyond the driving-time limit may be considered an egregious violation and subject to the maximum civil penalties. Also applies to passenger-carrying drivers.
Oilfield exemption	"Waiting time" for certain drivers at oilfields (which is off-duty but does extend 14-hour duty period) must be recorded and available to FMCSA, but no method or details are specified for the recordkeeping.	"Waiting time" for certain drivers at oilfields must be shown on logbook or electronic equivalent as off duty and identified by annotations in "remarks" or a separate line added to "grid."

The results of the suggested new HOS rules application are controversial. Many concerns are expressed regarding the potential impact on traffic congestion, environmental conditions and the economic standards of trucking industry. A characteristic example of new regulation impact focuses on the effects on drivers' working schedules due to the new rule which requires two rest periods from 1:00 to 5:00 a.m. off duty per week. By reviewing drivers working practices, this new rule will restrict truck movements. As a result, a large amount of truck drivers will restart a new weekly working cycle on Mondays after 5:00 a.m. so as to comply with new rules. These additional truck volumes can significantly affect traffic conditions of the corresponding networks, mainly during peak hours. The developed controversy regarding the effects of new HOS rules should be answered by investigating the potential consequences of the new regulations in different aspects of truck operations.

1.2 Research Objectives

The major objective of this project was to perform a thorough analysis regarding the effects of new HOS rules of CMV drivers on congestion levels of road networks. In order to identify the impact of new regulation, a part of I-40 network between Memphis and Nashville, Tennessee was applied as the case study area. Analysis was based on tracking potential changes on truck volumes due to the restrictions of new rules. Additional tasks of this study included the analysis of the affected truck trip patterns and the related trip characteristics of the selected case study area. The impact of these modified truck volumes and characteristics on traffic conditions and congestion levels were identified by investigating the corresponding effects on the Level of Service of the case study network.

The remainder of this report is as follows: chapter 2 refers to the literature review which describes the modifications of HOS rules through history and includes various research regarding HOS of CMV drivers and the impact of trucks on traffic congestion. Chapter 3 focuses on the methodology that was followed, while different subcategories describe the case study area and data characteristics. Chapters 4 and 5 focus on the study results and the corresponding conclusions respectively.

2. LITERATURE REVIEW

2.1 Introduction

The major objective of this report was to identify a potential impact of new Hours of Service (HOS) for Commercial Motor Vehicle (CMV) drivers on road congestion levels. In order to get an efficient background for accomplishing this task, a thorough literature review was carried out. The literature that was reviewed is categorized in three different sections. The first one focuses on how the HOS regulation has been modified in order to get its latest format by describing the most significant revisions that have taken place. Next section refers to research that has been done regarding HOS of drivers and their effects. The last one concentrates on the research that has been carried out regarding the effects of truck and heavy vehicles in total on traffic conditions and congestion.

2.2 Regulation

Various changes and revisions throughout history have been applied to regulation regarding HOS for CMV drivers. A potential identification of the optimal rules could ensure public safety and increase productivity of operations and economic benefits for both employers and employees at the trucking industry.

One of the first attempts for regulating limits regarding driving hours was conducted in 1936 by the Interstate Commerce Commission (ICC). The first version of these rules limited the maximum number of duty hours to 15 per day which included maximum 12 hours of work and 3 hours for drivers' rest and breaks. These rules ensured an off-duty recovery period of 9 hours. Additional restrictions were set regarding a maximum number of 60 duty hours per week or 70 hours per 8 continuous days. After a set of revisions and adjustments which took approximately 3 years, rules were updated by specifying the maximum allowable number of driving hours which were included in the number of working hours. Driving hours' limit was set to 10 while the total number of duty hours per day was increased to 16 by decreasing the maximum number of off duty rest recovery period. Rules regarding the maximum allowable number of duty hours per week or per 8 days remained the same (FMCSA, 2000).

The next major revision of the HOS regulation for CMV drivers took place in 1962 by ICC. The most important change of the new rules was that the 24-hour restrictions no longer existed. This fact combined with the existence of an 8-hour off duty recovery period and a maximum allowable number of 10 hours continuous driving resulted in cases where a large amount of drivers completed 16 hours of driving in one day. The final format of the specific regulation created the need for development of various exemptions regarding existing HOS rules (FMCSA, 2000).

Another significant change at the HOS rules took place in 2003 by the Federal Motor Carrier Safety Administration (FMCSA). According to this revised version, the maximum number of working hours was set to 14 per 24 hours, something which allowed a 10-

hour off duty rest recovery for drivers. In the 14-hour working period, an increased limit of 11 continuous driving hours was included. An important change to HOS rules was the addition of a 34-hour restart period provision which allowed drivers to restart a weekly working cycle after 34 continuous hours of rest. The limit of 60 hours per 7 days was retained (FMCSA, 2011).

The most recent changes regarding HOS regulation were suggested by FMCSA in 2011. Previous rules regarding the 14-hour limit of working hours and the 11-hour limit for driving hours remained the same as well as the 60 and 70 hour restrictions. A major change of the suggested rules was that if the 34-hour restart option was used, the next use of this rule should take place after 168 hours. Additionally, the 34-hour restart should be combined with 2 rest breaks between 1:00 and 5:00 a.m. Another important change included a rest break of 30 minutes for drivers who had completed 8 hours of continuous driving (FMCSA, 2011).

2.3 Research Regarding Hours of Service

Various studies in literature review analyze different aspects of the problem related to HOS for commercial motor vehicle drivers. Most of the available literature in this area focuses on evaluating HOS and their effects on safety, productivity, scheduling and economy in general.

First studies on this area focused on how HOS of drivers were related with safety issues (Harris and Mackie, 1972; Hackman et al., 1978) while others analyzed the impact of HOS on drivers' fatigue (Mackie and Miller, 1978). Jones and Stein (1987) studied the relationship between truck accidents and working hours of the involved drivers. The authors concluded that violation of the existing time period HOS regulation was one of the major parameters which affected crash rates.

HOS rules violation by truck drivers was the area of focus for a study which was carried out by Braver et al. (1992). The authors used the method of personal interviewing 1249 truck drivers and statistical analysis of the collected data to identify the levels of HOS violations and the related causes. Major conclusions included that around 75% of truck drivers violated regulations due to various reasons such as economic benefits, young age, etc. Need for developing efficient mitigation measures against violating rules was pointed out and further use of electronic in-vehicle devices or involving employers in drivers' guidance to follow rules were suggested.

Griffin et al. (1992) carried out an analysis on how drivers HOS affected various related areas such as productivity of operations, safety or drivers benefits. Due to lack of efficient data, whole analysis was based on developing and comparing alternative scenarios regarding driving hours and rest periods. Additional information was collected by interviewing drivers. Generally it was concluded that a 24-hour restart policy would result in economic and safety benefits for both employers and employees as it ensures more efficient rest periods for drivers and better operations' scheduling.

The relationship between working hours of drivers and safety was investigated by Lin et al. (1993). Dataset consisted of 1,924 crash/non-crash cases and was provided mainly from private company sources. The methodology that was followed in this study was based on the application of logistic regression models so as to find out the probability of an accident occurrence considering various parameters which included driving hours, schedules, time of day driving and working experience. Continuous driving hours were found to be a major factor which could result in increased crash ratios. Crash probability increased by 50% after 4 hours of consecutive driving and even more after 8 hours of driving. Drivers' age wasn't found to have a great impact; however, experienced drivers had a lower crash probability. Driving during night periods increased accident risk while off duty recovery periods didn't affect results significantly.

An analysis regarding HOS and speed violations from truck drivers in order to keep on schedule was carried out by Beilock (1995). The method of personal interviewing 498 truck drivers was followed so as to get the required data such as trip origin and destination points, existence of co-drivers, etc. After making various assumptions such as the existence of a constant average speed, the authors concluded that around 25% of drivers were violating regulations so as to comply with schedules and also levels of violation were higher in cases where no co-driver existed.

Arnold et al. (1997) reviewed opinions of people who were involved in truck operations in Australia regarding how important were working hours for truck operations and at which level they affected drivers' fatigue. A sample of 1249 drivers and 84 companies were involved in this study for data collection regarding driving hours, factors which could cause fatigue and additional information. Statistical analysis of the collected data followed while a major fact was that no drivers working hour restrictions existed during the specific study. The major findings included that a large number of the interviewed drivers were working more than 14 hours per day while sleep hours were limited. Additionally, it was found that opinions regarding the impact of fatigue varied a lot. Drivers who were operating under no restricting rules underestimated effects of fatigue on their productivity.

Wislocki (2000) evaluated the suggested changes of HOS rules at this time period by investigating opinions of people who were involved in the truck industry. A major concern was expressed regarding the fact that according to new rules, working hours were limited, mainly during night. Such a change would result in major road construction operations to take place during day and peak hours. The majority of the reviewed opinions focused on the increased traffic congestion due to daytime operations, however, others concentrate on safety issues regarding maintenance workers' risk rates.

Belzer et al. (2002) analyzed the suggested changes by the US government of HOS rules, focusing on the regulation which restricts maximum number of duty hours to 60 per week. First section of analysis identified various miscalculations in the original proposal regarding the benefits from the HOS reduction while at the second section a prediction of the economic results from the hours' reduction was described. In order to carry out the economic forecast analysis, the authors applied a macroscopic econometric model which proved that working hours' reduction will lead at major economic benefits due to new job openings or less accident costs.

Similar conclusions regarding the 2000 proposed changes of the HOS rules were reached by another study of Saltzman and Belzer (2002). Wrong initial estimation of the potential benefits from HOS rules revision and the fact that reduction at HOS of drivers will result in further economic gains and a lower cost of operations were also verified. The authors suggested that HOS regulation revision should focus on restoring a 24-hour work cycle regarding truck operations as it could assist in increasing driver's safety and health. Also it was concluded that it was crucial the revision of HOS rules to ensure reduction of violations by regulating penalties and economic consequences for both employers and employees in the trucking industry.

However, in a different article where Parker (2003) tried to identify opinions of various people who were related with trucking industry about new HOS rules, views varied significantly. In general many concerns were expressed regarding the fact that new rules could increase operational costs and limit productivity due to the reduction of working hours or the need for more drivers.

Amundsen and Sagberg (2003) conducted an extended literature review on how drivers working hours were related with road safety. The authors concluded that HOS are a crucial factor regarding truck involved accidents. It was found that accident probability increases significantly after 9 to 11 hours of continuous driving. High levels of HOS rules violations among drivers were also identified due to lack of strict penalties in many countries. An increased probability for violators to be involved in accidents was also found to exist. The authors suggested various measures for reducing violations by adjusting stricter regulation, reducing driving during nights, use of electronic devices, drivers' education and improvement of rest areas.

A different study from Monaco and Willmert (2003) tried to see if there was any correlation between levels of HOS regulations' violations and drivers' salaries. Analysis was based on an extensive dataset which included information collected in two different surveys with personal interviews. The methodology that was followed included statistical analysis of collected data. Major findings of this study included noticeable levels of regulations violation as approximately 26% to 42% of the interviewed drivers reported cases of violating HOS. Correlation between economic benefits and regulations violation was also verified as it was found that a potential increase in drivers' income will automatically increase probability of violating a rule.

Heaton (2005) investigated the efficiency of existing regulation regarding truck drivers HOS and what was the impact of such rules on health issues. Analysis was based on an extensive literature review that was carried out and focused on different policies-strategies related to HOS regulation. It was concluded that even though the main objective of the existing rules was to improve drivers' working conditions, their efficiency is doubted. Regulation by trying to protect drivers through reducing HOS forced them to violating rules for economic reasons. Such issues should be addressed with a revised version of HOS regulation which would probably be more adjusted to truck industry working environment.

Different opinions of people who were involved with truck industry regarding efficiency of the revised 2003 HOS rules were reported in another article (Occupational Hazards, 2005). Some focused on the positive side of HOS changes by pointing out that drivers' safety and health were protected. On the other side, different concerns were expressed regarding a significant increase at working hours due to the 34-hour restart option.

Jones et al. (2005) carried out a study which focused on comparing rules which exist in different nations regarding working hours in all modes of transportation. Two major categories of regulations were identified. Prescriptive HOS rules suggested a maximum number of working hours, while non-prescriptive rules were identified by a methodology developed by each company for fatigue management. The authors concluded that non-prescriptive rules needed to be enhanced and an efficient combination of both regulations' type might be the optimal solution.

Another study from Jovanis et al. (2005) tried to evaluate the impact of HOS regulation changes on accident levels and safety in total. Statistical analysis that was carried out was based on use of a time dependent regression model which predicted the probability of an accident to occur considering different parameters. An extended sample of 693 crash/non-crash cases was used. According to major conclusions of this study, an accident possibility increases significantly after 11 hours of continuous driving. Also, it was found that an accident probability for sleeper operations was more related to consecutive driving hours while for non-sleeper operations was more related to multi-day working.

An additional analysis related to new HOS rules was conducted by Olson (2006) who focused among others on opinions of truck drivers regarding the suggested HOS regulation changes. Methodology was based on a dataset which was collected from 103 drivers with a combination of electronic devices and questionnaires. From this study, acceptance of the HOS rules changes was verified as drivers highlighted the positive side of the 34-hour consecutive rest rule or the ability to sleep more.

Dick et al. (2006) carried out a two-phase study in order to evaluate the 2004 changes of HOS regulation for truck drivers. The first phase of this study focused on the acceptability of new rules from truck drivers and was based on the method of personal interviewing a sample of approximately 1000 divers. The second phase included identification of the consequences of HOS revision on safety. Statistical methodology was based on data collected from a large number of vehicles which belonged to 23 truck companies and were provided by American Trucking Association. From drivers' interviews, acceptability of the new regulation was verified as in general new rules resulted in reducing driver fatigue however an opposition regarding some rules such as the limit of 14 hours of work was expressed. Regarding the safety parameter from data comparison it was found that new regulation resulted in reducing crash rate by 3.7%.

A different aspect of freight operations and how such operations were affected by HOS rules was analyzed by Goel and Gruhn (2006). In this study, an investigation on how regulations regarding working hours of drivers affected vehicles' routes and schedules was carried out. The authors had to deal with a modified vehicle routing problem with time windows in order to include the consequences of driving hours as they highly affect scheduling. Metaheuristics were applied for problem solution. Generally, a significant role of driving hours in vehicle routing and scheduling was verified since HOS highly affect vehicle travel times.

Maier-Speredelozzi (2006) focused on how the suggested reduction of HOS of heavy vehicle drivers would affect warehouse operations. A major problem was that according to new rules loading/unloading time was included in drivers working hours so operations' duration should be minimized in order drivers to comply with working schedules. Main objective of this study was to identify the consequences of the regulation change and to suggest mitigation solutions. Methodology was based on a simulation analysis of warehouse operations. The authors concluded that economic consequences of the new rules due a potential need for more drivers could be avoided by a more efficient design of warehouse receiving operations which could reduce operations duration and drivers waiting time.

A different study concentrated on how HOS of drivers could affect accidents ratio in which trucks were involved and the cost of operations in total (Mukherjee and Hall, 2005; Mukherjee et al., 2006). Methodology was based on a large dataset which was acquired from various private companies and agencies. For identification of the relationship between HOS and accident ratio, a statistical analysis with use of various tools such as probability distributions and odd ratios were used. Regarding the correlation between HOS and cost consequences, analysis was based on the application of a linear model. It was found that a limit of 8 to 9 hours of consecutive driving could reduce the number of potential accidents by 3% to 5%.

Robin-Verger (2007) conducted a critique regarding the existing at this time period HOS rules for truck drivers. The author through carrying out an extended literature review and a deep investigation of the HOS regulation came up with suggestions for potential changes in a future regulations' revision. One major finding to support the authors opinion regarding the need for revised rules was that the existing regulations were developed based on assumptions and statistical miscalculations of the related costs. Revision suggestions include the reduction of the allowable number of continuous driving to 10 hours or the cancellation of the rule regarding an off-duty recovery period of 34 hours. Also, it was suggested that the hours' violations should be checked through electronic devices so as to ensure the results' validness.

A study from Hanowski et al. (2007) focused on how 2003 HOS rules affected sleep hours of truck drivers and as a result driving behavior. Data sample included 73 drivers and related information was collected through a combination of video devices, specialized software and personal questionnaires. Analysis concentrated on identifying how sleep hours could affect critical incidents which describe cases where an accident or conditions close to accidents occur. Critical incidents were identified through sensors which could report unusual conditions such as sudden accelerations. The authors concluded that even though 2003 HOS provide more time for drivers' sleep, accidents still occur. Long hour driving found to greatly affect drivers' performance as 58 incidents were reported after 10 hours of drive. Majority of such incidents were related with lack of sleep prior to a critical incident.

A similar study was conducted from Hanowski et al. (2008) where the authors tried to identify effects of 2003 HOS rules on drivers' performance and safety. One of the major changes that were suggested from these regulations was an increase of the allowable limit of consecutive truck driving hours from 10 to 11 per day. Analysis focused on identifying how new regulation was related with levels of critical incidents occurrence. The methodology that was followed was similar to the previous study and was based on the use of specific software programs in order to report an incident occurrence. Generally it was found that the one hour increase at the maximum number of driving hours does not result in an increased number of critical incidents.

Another analysis on how HOS rules for truck drivers which require a 10-hour break, affected vehicle routing and scheduling problem was conducted by Divyang-Shah (2008). An optimization problem was formulated and main objective was minimization of truck travel times, considering present HOS regulation. HOS rules were considered by including in problem's formulation specific time windows and limitations. A major difference of this study was the fact that impact of road congestion was considered in modeling process. Metaheuristics were applied for vehicle routing problem and identification of optimal solutions.

A different study focused on evaluating the changes of HOS for truck drivers (McCartt et al., 2005; McCartt et al., 2008). Analysis was based on a comprehensive dataset of approximately 1,921 drivers and data was collected through personal interviewing. Methodology included mainly statistical analysis of the collected data. A major consequence of regulation changes was an increase on drivers' fatigue due to an increased number of driving hours. Levels of rules violation weren't significantly affected after regulations change however various reasons such as truck schedules, parking or absence of resting areas were found to lead in violations. The beneficial role of vehicle electronic devices for data collection was also verified.

Benstowe (2008) investigated the consequences of long working hours and generally HOS of truck drivers on health issues that might arise. Study was mainly based on literature review. A major conclusion of this study highlighted the great effect of working hours on drivers' health and came up with various suggestions regarding working conditions of truck drivers (rest periods, amenities, etc.). Such suggestions could potentially improve drivers' performance and mitigate consequences of long hour driving.

Min (2009) carried out a comprehensive literature review on the relationship between drivers HOS and truck operations efficiency and safety. The author found that safety could be affected by various parameters such as road and rest areas conditions; however, drivers fatigue was the major one. Various factors were related with fatigue so an optimal balance between driving hours and rest periods should be figured out. Another major finding from literature was the high levels of rules violation due to economic benefits. Regulating strict penalties for violators was suggested. Additionally, ideas for future research in various areas such as rest periods and sleep, time of day driving, safety and other topics were provided.

A similar study regarding how drivers' health was affected by working hours was carried out by Jensen and Dahl (2009). Analysis was based on carrying out an extensive literature review regarding various HOS regulation for truck drivers worldwide. Then a comparison and evaluation of these different rules followed. The authors found that in general, long working hours can have a high negative impact on drivers' health and well-being. Additionally, it was concluded that regarding European regulation, health parameter should be more considered. Disadvantages such as inflexibility of European regulations were also reported.

Goel (2009) concentrated on how HOS regulation for commercial vehicle drivers was related with trip scheduling and vehicles routing. Methodology focused on European HOS regulations and a complete description of these rules was presented during this study. Routing problem was formulated as a vehicle routing optimization problem with time windows. Time windows were used in order for different time limitations related to drivers' working hours to be considered. Major objectives of the optimization formulation were the minimization of fleet size and travel distance. Different methods such as naïve and multilabel were applied for the scheduling problem, while the solution of routing problem was based on using the Large Neighborhood Search algorithm. This study showed how rules regarding drivers' working hours highly affect trips scheduling and routing. The authors concluded that trip scheduling could be much more efficient if somehow drivers' rest periods were included to the available driving hour limit.

Another study also analyzed how drivers' HOS regulations affected vehicle scheduling and routing (Min, 2009; Min, 2011). Impact of time limitations due to the maximum allowable number of driving hours was identified. Formulation included a mixed integer optimization problem with the major objective of minimizing total travel time by reducing truck driving hours in order to comply with suggested HOS regulation. The problem solution involved a combination of different strategies. These included Dijkstra algorithm for identification of shortest path between origin and destination and application of Metaheuristics and mainly the Simulated Annealing methodology for identification of optimal solution. Validness of the suggested methodology was tested and it was found to produce results for routing-scheduling problem within the 1% range of optimality.

A different analysis from Goel (2009) tried to model truck scheduling according to existing HOS regulation at this time period. The problem was formulated as a scheduling problem under specific time windows which occurred because of time limitations related to drivers' allowable working hours. The methodology that was followed was characterized by development and application of a pseudo-code which was able to identify optimal truck schedules. The suggested methodology was developed for applications in cases of truck scheduling for one week time periods or more. The authors concluded that the developed model could also be used for investigating the relationship between drivers working hours with fatigue and safety issues in general.

Gron (2009) investigated factors which lead drivers to violating HOS regulation. Analysis focused on HOS rules as they were defined by the European Union. Dataset included information regarding daily behavior of 16 truck drivers of a private company. Various factors were found to be related with regulations violation. Violation of rest hour periods from drivers was a major issue. Other parameters that affected the level of violation were related to the strictness of HOS rules which did not provide freedom to drivers on adjusting their schedule and manage fatigue. Additionally, the fact that existing rules focused on long-distance drivers, created problems as this regulation could not efficiently be applied for short distance truck drivers. Furthermore, economic benefits for both employers and employees in truck industry resulted in extending driving hours. A major conclusion from this study was that truck employers and employees should be more involved in the process of defining HOS rules.

The relationship between truck drivers' HOS and collision rates was studied by Park and Jovanis (2010) as an extension of the work which was carried out by Jovanis et al. (2005). Analysis was based on a complete dataset of 693 crash/non-crash cases. Methodology included statistical regression analysis in order to identify probability of a crash based on time parameters. Additional parameters such as time of day, rest periods, working hours and berth sleeping were found to be related with accident levels. Multiday driving and off duty rest periods greater than 46 hours were found to increase crash rates significantly. A less significant impact of early morning driving was also reported. A major conclusion was that a significant increase of 56% and a greater than 200% on crash risk after 6 and 10 hours of continuous driving respectively occurred. A major limitation of this study was the small amount of collected data, so the authors suggested a future extension of this study which would probably be based on a larger dataset.

American Trucking Associations (2010) carried out a study in response to various suggestions for revising HOS regulations for truck drivers, focusing on the positive side of existing regulation. The authors tried to address various concerns that had been expressed by providing facts which proved the efficiency of existing rules. It was reported that in a 4-year period form 2004 until 2008, there was a reduction of 16% to 21% in cases where trucks were involved in accidents while truck use was increased at the same period. Additionally, driving hours' violations were also reduced by 22%. By providing such facts, it was concluded that no revision of existing HOS was needed as potential changes could affect safety levels and economic productivity. The authors identified a need for more research in areas such as training and education, truck parking and driver fatigue mitigation.

Different opinions regarding suggested changes to HOS regulation and their potential effects were included in an article of Cassidy (2010). Various safety groups suggested a reduction of consecutive driving hours to 8 per day and a reduction of working hours in total to increase drivers' safety and health levels. Many expressed a clear opposition to such changes by referring to a potential danger for public safety due to an increase of congestion and crash rates as a result of hours' reduction. Others focused on economic consequences not only for trucking industry but also for the economy of U.S. in total. A suggested idea instead of reducing driving hours was to provide more flexibility to drivers in arranging their schedules and rest periods.

An analysis which considered drivers' HOS regulations in the process of identifying truck routes and schedules was carried out by Rancourt et al. (2010). A combined vehicle routing-scheduling problem with time windows was formed in order North American HOS rules which defined allowable driving hours, breaks and rest periods to be addressed. Significant differences compared to previous research included breaking of rest period in more parts, existence of different type of vehicles and analysis of operational costs. The objective function of the developed optimization problem focused on minimizing fleet size however additional objectives included the minimization of trip distance and operational costs. Regarding the solution procedure that was followed, the authors extended the formulation of Goel and Kok (2010) and based their methodology on using Tabu Search algorithm. It was concluded that a more efficient scheduling-routing solution could be reached if drivers rest time could be broken and also if these rest time could be included to driving time.

Wu and Jovanis (2010) investigated the effects of rest and off-duty recovery periods on the number of accidents that truck drivers are involved. Data collection included approximately 696 crash/non-crash cases and was completed in two phases as datasets from different time periods were combined. The statistical analysis was based on the use of logistic regression models in order to identify the related accident rates. The major findings included that after 6 hours of consecutive driving, the possibility of an accident increased. Also it was found that rest periods during working hours resulted in reduced crash ratios; however, the 34 hour off duty recovery period seemed to have negative consequences as it was more possible for drivers to be involved in accidents.

Jovanis et al. (2011) extended the work of Wu and Jovanis (2010) by carrying out an extensive analysis on the relationship between HOS regulations for truck drivers and accident ratios. A major difference of this study was that the authors considered the existence of a mixed fleet with Truck Load (TL) vehicles which usually serve one customer and less-than-truckload vehicles (LTL) which serve multiple customers. Dataset consisted of 878 observations which were collected in different time periods. This study was based on the same methodology of Wu and Jovanis (2010) which included the use of logistic regression models for statistical analysis of the collected data. Conclusions shown that after 6 hours of consecutive driving, LTL drivers had a significant increase of an accident possibility which reached its maximum value at the 11^{th} hour. A positive role of rest breaks was confirmed as after two rest breaks, the possibility for a driver to be involved in an accident was reduced by 32% and 51% for TL and LTL drivers respectively. Regarding off duty rest periods, it was found that the 34 hour off duty period had a negative impact on accident probabilities for both TL and LTL drivers.

A critique on the study of Jovanis et al. (2011) was carried out from Knipling (2011). The author focused criticism on the conclusions of this study regarding truck driving hours and especially doubted the small number of crash observations after 11 hours of driving. Additional concerns were expressed about data collection and editing while findings such as that the 34 hour off duty period had negative impact on accident probability should be further investigated. The author reported that more analysis should be conducted on issues such as time of day impact or crash characteristics effects.

Feasibility of results was doubted and the absence of a validation process in total was also reported. Finally the author suggested that the role of fatigue and other accident factors should be further analyzed

Jansy (2011) conducted a study regarding the evaluation of 2010 HOS rules for truck drivers and a potential need for revising. The author focused on the suggested changes by USDOT which included reduction of allowable consecutive driving hours or reassessment of the duty rest periods. Study was based on an extensive literature review that was carried out. From literature, it was found that the possibility for a truck driver to be involved in an accident increased significantly after 8 hours of driving. Also, inefficiency of daytime sleep and the fact that existing regulations limited drivers sleep to 6 hours were reported. The author concluded that the suggested changes of the HOS regulation could improve both safety and economic factors which were related with truck industry.

Another study which focused on evaluating suggested changes of truck drivers HOS as they were published from related agencies on 2010 was carried out by Scribner (2011). The author after identifying the characteristics of the suggested changes came up with three major comments/concerns regarding the nature of new HOS regulations. A first concern had to deal with accuracy of the methodology that was followed in identifying the proposed HOS changes. According to the author, various assumptions that were considered led to miscalculations of related costs. Additional concerns were expressed regarding the fact that suggested changes didn’t consider special cases such as economic benefits of risky drivers who violate regulations. Finally, efficiency of the whole process of licensing and insuring trucks was doubted in total as it greatly affected road safety and public health.

A different analysis regarding effects of HOS regulation focused on safety parameters (Blanco et al., 2011; Soccolich et al., 2012). Major objective of this study was to find out the relationship between HOS rules and accident probability by identifying a safety-critical event (SCE) factor which describes accidents, or cases close to crashes. A comprehensive naturalistic dataset which included a sample of 97 truck drivers was collected with a combination of video and sensor tools with questionnaires. Methodology was based on statistical analysis of dataset using various regression models. The study defined the various parts of a typical 14 hour workday for a driver as 66% driving operations, 23% non-driving operations and 11% rest periods. Analysis showed that there was a significant increase in possibility of a critical event to occur, comparing the 1st with the 11th hour of driving; however, there was not any noticeable difference comparing the 10th with the 11th hour. Additionally, it was found that if driving operations were conducted close to the end of a 14 hour work day, the SCE risk was higher. The positive role of rest breaks during a typical workday was also confirmed.

A critique regarding the previous study of Blanco et al. (2011) was conducted by Knipling (2011). The critique focused on the data collection model by doubting the accuracy of the naturalistic data methodology collection. Through an analytical investigation of all the parameters that were considered in the analysis of Blanco et al., the author doubted if the safety-critical event (SCE) factor could precisely depict drivers fatigue and as a result the corresponding levels of traffic safety. Additional concerns were expressed regarding the whole nature of naturalistic methods, their application cost and their effect from traffic conditions. Validation of results regarding rest breaks or impact of consecutive driving hours was also doubted.

An evaluation study of the Federal Motor Carrier Safety Administration proposal regarding HOS regulation changes was conducted by Edgeworth Economics (2011). The study focused on evaluating alternative options regarding the suggested changes which included reduction of working hours per day, reduction of driving hours or adjusting off duty hours. The authors after a deep examination of the related proposal came up with various doubts regarding the accuracy of the final results due to cases of incorrect cost methodology approach, use of inadequate data and infeasible assumptions. Additional concerns were expressed about the fact that the use of invalidated assumptions could have resulted in miscalculation of cost benefits from hours or crash reduction. Furthermore, conclusions regarding fatigue probability and sleep availability of drivers were based on unsupported assumptions. At the last part of the evaluation study, an updated and corrected version of the related costs (in cases where this was feasible) was provided.

A different study focused on the effects of the HOS changes for Commercial Motor Vehicle drivers (FMCSA, 2011). Impact analysis compared and evaluated four alternative scenarios of HOS revisions in order to identify the most profitable changes. The effects of future changes were located in different areas which included safety, cost and health impact. Methodology regarding impact analysis included statistical manipulation of the acquired data, by using regression analysis or application of different mathematical formulations for identifying values of various economic variables. Cost impact was estimated in terms of productivity change, safety effects were defined in terms of reducing accidents rates and health impact was estimated by identifying mortality risk ratios. From the analysis that was carried out, it was concluded that the third alternative scenario, which included the addition of rest break during working hours, limiting the 34-restart option to 1 every 7 days and retaining the 11-hour driving limit, was the optimal one.

An evaluation of the suggested changes on HOS regulation from FMCSA was conducted the same period (American Trucking Associations, 2011). After a brief description of the suggested changes, the authors focused on future consequences by highlighting negative aspects of the proposed regulation changes. A significant increase in operational costs was predicted due to limitation of working hours, need for more drivers or rescheduling of operations. Additionally the claim of FMCSA regarding an improvement of health and safety levels because of the proposed changes was doubted in total. Increased congestion was also pointed out as a potential consequence of suggested rules. The authors doubted the efficiency of the suggested HOS revision in total.

One of the most recent studies was conducted by Goel and Vidal (2012) who focused on how HOS regulations affected truck routes and schedules. The problem was formulated as a mixed vehicle routing-truck scheduling problem with time windows and the major objective was minimizing operational cost. An additional goal of the authors was to identify how HOS regulations affected cost parameters. Regarding the methodology that was followed, the authors focused on metaheuristics by developing and applying a genetic algorithm to solve the problem. The major difference of the suggested methodology was that the developed algorithm with a proper adjustment for time windows could be used for comparing and evaluating different HOS options. The main conclusions of this study included that European HOS regulation could result in higher levels of road safety and the strictness of Canadian regulations was also pointed out. Australian rules were characterized by high risk levels, while current changes in US regulations were found to have a positive impact by decreasing accident probability.

Analysis that was carried out by Blalnchard (2012) focused on the revised HOS rules for truck drivers and the corresponding levels of acceptability from people who were closely related with truck industry. The author identified high levels of rejection of new regulation as many truck drivers clearly stated an opposition regarding new rules. It was reported that new rules such as the reduction of allowable working hours per week to 70 and rest periods from 1:00 to 5:00 a.m. will increase road congestion as many trucks will operate during peak hours. Additional safety concerns were expressed as high truck volumes during peak hours could potentially increase crash rates with private cars, so public safety was doubted. Generally it was found that many drivers suggested the cancelation of new regulation application.

Johnston (2012) focused on economic results of the latest regulations regarding drivers HOS. Data collection was based on combining different sources which included 14 truck companies and private firms for economic information. Statistical analysis of dataset included development and application of three economic models which identified different factors related to the productivity and profitability of truck operations. The authors found a direct connectivity between driving hours and the previously described economic factors. It was concluded that a further reduction of driving hours would probably affect productivity however some factors of profitability could be retained.

One of the most recent articles regarding HOS regulation by Ross (2013) analyzed the concerns of American Trucking Association (ATA) regarding the efficiency of new rules and the requested delay in the compliance deadline. New regulation would require training of truck industry personnel and programs update. Compliance delay was requested by ATA in order to consider the jurist decision against the new rules. This could potentially reduce the risk and cost of an unnecessary training and programs upgrade. The additional objections of ATA regarding the accuracy of the benefit/cost analysis that was conducted by FMCSA were described. Similar concerns were expressed regarding the safety improvements that FMCSA forecasted to occur after the compliance with the new rules. According to ATA, an overestimation of the truck crash rates which were related with drivers fatigue took place.

2.4 Research regarding Truck Volumes and Congestion

An important task of this report is to identify potential effects of HOS changes on congestion. In this section, a literature review was carried out on how traffic conditions and congestion are affected by heavy vehicles operations in total. One of the earliest studies that tried to identify the impact of heavy vehicles on traffic by analyzing the related travel times or intersection delays, was carried out by Fisk (1990). Grenzeback et al. (1990) investigated the consequences of truck operations on congestion during peak hours. The authors found that truck volumes did not significantly affect congestion during peak traffic periods; however, congestion levels were greatly increased in cases of truck involved crashes.

Regarding the impact of trucks on congestion, Kockelman and Shabih (2000) analyzed how truck volumes affected traffic conditions at signalized intersections. The authors focused on cases of light trucks. Analysis was based on a dataset which were collected with video devices from two different signalized intersections and included different information such as travel time, type of vehicle, etc. Methodology was based on statistical analysis and regression models were used to identify the time needed in order to serve all vehicles of a signalized intersection. It was found that light trucks greatly affected traffic conditions at signalized intersections by increasing congestion. Light trucks were approximately equal to 1.2 cars, something which resulted in a 10% reduction of intersection capacity while 20% of time was lost because of starting times of light trucks at fronts of a queue. The authors concluded that more research should be carried out as light truck volumes increased significantly congestion levels.

Effects of increased freight and especially truck volumes on the Ohio state road system were also analyzed by Cambridge Systematics (2000). Methodology included an extensive analysis of existing data regarding freight movements and application of a statistical forecast model. A major objective was, among others, the identification of the future impact of truck freight increase on traffic conditions, focusing on congestion. It was concluded that the predicted increase of 58% truck volumes by 2020 would result in an increase of approximately 80% in congestion levels, while a 60% increase of accident costs would also occur. The authors reported that the predicted consequences on congestion should be mitigated as global economy would be greatly affected by new traffic conditions. Roadway maintenance and improvement, construction of new road facilities or application of intelligent transportation systems were mainly suggested.

Another study related to effects of trucks and heavy vehicles on signalized intersections was also conducted by Haldane and Bunker (2002). Analysis used data that was collected with on-site inspection. Methodology was based on various on-site tests which represented conditions of clearing out a queue at signalized intersections. The authors confirmed the impact of large trucks on traffic conditions as it was found that they were equal to approximately 2.5 to 7 cars, depending on the corresponding size.

Al-Kaisy and Jung (2004) studied the impact of truck volumes in cases of roadways with increased congestion levels. Methodology was based on applying a simulation model which could show how different parameters were related with trucks' impact on traffic conditions. Identifying the passenger car equivalent factor for trucks was a key element of this study. Field data were used for calibration and validation. The authors confirmed the close relationship between heavy vehicles and traffic congestion. Additional factors which include road grade and existence of restrictions regarding the use of left lanes from trucks were also found to be significant contributors in increasing congestion.

Ramsay et al. (2006) also investigated the impact of heavy vehicles on road traffic conditions. Analysis focused on developing a simulation model of a selected road segment by using micro-simulation software for representing everyday traffic conditions. Effects of trucks on traffic were identified by analyzing how the model's measures of effectiveness, which included speed, capacity, delay etc., where affected by a hypothetical large increase of truck volumes. Model calibration was based on adjusting speed and acceleration parameters according to data which were acquired through GPS devices. Findings of this study included that a potential increase of truck volumes will result in a decrease of systems travel speeds and especially significant decrease of private cars speed. Additionally an increase of systems delay times and a reduction at intersection service rates were also reported. Different mitigation strategies regarding consequences of truck traffic which involved signal adjustments or lane restrictions were also evaluated.

Washburn and Cruz-Casas (2007) carried out an extensive analysis on how trucks affected traffic conditions in general, focusing on cases of signalized intersections. Impact of trucks on traffic was usually estimated using passenger car equivalent (PCE) factor. The authors tried to evaluate the accuracy of existing views regarding trucks impact as they were expressed through Highway Capacity Manual (HCM). Study was based on data which were collected through camera devices and included traffic and signal information. Data analysis involved developing a simulation application which allowed more efficient data manipulation. Final objective of this study was the development of updated mathematical models for precise calculation of PCE factor. In general it was found that the impact of truck traffic was more significant than previously believed. The authors suggested an update of the existing HCM guidelines by increasing value of PCE for trucks from two to three so as the increased effect of trucks on traffic conditions to be more accurately represented.

Another study, which was conducted by Vierth et al. (2008), investigated effects of large trucks in general by analyzing different aspects which included traffic conditions, safety, costs and environmental consequences. Data were collected from different sources and involved various public agencies. A major element of the developed methodology was the statistical analysis of the acquired data by applying various mathematical formulations. Increased delay times for cars due to increased truck volumes, which resulted in higher levels of congestion, were confirmed.

Harris and Anderson (2009) investigated how increased truck volumes affected different aspects of transportation which included safety, facilities condition and traffic congestion. Methodology included combining a traffic simulation modeling software with a travel demand model in order to produce an accurate simulation model which represented traffic conditions of the study network. Analysis focused on how different future scenarios of increased truck volumes affect measures of effectiveness such as travel times or areas with increased levels of congestion. It was concluded that predicted increased truck volumes would greatly affect traffic conditions by highly increasing congestion levels of the network unless various mitigation measures were considered.

A different study tried to identify how empty truck volumes affected congestion and pollution levels under various scenarios where truck operations started from different origin points due to a new inland port on the greater study area (Englert and Lam, 2009; Englert and Lam, 2011). Analysis included collection of an extensive dataset with the method of personal interviewing and involved a great sample of truck drivers and employers from 65 different companies. Methodology focused on statistical analysis of collected data in order to predict consequences of different truck volumes and routes scenarios. The authors concluded that empty truck volumes highly affected congestion levels and in the majority of the scenarios that were tested, changing vehicle routing by altering origin points resulted in increased congestion. It was stated that a relocation of trucks origin due to a development of a new inland port should be the result of a thorough investigation of potential consequences.

Another study analyzed the impact of truck volumes on road congestion especially due to movement of trucks during peak hours (Aschauer et al., 2010; Aschauer et al., 2011). Various data such as traffic and weather information, truck schedules, etc. from different sources, which included public and private agencies, were used. Methodology was based on predicting the potential consequences of different scenarios of peak hour truck volumes reduction on traffic and the related costs. Analysis was carried out with development of a computer application which allowed manipulating data and calculating-predicting future traffic-cost changes based on specific mathematical formulations. It was found that a reduction of 20% to 60% on truck volumes during peak hours could significantly result in reduction of congestion levels as corresponding travel times became smaller. However, a higher than 60% reduction was not suggested as it resulted in high congestion levels during off peak hour periods.

2.5 Conclusions

From literature review it was concluded that major changes have taken place in the format of HOS rules as related agencies tried to find an optimal balance between public safety and profitability for companies and drivers. Significant research has been done regarding HOS regulations and their impact on different areas which included safety and drivers' health, employer and employees' profits, scheduling and productivity of operations. Regarding the effects of heavy vehicles on traffic congestion, some studies focus on this area. However, from the literature review it was found that only few studies focused on the effects of HOS rules on traffic congestion. Regarding the potential impact of the suggested 2011 revised HOS rules for CMV drivers on congestion levels there is a clear need for more research in this area. This report's major objective is to fill this gap.

3. METHODOLOGY

This chapter focuses on the methodology that was followed in order to model the effects of new HOS rules on traffic conditions. Different sub-categories of this chapter provide an overview of the methodology that was followed and also describe the case study area and dataset characteristics. Additionally, the software selection process and their application are described. The last part focuses on the congestion impact analysis that was carried out.

3.1 Overview

As mentioned earlier, the major objective of the suggested methodology was to specify the impact of the new HOS regulation for CMV drivers on traffic conditions. The major change regarding drivers' working schedules will take place due to the new regulation which requires two periods from 1:00 to 5:00 a.m. off duty per weekly working cycle. This will restrict truck movements and will lead a large amount of truck drivers to wait until Mondays 5:00 a.m. to restart a new weekly working cycle in order to comply with new rules. This fact could significantly affect traffic conditions as high truck volumes would utilize specific segments of road networks during peak hour periods.

The first step in order to identify the impact on traffic conditions and congestion levels included the selection of the case study area, which was based on data availability. Then the major concept behind the developed methodology was to estimate the number of truck movements that would potentially be affected by the new rules. Analysis focused on identifying the exact number of truck trips, which took place on a typical Monday from 1:00-5:00 a.m. within the borders of the case study area, heading from Memphis to Nashville area. These truck volumes would be restricted and proportions of them would be gradually loaded on the network after 5:00 a.m. of the new weekly restart period. An important limitation of the provided data was that they referred to approximately 3%-8% of the actual daily truck volumes. This created the need for some adjustments to take place in order for the final results to capture real traffic conditions.

Next step focused on the impact of the increased truck volumes on traffic congestion. This was answered by following the methodology that was provided by the Highway Capacity Manual (HCM) in order to identify how these increased truck volumes could affect the Level of Service (LOS) of the case study area. Different scenarios which referred to cases where proportions of the restricted truck volumes were simultaneously loaded on the case study network were tested, following the new HOS rules limitations.

3.2 Description of Case Study Area

Part of Interstate 40 (I-40) road network was selected as the case study area. I-40 is the third longest Interstate Highway in United States with a total length of approximately 2,555 miles long, connecting the east with the west part of the country. The eastern border of I-40 is located at Wilmington area, North Carolina while the western border is located at Barstow area, California (i40highway.com, 2013). A general map of I-40 is presented in Figure 1:

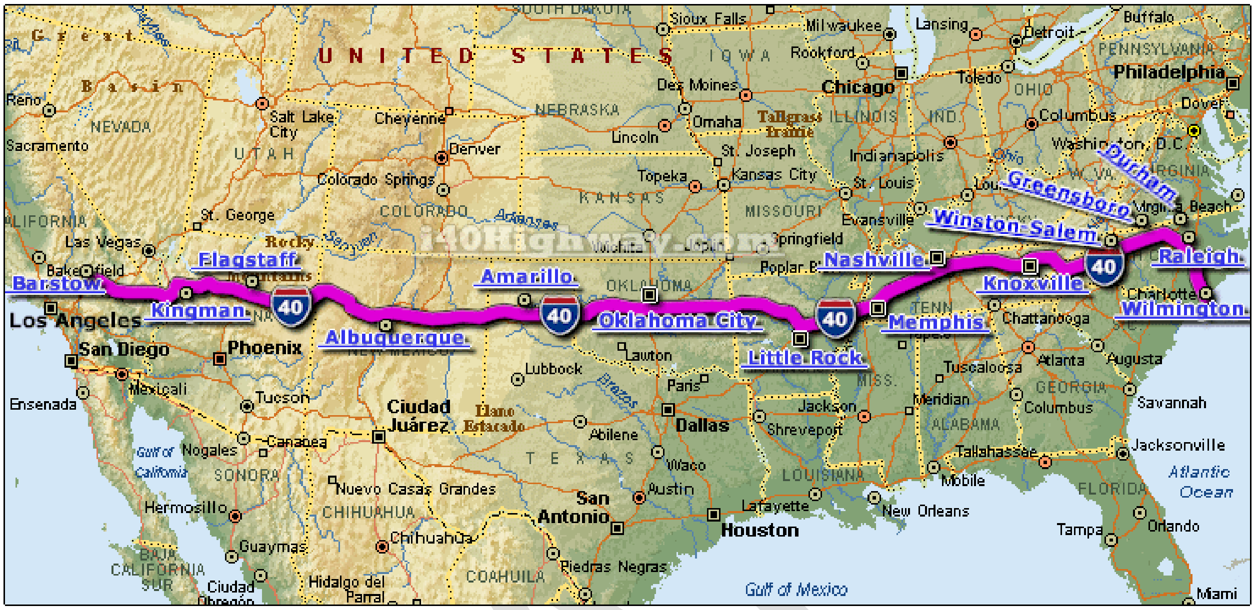


Figure 1: Interstate 40 Map (Source: i40highway.com)

Our analysis focuses on a part of I-40 between Memphis and Nashville, Tennessee which includes a network's segment of approximately 212 miles long. The specific area was selected mainly because of data availability and it is presented in Figure 2:

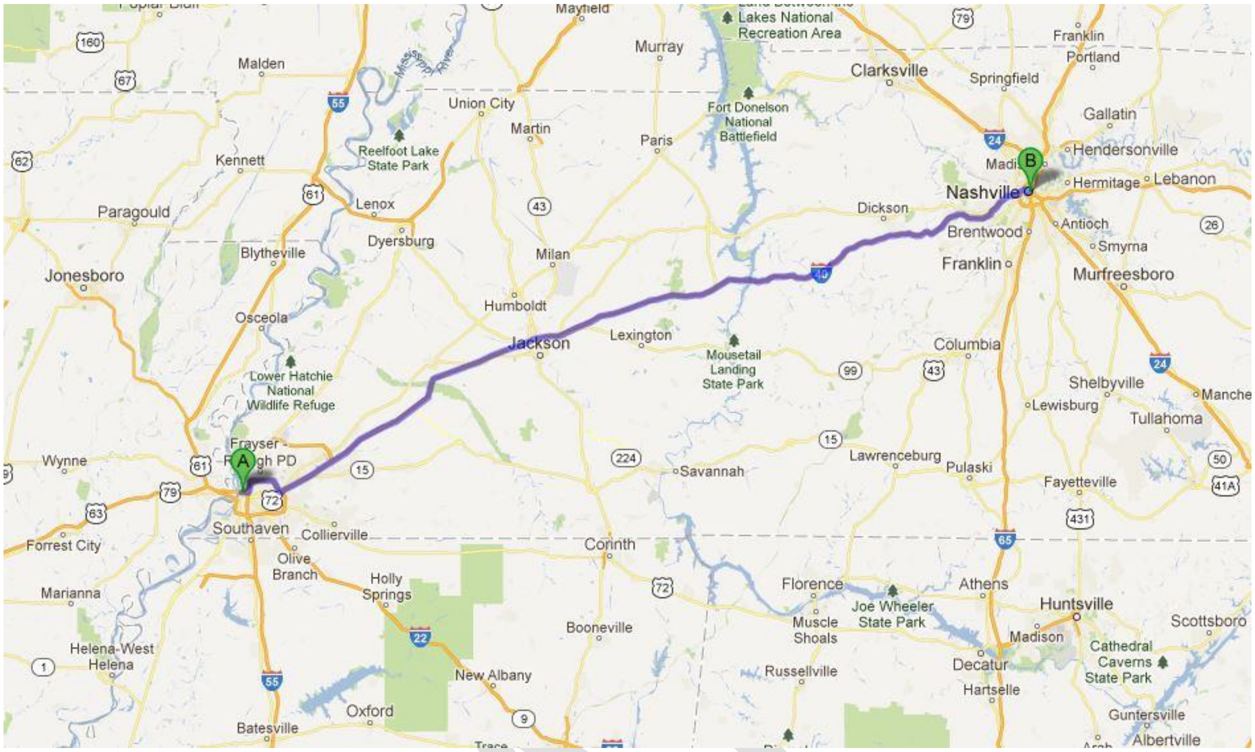


Figure 2: Case Study Area (source: maps.google.com)

3.3 Data Description

Analysis was based on the use of a comprehensive dataset provided by the American Trucking Research Institute (ATRI). Database included Global Positioning System (GPS) data, which tracked the route and trip characteristics of each truck operating within the borders of the case study area. As it was mentioned earlier, the data sample that was available referred to 3%-8% of the total population (everyday truck volumes between Memphis and Nashville). The dataset included information covering a two month period from September 1st, 2011 until October 31st, 2011 with a total of 13,510,974 observations. The major attributes of the provided database are summarized below:

“x”- Horizontal coordinate of truck location

“y”- Vertical coordinate of truck location

“truckid”- Unique ID of each different truck

“readate”- Date of observation

“time”- Time of observation

“speed”- Truck speed

“heading”- Truck heading

A sample of the provided database is presented in

Table 3:

Table 3: Data Sample

	x	y	truckid	readdate	time	speed	heading
1	-86.7697702	36.1176578	100634	9/1/2011	15:05:00	58	SW
2	-86.7604118	36.0916562	100634	9/1/2011	15:10:44	4	S
3	-86.7603566	36.0908501	100634	9/1/2011	12:11:34	8	SE
…							
…							
…							
…							
…							
13,510,972	-89.7235719	35.2311472	98980	10/31/2011	5:24:00	58	NE
13,510,973	-89.6532061	35.2682464	98980	10/31/2011	5:29:00	53	NE
13,510,974	-89.7319791	35.2264422	99128	10/31/2011	19:05:38	61	SW

Additional data regarding truck and freight movements in general were also collected from different sources, including Freight Analysis Framework (FAF) database. Different type of information such as current freight movements, forecasts for future truck volumes and characteristics of freight operations can be acquired using FAF database. Our data collection process focused among others on any available information regarding the Average Annual Daily traffic (AADT) and the related truck volumes which corresponded to the selected case study area.

3.4 Software Selection

Regarding software selection, analysis was based on the use of ArcGIS and MathWorks MATLAB software. The ArcGIS application was selected due to its efficient capabilities for data analysis and its compatibility with data format (GPS data). MATLAB software was chosen since it allows the simultaneous manipulation of a large amount of data which can result in great time savings regarding analysis duration. The availability of the specific software platforms was an additional reason for using these tools.

Geographic Information System (GIS) is a system which was mainly designed for geographical data manipulation. GIS applications are tools that allow users to create interactive queries, analyze spatial information, edit data in maps, and present the results of all these operations (Clarke, 1986). One of the major steps regarding GIS development took place back on 1960 in Ottawa, Canada by the federal Department of Forestry and Rural Development. The initial format of GIS was developed as the Canada Geographic Information System (CGIS) and was applied in different cases in order to analyze data for the Canada Land Inventory (Tomlinson, Retrieved 2007). Since then, researchers have been in a continuous effort of improving GIS capabilities by providing new and more powerful versions of GIS software.

Matrix Laboratory (MATLAB) is a fourth-generation programming language. MATLAB programming environment and features allow data manipulation, algorithm application and models' development (Altius Directory, 2010). A primal format of MATLAB software was initially developed in the University of New Mexico in 1970s. A significant step regarding MATLAB development took place in 1984 by MathWorks by rewriting MATLAB in C programming language. Since then, MATLAB is under a continuous process of update and development (Moler, 2004).

3.5 GIS Analysis

Among the different application of ArcGIS suite, ArcMap and ArcCatalog were the two major tools which were used. ArcMap is the major application for analyzing and manipulating geospatial data and creating the related maps. ArcCatalog is an additional tool for database management and organization.

Prior to the import of GPS data to GIS platform, due to data size limitations, database was modified using SPSS Statistics software. SPSS Statistics is a platform, suitable for statistical analysis which allows managing databases of large size. In order to overcome the size problem of the provided database (13,510,974 truck observations), 60 separate "CSV" files were created using SPSS software, corresponding to each one of the different days of the two month observation period (Sep 1st - Oct 31st).

The next step focused on developing a Geo-database using ArcCatalog application which included all the required information (Maps, GPS data) for the methodology accomplishment. A large Geo-database which included 60 CSV files with GPS data and the corresponding Google maps of the case study area was created and then imported in ArcMap tool for further analysis.

ArcMap application was the major tool for identifying truck data which were related with the case study area. This information was crucial for the further data analysis using MATLAB software. The first step included the proper import of GPS truck data (CSV files) in ArcMap platform and the display of the provided information. A sample of the data display which refers to one single day of observation is presented in Figure 3:

Figure 3: GPS Data Display

Then, analysis focused on specifying the GPS data which refer to the case study area. This was done by specifying the truck occurrences within the greater borders of Memphis and Nashville area, respectively, and creating the corresponding databases which refer to the two separate areas. These areas were specified using ArcMap selection tool.

The data, which were related with the greater Memphis area, are presented in Figure 4:

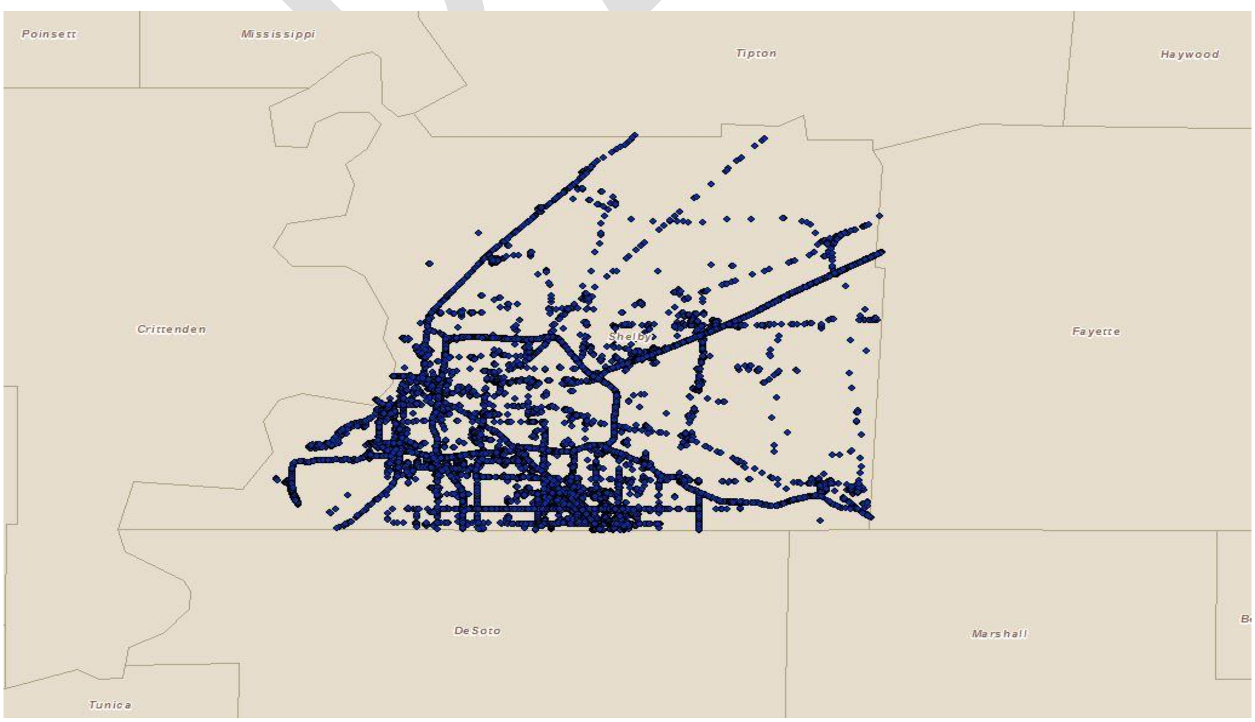


Figure 4: Truck Data for the Memphis Area

The GPS truck data, which referred to truck observations in the greater Nashville area, are shown in Figure 5:

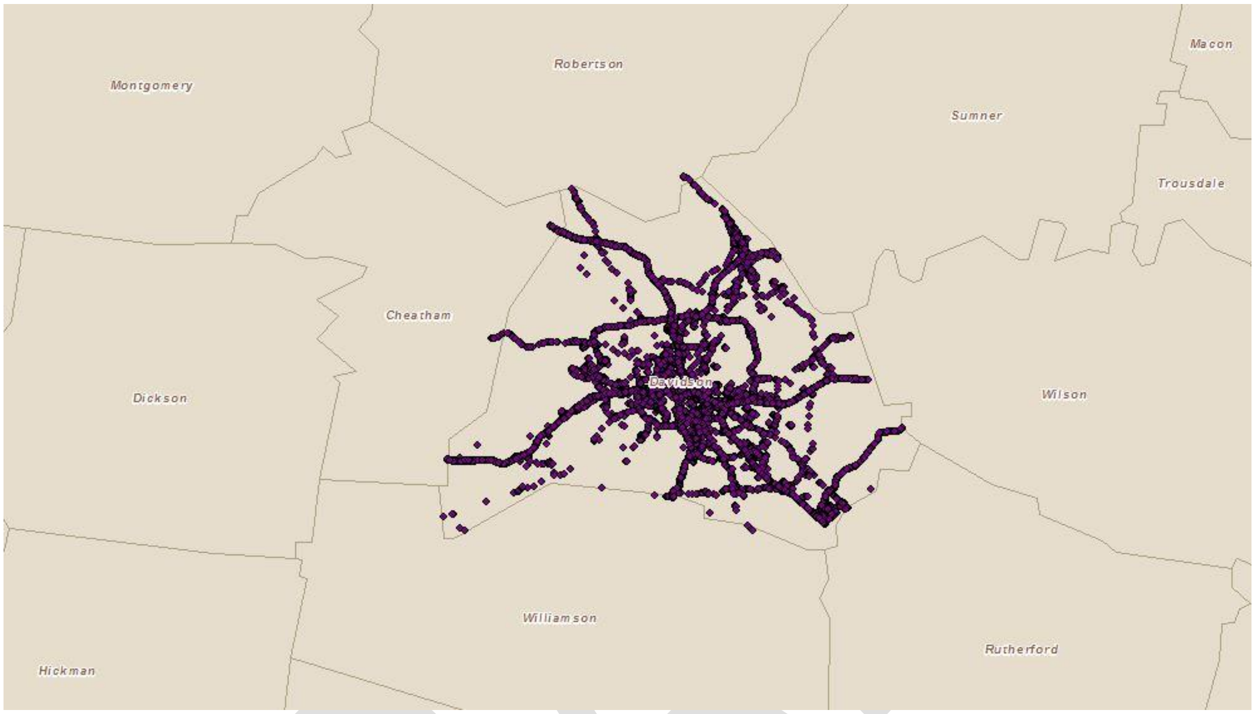


Figure 5: Truck Data for the Nashville Area

The output information of GIS analysis was provided as separate CSV files which referred to Memphis and Nashville areas separately and included the corresponding truck observations and their characteristics. A total of 120 different CSV files were created for describing the output results and then were imported in MATLAB software for further analysis which included truck volumes and trip times' identification on I-40 roadway segment.

3.6 MATLAB Analysis

MATLAB software was used to analyze the GPS data which were manipulated by GIS tools. MATLAB analysis was completed in two separate phases. The first one focused on identifying truck volumes and trip characteristics while the other one analyzed the impact of new truck volumes (due to new HOS rules restrictions) on congestion levels.

3.6.1 Truck Volumes and Trip Characteristics

As mentioned earlier, GIS analysis was able to capture data for every day of the study period. MATLAB provided the capability of accurate matrix table comparisons using an iterative process. Given the significant amount of data, this was selected as the most efficient method of analysis.

Data were received from GIS software in CSV files that were separated by both day and city (Memphis or Nashville) criteria. A file read function in MATLAB enabled the download of the files to matrix tables within the program. The process was conducted for both cities and for each day of data availability. Due to the processor limitations, departure time, trip time, and volume analysis could only be conducted for one day of data at a time. Iterating this process in MATLAB enabled the faster files download. Once a day's data for the two cities had been downloaded, a series of sorts and calculations followed. The sorting process ordered data in ascending order by truck ID and time. This process grouped the data by individual truck ID and then by time of day.

As mentioned earlier, these calculations produced departure time and trip time for each truck during each separate day and the corresponding truck volumes on a 24-hour basis. Trip time was calculated by comparing the recorded times for a unique truck ID in both cities. The process looped through the data hundreds of times looking for recorded time points in the Memphis area data that correlated chronologically with recorded time points for the same truck ID in Nashville area. When a match was found, the match was verified by comparing the Nashville time observation to the next recorded time observation for that unique truck in the Memphis data. If the values were verified, trip time was then calculated by setting the Memphis recorded time as the departure time and the Nashville recorded time as the arrival time and then calculating the corresponding difference. This process also produced the required departure and arrival times. Volume calculations consisted of trucks that were present along the link between Memphis and Nashville during a given period of time, on a 24-hour basis.

Error! Reference source not found. shows the process of calculating truck volumes and the corresponding departure and trip times. M_x and N_x represent the individual lines of data within the Memphis and Nashville data, respectively. After sorting, the process entered into the trip time calculation where individual lines of data were matched and compared. M_{x+1} represent the next consecutive line of data within the Memphis data. This process continued until the end of the Memphis data was reached. The Nashville data started over at the beginning every time a departure-arrival time had been matched and progressed through the data until all intercity movements had been recorded. At the end of Memphis data, the process switched to volume calculation, where it again entered an iterative process of comparing departure-arrival times to a set time of day. These are periods of one hour in which a truck was counted as occurring on the link if the departure and arrival times fall within a given hour. This process was repeated for each hour of a 24-hour day. The output was the truck volumes that were present on the link during a specific time period of day.

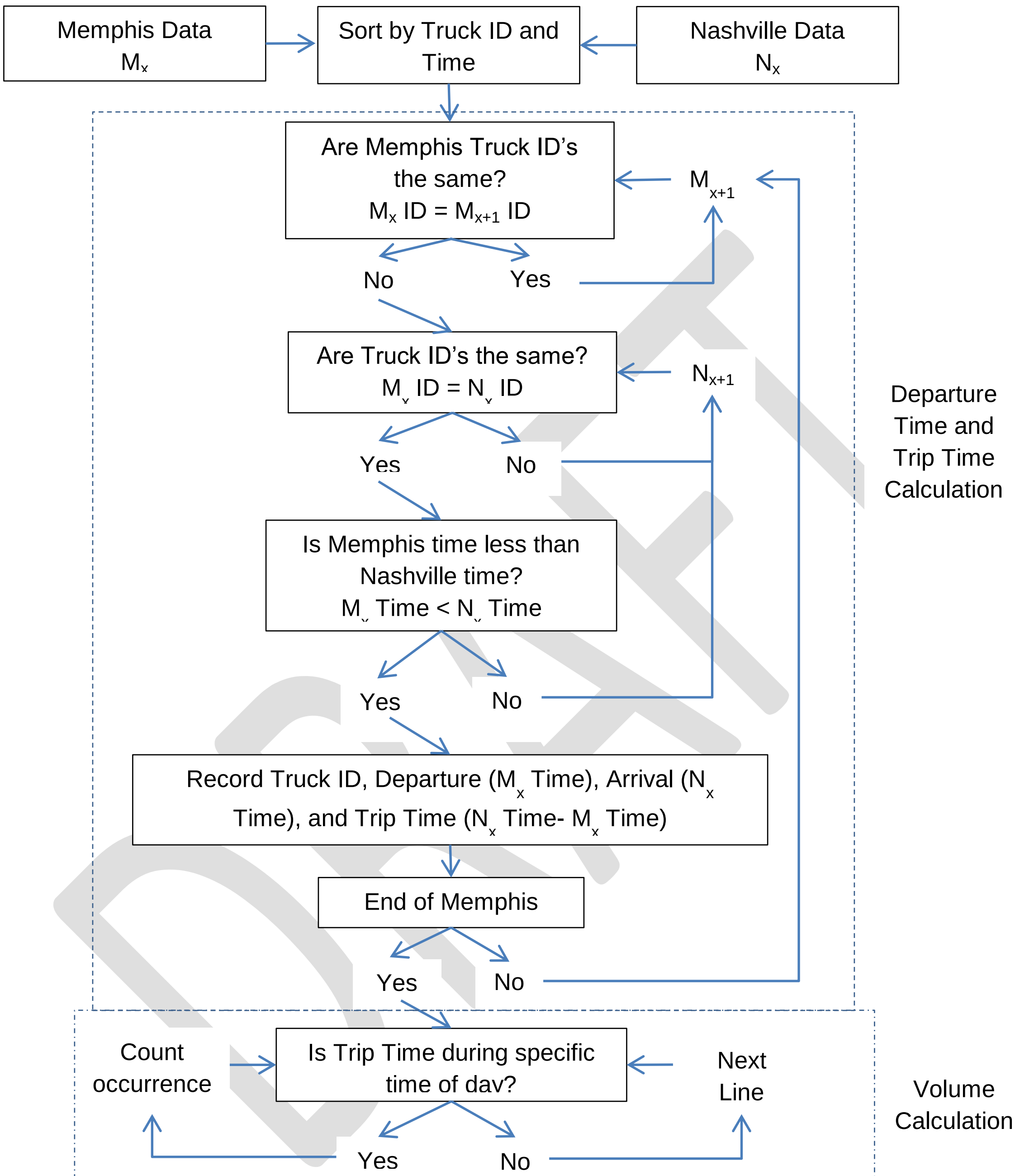


Figure 6: MATLAB Analysis Flowchart

3.6.2 Congestion Impact

The next phase of MATLAB analysis focused on the effects of new HOS of truck drivers on traffic conditions and manly congestion levels of the case study area. Congestion impact was estimated by tracking changes of the corresponding Level of Service (LOS) of the selected I-40 freeway segment. LOS is defined as a measure of traffic operation conditions and is evaluated in a scale from A through F. The definition of the evaluation scale is described in

Table 4 as it is provided by the HCM 2000 version:

Table 4: LOS Definition (Source: HCM 2000)

LOS		Definition
Acceptable	A	Represents a free-flow operation. Vehicles are almost completely unimpeded in their ability to maneuver within the traffic system.
	B	Represents reasonably free-flow operation. The ability to maneuver within the traffic stream is slightly restricted.
	C	Represents a traffic flow with speeds near or at free-flow speed of the freeway. Ability to maneuver within the traffic stream is noticeably restricted.
	D	Represents speeds that begin to decline with increased density. Ability to maneuver within the traffic stream is noticeably limited.
Unacceptable	E	Represents operation at its capacity. Vehicles are closely spaced within the traffic stream and there are virtually no useable gaps to maneuver.
	F	Represents a breakdown of vehicle flow. This condition exists within queues forming behind the breakdown points.

Analysis followed the methodology suggested by the Highway capacity manual (HCM) regarding the LOS estimation of basic freeway segments. LOS was estimated for both the current and the new traffic conditions, which were created due to the updated HOS rules. A general version of this methodology is presented below.

One of the major parameters that had to be estimated was the corresponding flow rate (V_p). The basic equation which was used for estimating flow rate (V_p) is presented in equation 1:

$$V_p = \frac{V}{PHF*N*f_{HV}*f_p} \qquad \text{(Eq. 1)}$$

Where

V_p: refers to 15-min passenger car equivalent flow rate (pc/h/ln)

V: refers to hourly volume (veh/h)

PHF: refers to peak hour factor

N: refers to number of lanes

f_{HV}: refers to heavy vehicle adjustment factor

f_p: refers to driver population factor

Regarding the identification of the heavy-vehicle adjustment factor (f_{HV}), this is described in equation 2:

$$f_{HV} = \frac{1}{1+P_T(E_T-1)+P_R(E_R-1)} \qquad \text{(Eq.2)}$$

Where

E_T, E_R: refer to passenger-car equivalents for trucks/buses and recreational vehicles (RVs) in the traffic stream respectively

P_T, P_R: proportion of trucks/buses and RVs in the traffic stream respectively

Another crucial factor regarding the precise identification of LOS is the corresponding free-flow speed (FFS) levels. Free-flow speed is estimated using equation 3:

$$FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID} \qquad \text{(Eq. 3)}$$

Where

FFS: corresponds to free-flow speed (mi/h)

$BFFS$: corresponds to base free-flow speed, 70 mi/h (urban) or 75 mi/h (rural)

f_{LW}: corresponds to adjustment for lane width

f_{LC}: corresponds to adjustment for right-shoulder lateral clearance

f_N: corresponds to adjustment for number of lanes

f_{ID}: corresponds to adjustment for interchange density

Then, considering the corresponding values of free flow speed (FFS) and flow rate (V_p), LOS can be identified using Table 5, provided by HCM:

Table 5: LOS Criteria for Basic Freeway Segments (Source: HCM 200)

Criteria	LOS				
	A	B	C	D	E
FFS = 75 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	75.0	74.8	70.6	62.2	53.3
Maximum v/c	0.34	0.56	0.76	0.90	1.00
Maximum service flow rate (pc/h/ln)	820	1350	1830	2170	2400
FFS = 70 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	70.0	70.0	68.2	61.5	53.3
Maximum v/c	0.32	0.53	0.74	0.90	1.00
Maximum service flow rate (pc/h/ln)	770	1260	1770	2150	2400
FFS = 65 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	65.0	65.0	64.6	59.7	52.2
Maximum v/c	0.30	0.50	0.71	0.89	1.00
Maximum service flow rate (pc/h/ln)	710	1170	1680	2090	2350
FFS = 60 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	60.0	60.0	60.0	57.6	51.1
Maximum v/c	0.29	0.47	0.68	0.88	1.00
Maximum service flow rate (pc/h/ln)	660	1080	1560	2020	2300
FFS = 55 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	55.0	55.0	55.0	54.7	50.0
Maximum v/c	0.27	0.44	0.64	0.85	1.00
Maximum service flow rate (pc/h/ln)	600	990	1430	1910	2250

3.6.2.1 Formulation Adjustments

However, due to some special characteristics of this case study and data limitations, different adjustments on the suggested methodology were applied. The adjustments that were made are described for each different case separately.

3.6.2.1.1 Current Traffic Conditions

Current traffic conditions refer to the case where new HOS rules have not been applied and their impact was not considered.

Equation 1 which was used for estimating flow rate (V_p), was modified as follows:

$$V_p = \frac{PDT*Dtot*AADT}{PHF*N*f_{HV}*f_p} \qquad \text{(Eq. 4)}$$

Where:

AADT: is the annual average daily traffic (provided by FAF database)

Dtot: is the directional split and refers to the directional distribution of total hourly volume

PDT: is the percent of hourly AADT and refers to the corresponding daily traffic demand pattern. This specifies the proportion of the total AADT which affects traffic conditions of a roadway link during a specific time period of the day

Equation 2 which was used for the identification of the heavy-vehicle adjustment factor (f_{HV}), was modified as follows:

$$f_{HV} = \frac{1}{1+\frac{Dtr*TPDT*TAADT}{Dtot*PDT*AADT}(E_T-1)+P_R(E_R-1)} \qquad \text{(Eq. 5)}$$

Where:

TAADT: is the truck annual average daily traffic (provided by FAF database)

TPDT: is the truck percent of TAADT and refers to the corresponding daily truck traffic demand pattern

Dtr: is the directional split and refers to the directional distribution of trucks hourly volume

AADT: is the annual average daily traffic (provided by FAF database)

Dtot: is the directional split and refers to the directional distribution of total hourly volume

PDT: is the percent of hourly AADT and refers to the corresponding daily traffic demand pattern. This specifies the proportion of the total AADT which affects traffic conditions of a roadway link during a specific time period of the day

The final format of the modified formulation for estimating the flow rate (V_p) is presented in equation 6:

$$V_p = \frac{PDT*Dtot*AADT}{PHF*N*\frac{1}{1+\frac{Dtr*TPDT*TAADT}{Dtot*PDT*AADT}(E_T-1)+P_R(E_R-1)}*f_p} \qquad \text{(Eq. 6)}$$

3.6.2.1.2 New Traffic Conditions

New traffic conditions correspond to the case, which due to the new HOS rules, additional truck volumes were considered. Additional trucks (AT) were estimated using the provided GPS data and identifying the trucks which were operating between 1:00 and 5:00 a.m. on a typical Monday. However, different adjustments took place.

The provided GPS data were a sample of the total truck population therefore an adjustment factor (CF), which corresponded to the proportion of the total truck population, was considered. So additional truck volumes were as follows:

Additional Truck Volumes: *AT/CF

Other adjustments that had to take place regarding the additional truck volumes referred to the portion of the additional truck (PT) which affected traffic conditions on any separate link of the case study network during specific time periods.

The levels of impact on each different time period had to be defined by:

- Departure time at the origin point
- Corresponding trip time to the destination point (case study link)

The additional truck volumes were identified as:

Additional Truck Volumes: (PT*AT)/CF

The modified equation for estimating flow rate (V_p), is presented in equation 7:

$$V_p = \frac{PDT * Dtot * AADT + \frac{PT * AT}{CF}}{PHF * N * f_{HV} * f_p} \qquad \text{(Eq. 7)}$$

Where:

AADT: is the annual average daily traffic (provided by FAF database)

Dtot: is the directional split and refers to the directional distribution of total hourly

PDT: is the percent of daily traffic factor and refers to the corresponding daily traffic demand pattern

PT: is the proportion of the additional trucks which affected a specific road link during a time period of the day

CF: is an adjustment factor and corresponded to the proportion of the total truck population

AT: is the number of additional trucks which were operating between 1:00 and 5:00 a.m. on a typical Monday

Additionally, the equation regarding the estimation of the heavy-vehicle adjustment factor (f_{HV}), was modified as follows:

$$f_{HV} = \frac{1}{1 + \frac{Dtr * TPDT * TAADT + \frac{PT * AT}{CF}}{Dtot * PDT * AADT + \frac{PT * AT}{CF}}(E_T - 1) + P_R(E_R - 1)} \qquad \text{(Eq. 8)}$$

The updated final format of the formulation for estimating the flow rate (V_p) is presented in equation 9:

$$V_p = \frac{PDT*Dtot*AADT + \frac{PT*AT}{CF}}{PHF*N*\frac{1}{1+\frac{Dtr*TPDT*TAADT+\frac{PT*AT}{CF}}{Dtot*PDT*AADT+\frac{PT*AT}{CF}}(E_T-1)+P_R(E_R-1)}*f_p} \qquad \text{(Eq. 9)}$$

4. RESULTS

As described in previous chapters, analysis data referred to Memphis-Nashville section of I-40 during the months of September and October, 2011. The first part of this analysis focused on identifying the characteristics of two parameters that were significant regarding the impact of new HOS rules. These two parameters were trip time by time of day and volume by time of day and were analyzed on a daily and weekly/weekend basis. This allowed for a detailed snapshot of activities during a particular period of time. In order to overcome some irregularities which appeared due to data limitations, averages of the hourly trip times and volumes were taken. The next part of the analysis focused on the impact of new regulation on traffic conditions and the corresponding congestion levels of the case study area.

This chapter includes three sections in total. The first one describes the truck volumes of the case study area for different time periods, while the next one refers to the corresponding trip times of trucks for the I-40 segment between Memphis and Nashville area. The last section includes the analysis results regarding the impact of new HOS rules on LOS and congestion levels.

4.1 Truck Volumes

Trucks can have a significant effect on traffic conditions and congestion levels. The new HOS regulations may cause an increase on the corresponding truck volumes on road networks. In order to determine the possible magnitude, if any, of this shift, an initial state of the system should be determined. Truck volumes were firstly defined for each separate day of the 2-month observation period. A sample of truck volumes for two randomly selected days along the Memphis to Nashville link are presented in Figure 7 and Figure 8. Truck volumes drastically change from hour to hour.

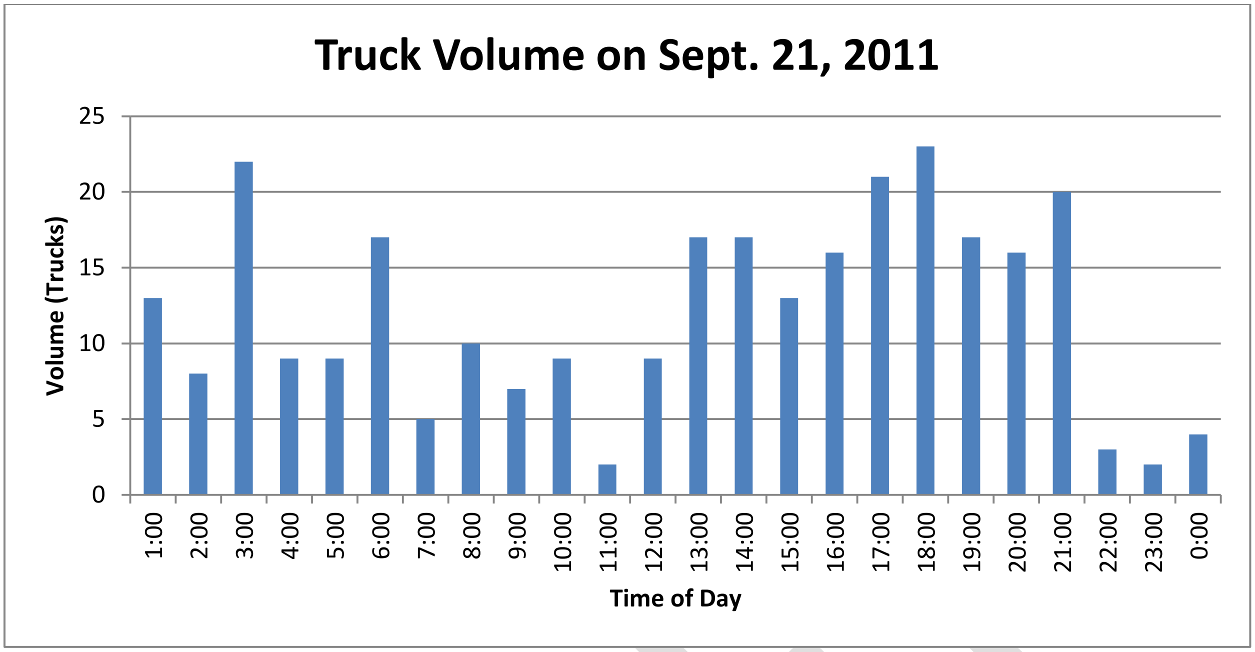


Figure 7: Sample of Daily Truck Volume (21-Sep-2011)

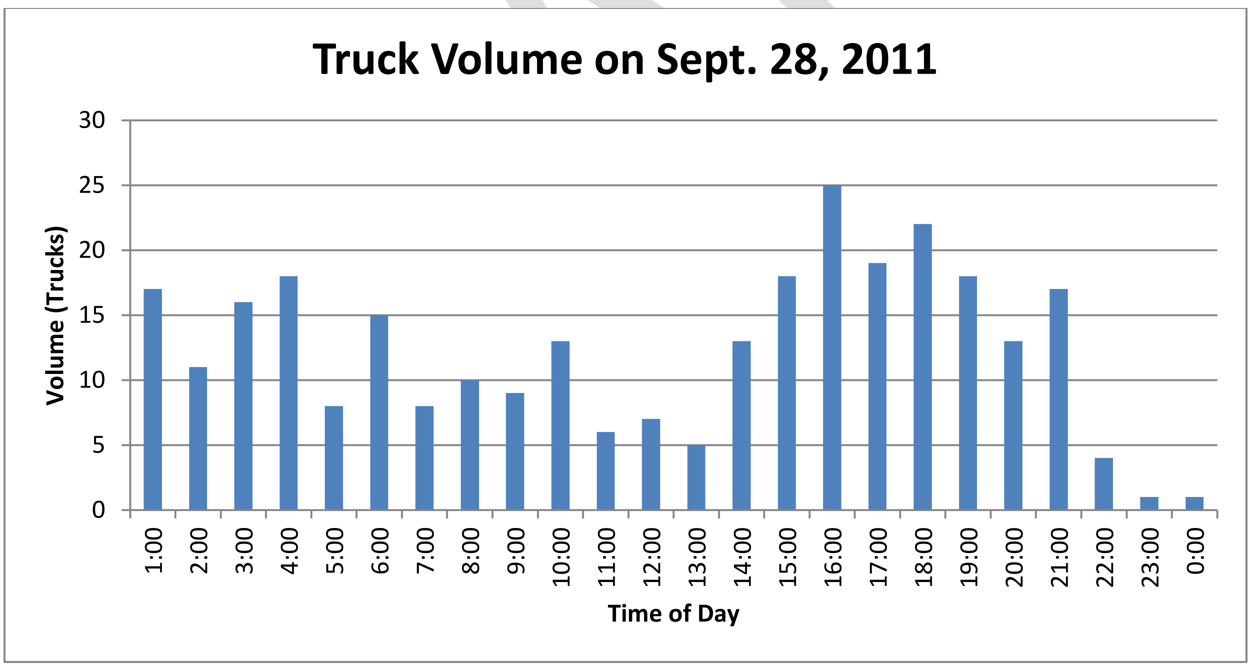


Figure 8: Sample of Daily Truck Volume (28-Sep-2011)

The resulting weekday aggregated volumes paints a much different picture of the average volumes than the daily graphs. Figures 11 through 17 show the volumes for each day of the week after averaging the corresponding values of the 2-month data period. When viewed side-by-side, a noticeable pattern emerges. During the early hours of the day (12AM-6AM), truck volumes were higher than during the morning period (6AM-12PM). This could have been affected by the number of trucks that were immobilized (rest periods) during early hours' period at rest areas along the link. Along morning progress, truck volumes decreased as the trucks re-entered the network and later cleared the case study segment. During afternoon hours (12PM-6PM), there was a large spike in the number of trucks operating on the link. This would suggest that the majority of truck operations occurred during this period of the day as trucks departed from origin points in Memphis and arrived at destinations in Nashville. After 9PM, on most weekdays, truck volumes drastically decreased suggesting that few new trucks entered the case study links at this time period.

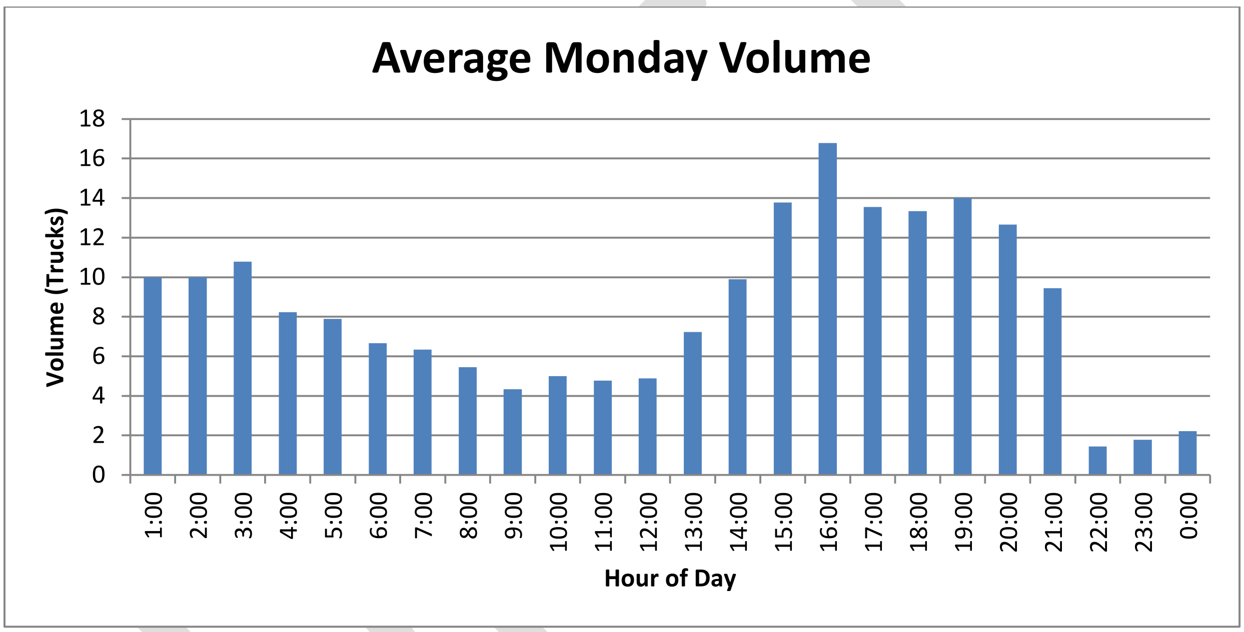


Figure 9: Average Monday Truck Volumes

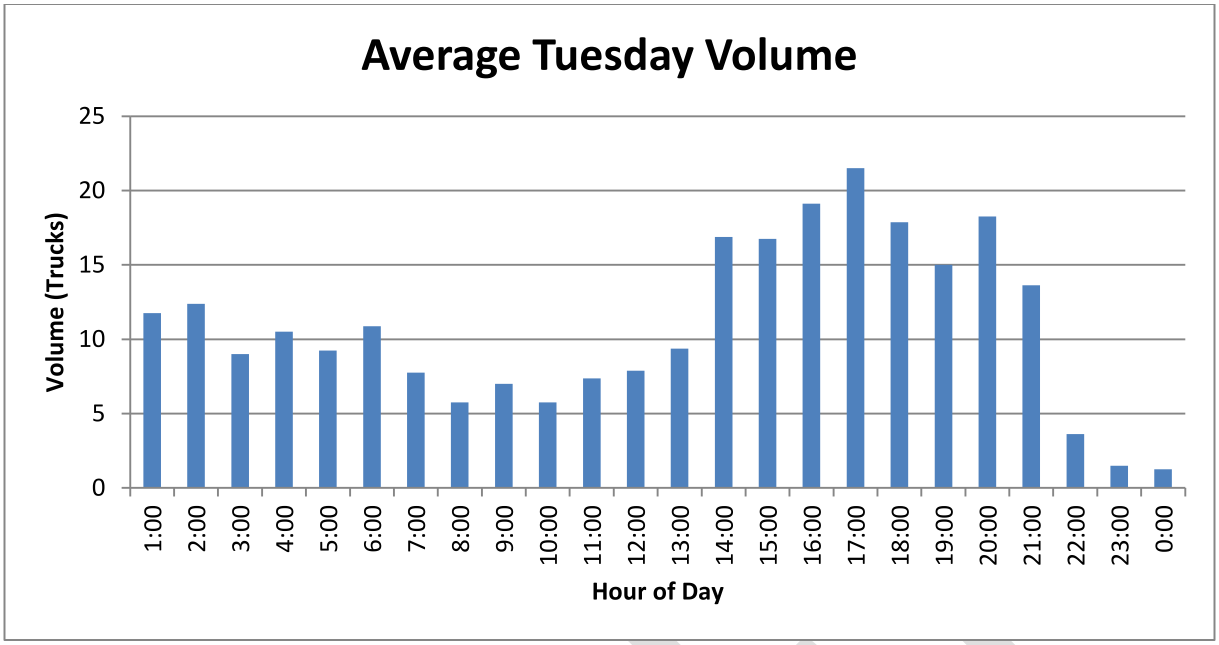


Figure 10: Average Tuesday Truck Volumes

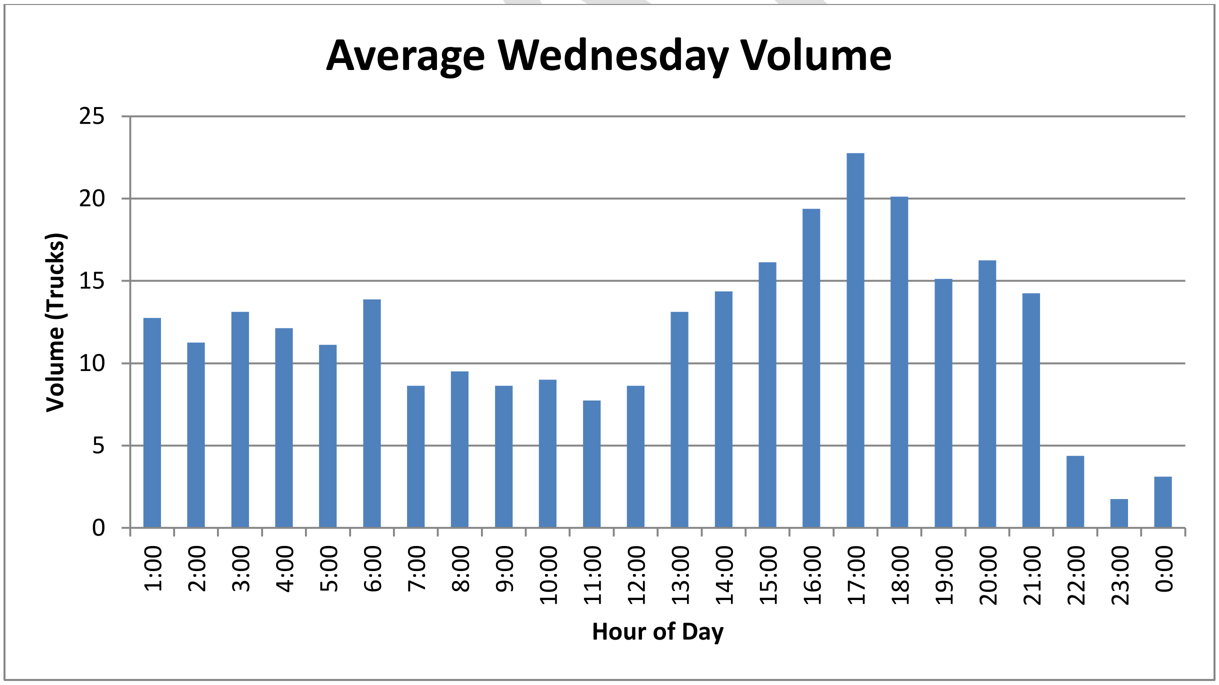


Figure 11: Average Wednesday Truck Volumes

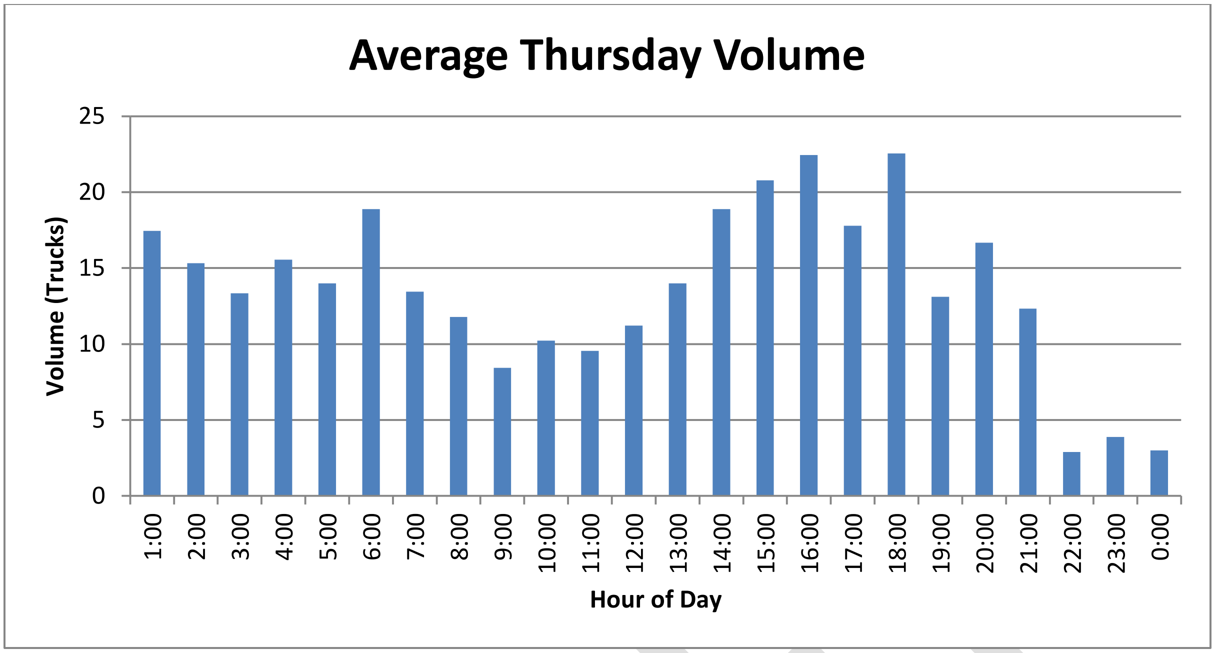


Figure 12: Average Thursday Truck Volumes

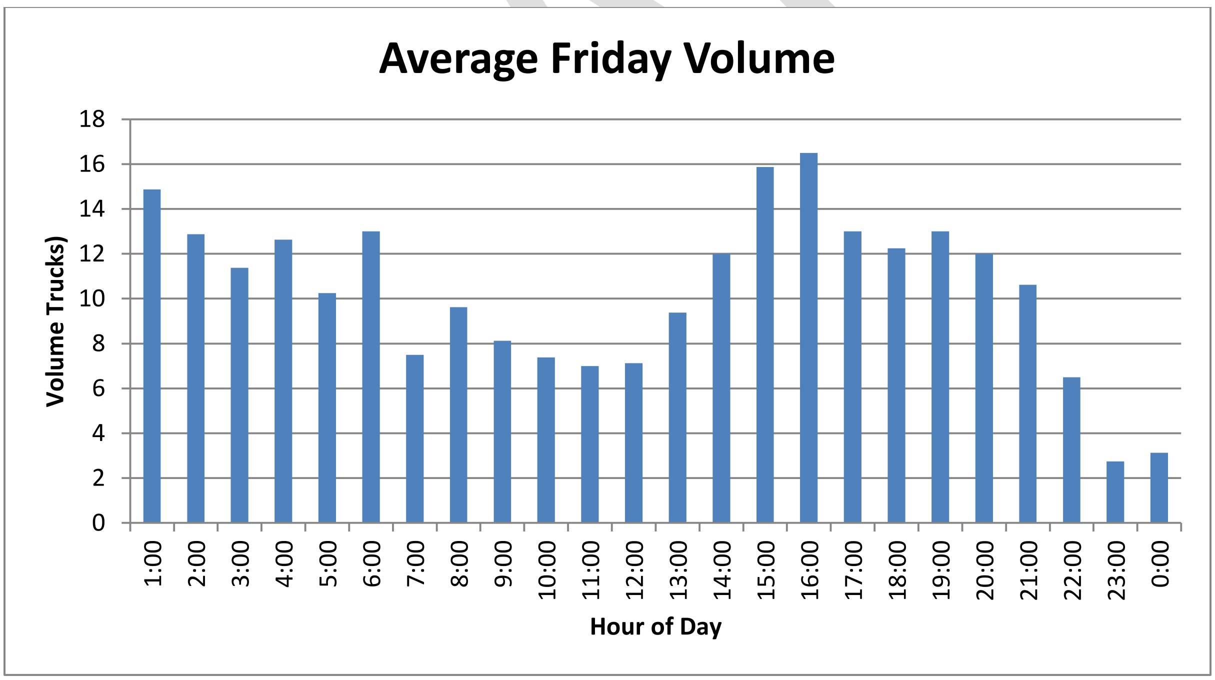


Figure 13: Average Friday Truck Volumes

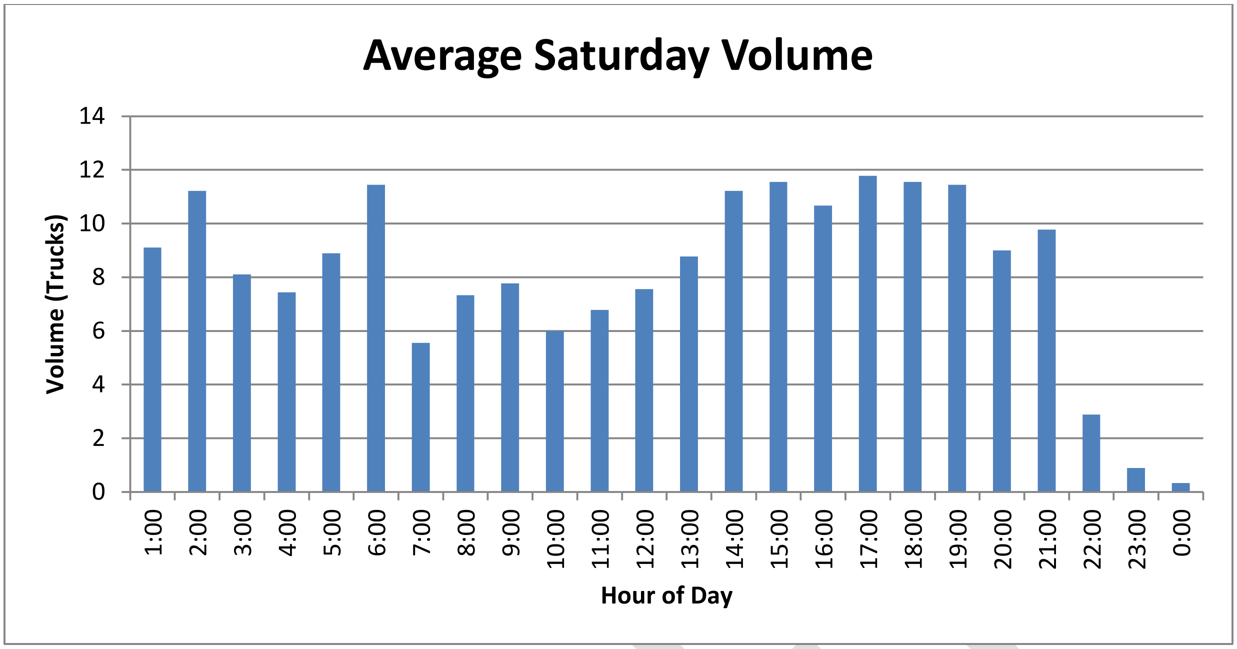


Figure 14: Average Saturday Truck Volumes

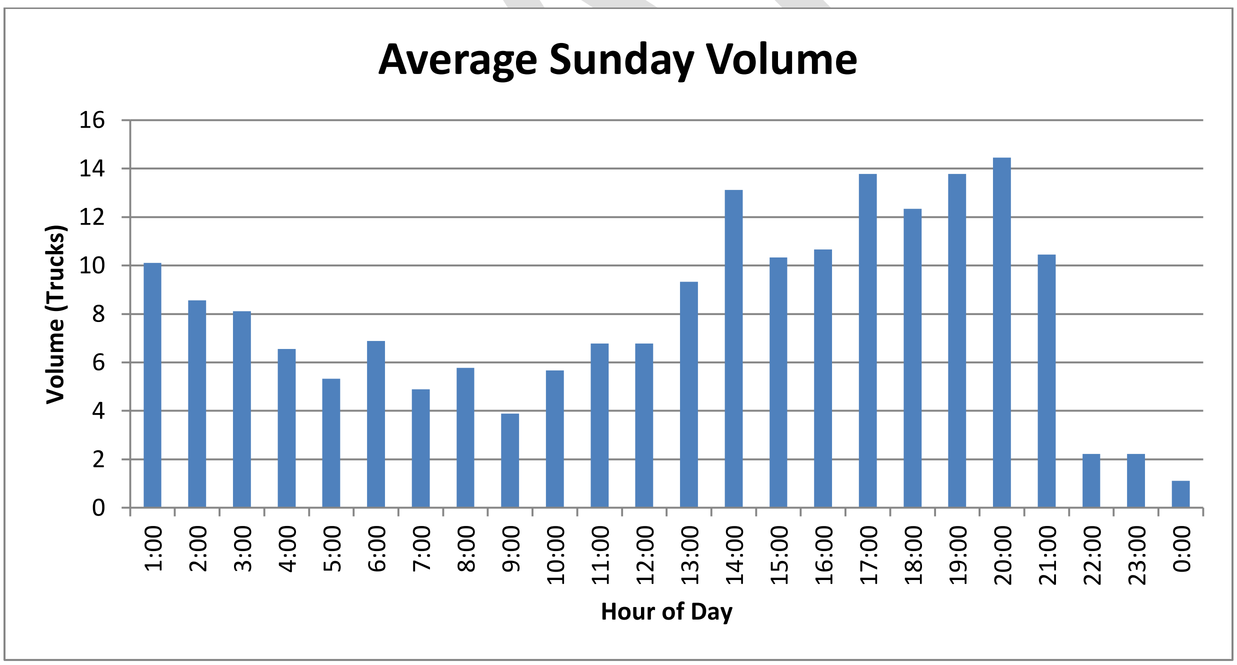


Figure 15: Average Sunday Truck Volumes

Analysis then focused on the corresponding results of averaging truck volume data of weekdays in total. Figure 16 shows an identical pattern in the weekly volumes along the link. The decreasing volumes in the morning hours were indicative of a relatively small number of trucks entering the network during this period. Conversely, a mass of trucks entered the link during afternoon hours of the day. This suggested that the majority of trucks utilized roadway links more during afternoon hours rather than morning hours. Similar conclusions can be reached regarding the characteristics of average weekend truck volumes as showed in Figure 17.

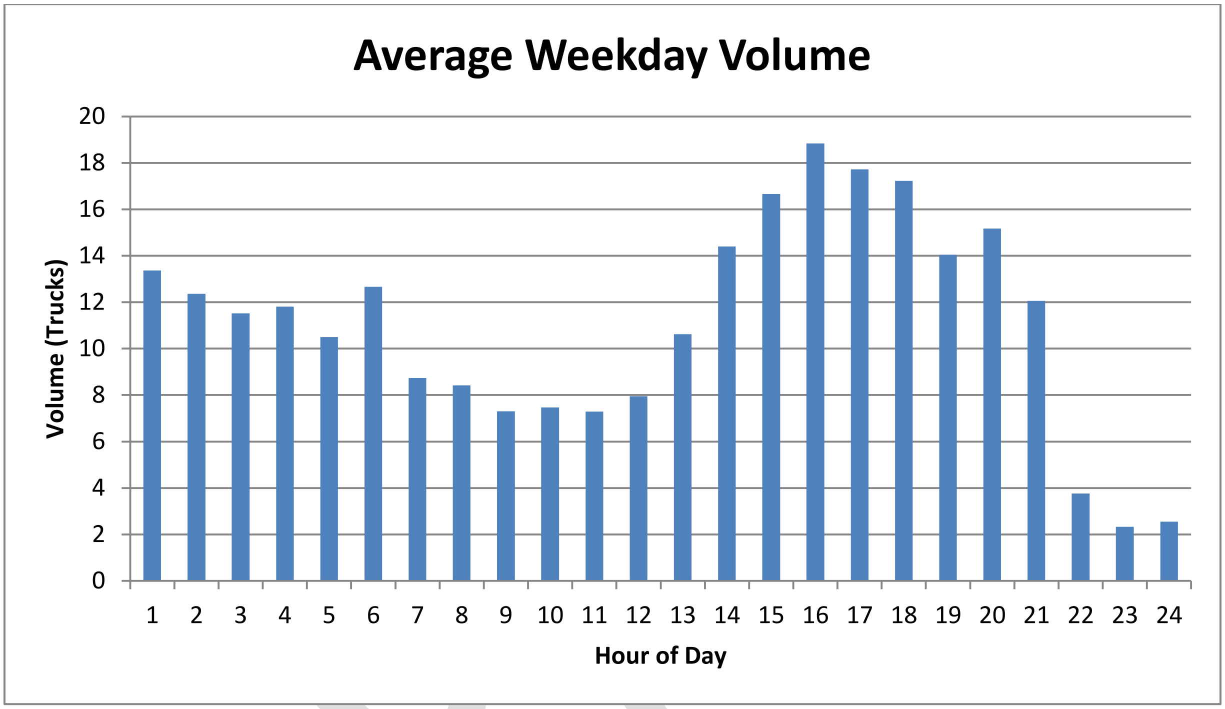


Figure 16: Average Weekday Truck Volumes

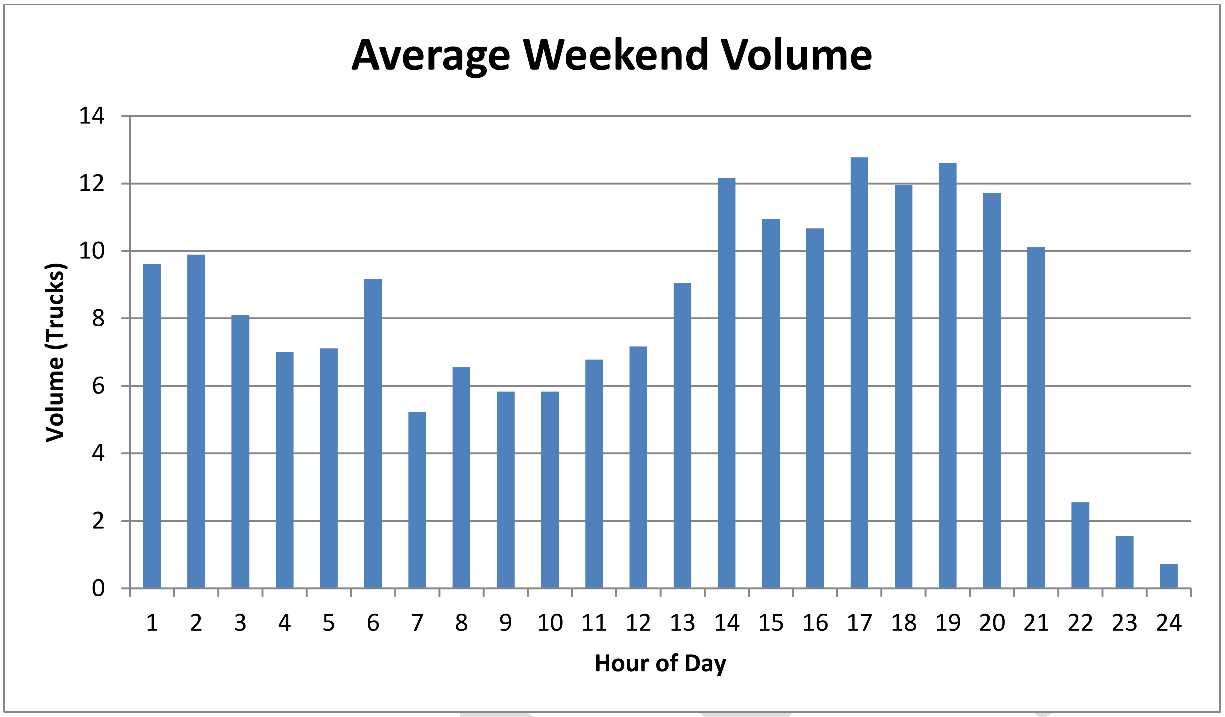


Figure 17: Average Weekend Truck Volumes

4.2 Truck Trip Times

Analysis of trip times was conducted by investigating the trip time patterns of the trucks on a daily and weekly basis. Initially trip times were identified for each separate day considering the available data. Figure 18 and Figure 19 show the typical results produced when analyzing trip times for two randomly selected single days.

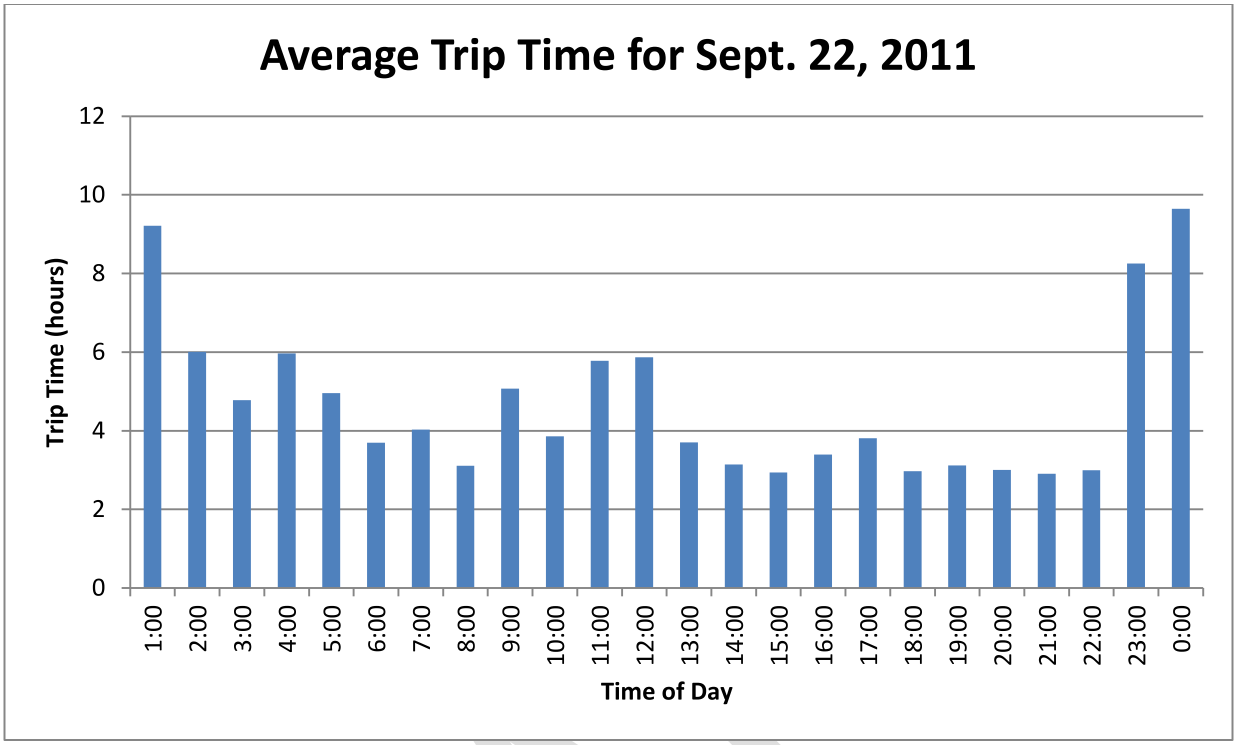


Figure 18: Sample of Daily Trip Time (22-Sep-2011)

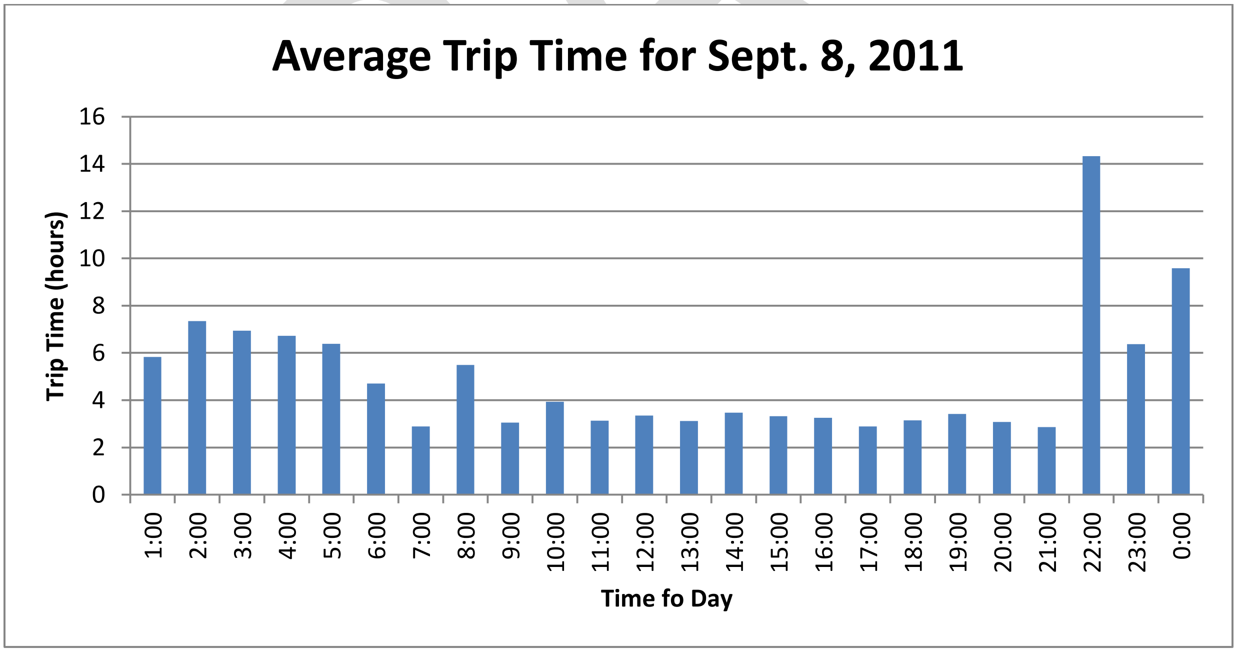


Figure 19: Sample of Daily Trip Time (08-Sep-2011)

From the figures above it was shown that during the hours between 6AM and 9PM, trip times were relatively consistent. Also, the outlying nighttime hours between 10PM and 5AM typically had much higher trip times than the daytime hours. However, safer results might be reached by investigating the average truck trip times for each separate day as they were produced by averaging the corresponding trip times of the two month data period.

Figures 22 through 28 present average daily trip times for trucks for each single day. During the early morning hours (12AM to 5AM) trip times were significantly higher, compared with the daytime hours. This could be caused due to the fact that early morning hours could be used as rest and break periods for a large number of truck drivers, something which could significantly affect the corresponding trip times.

During the day time hours (6AM to 9PM), trip times averaged between 3-4 hours. This was the typical truck trip time between Memphis and Nashville area without significant rest or break periods. Additionally, a slight decline in the average trip times as the day progressed towards the late afternoon hours was observed. One cause of such a decrease might be the need for truck drivers to accomplish a delivery within specific time windows; however, this decline was very gradual and might merely be the result of data type and quality.

In the late evening hours (10PM to 12AM), the travel time spiked. This was similar to what was observed in the early hours of the morning. Drivers might include rest periods in their schedules during this time causing the trip time between Memphis and Nashville to increase. A notable difference at this time period of the day occurred on Fridays. Figure 24 showed that the average trip time during the late night hours was much lower than the other days of the week. One cause of this phenomenon could be regarding the type of driver that operated during the weekdays versus the weekends. Different companies have different policies on the operational hours of truck drivers. A number of companies only operate during the weekdays which would mean that come Friday night many of these drivers are off the road. This could potentially explain the differences in late night trip times observed on Fridays.

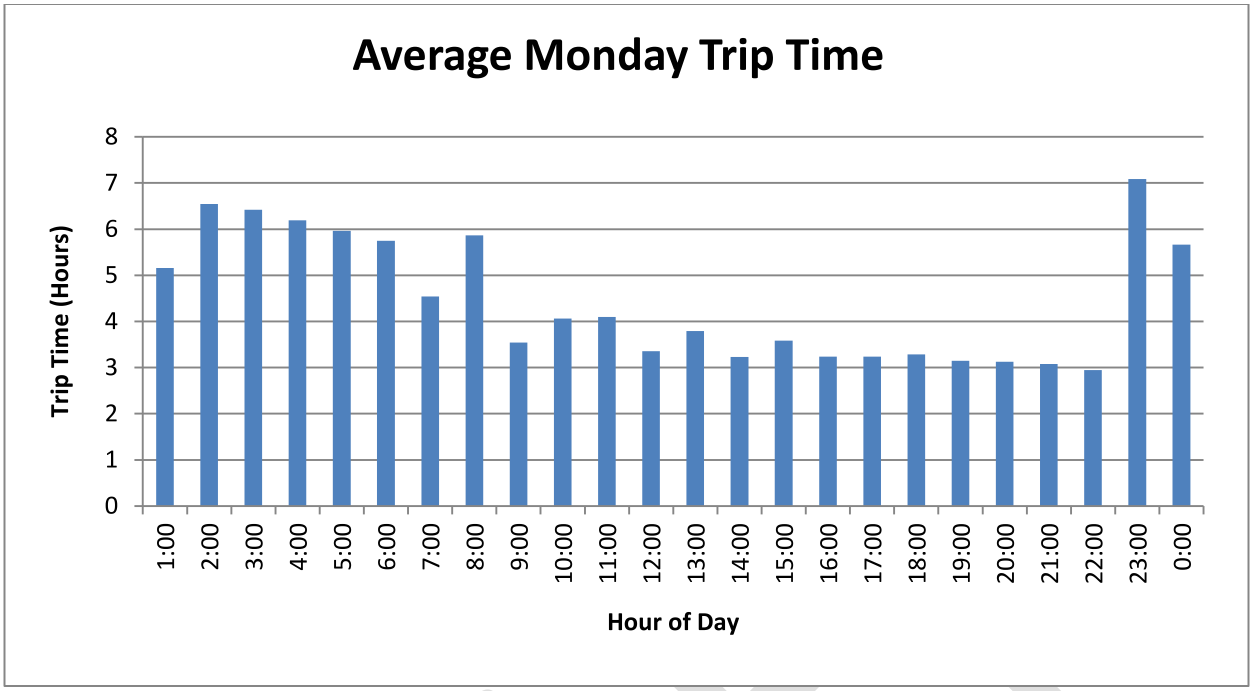


Figure 20: Average Monday Trip Time

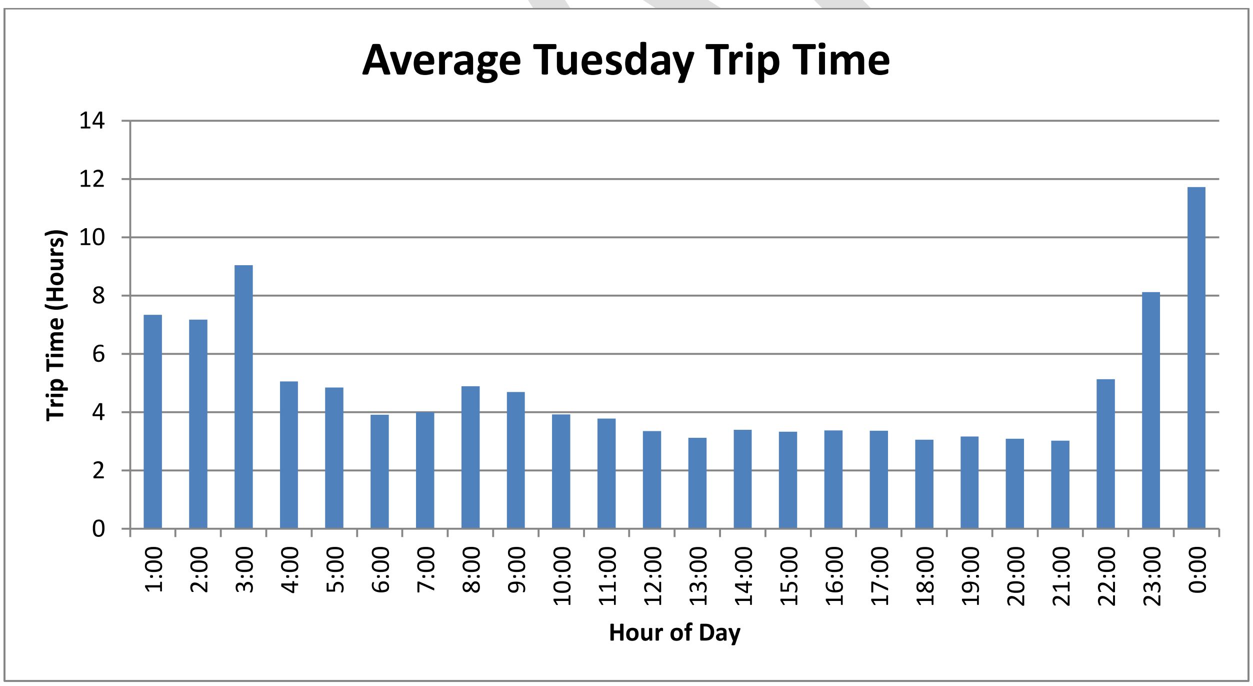


Figure 21: Average Tuesday Trip Time

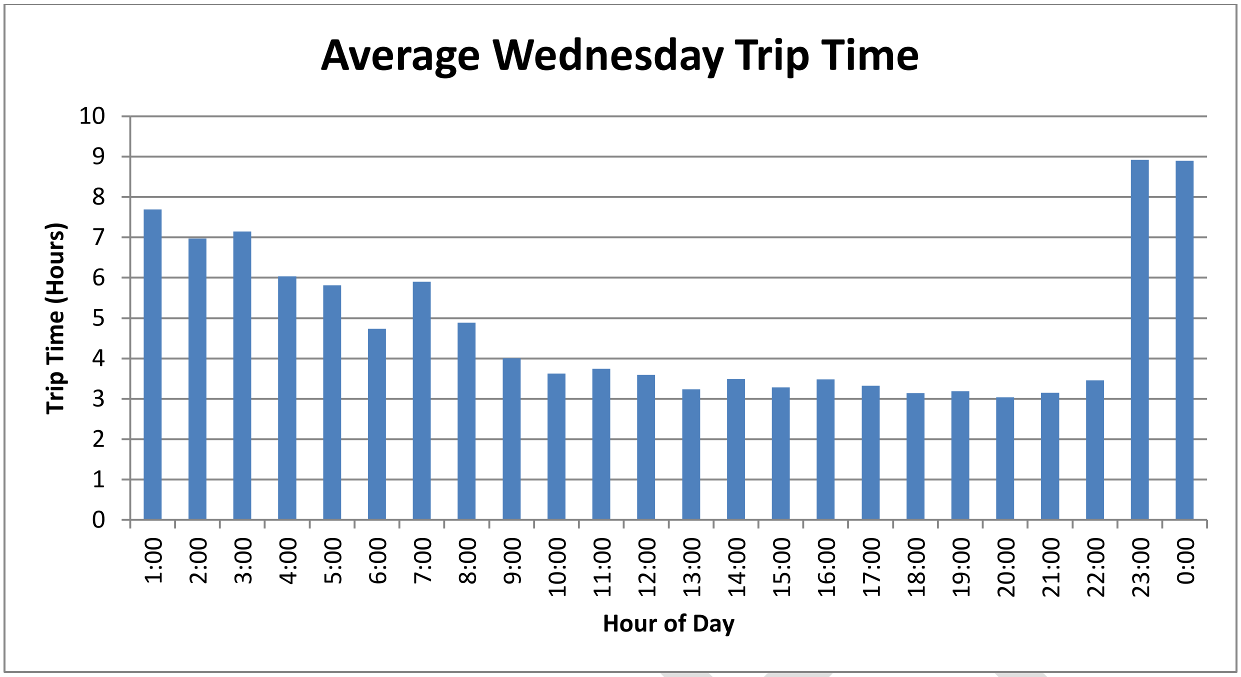


Figure 22: Average Wednesday Trip Time

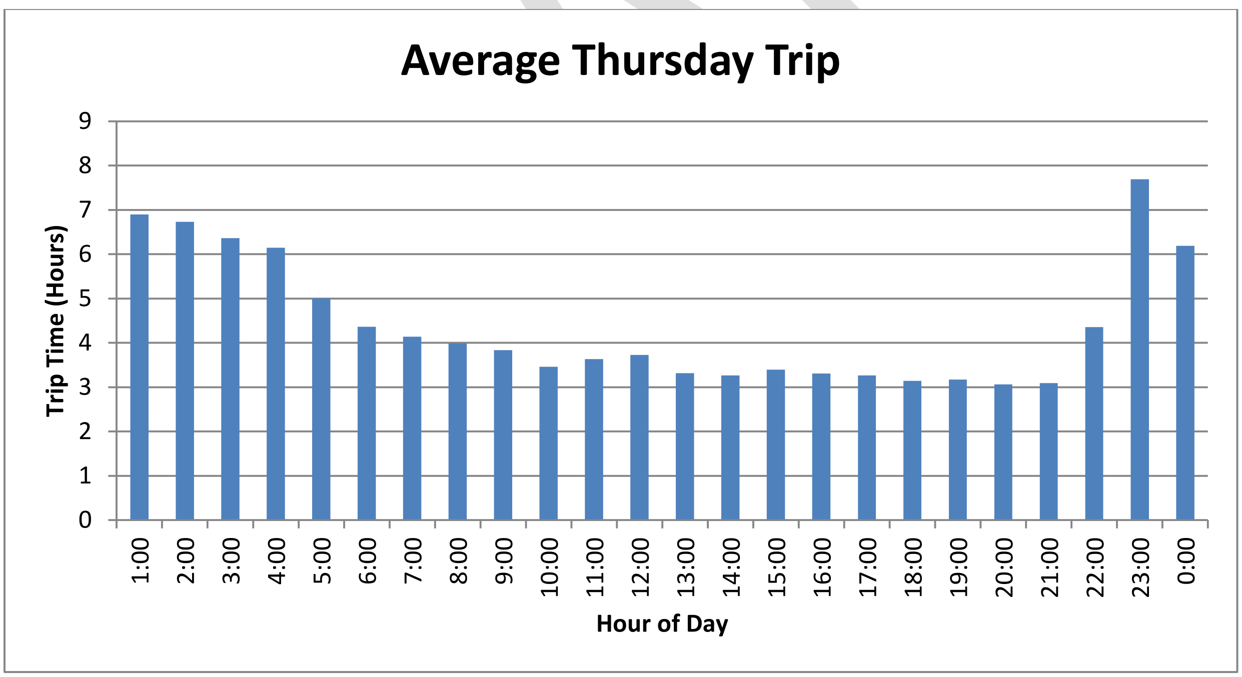


Figure 23: Average Thursday Trip Time

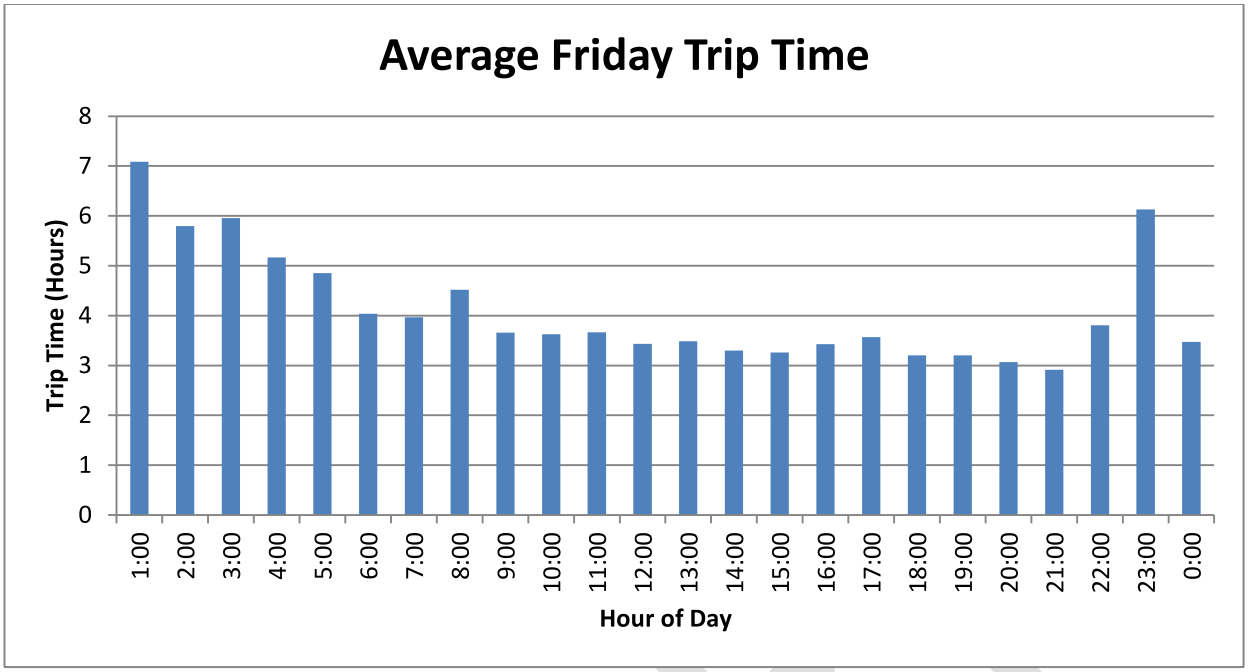


Figure 24: Average Friday Trip Time

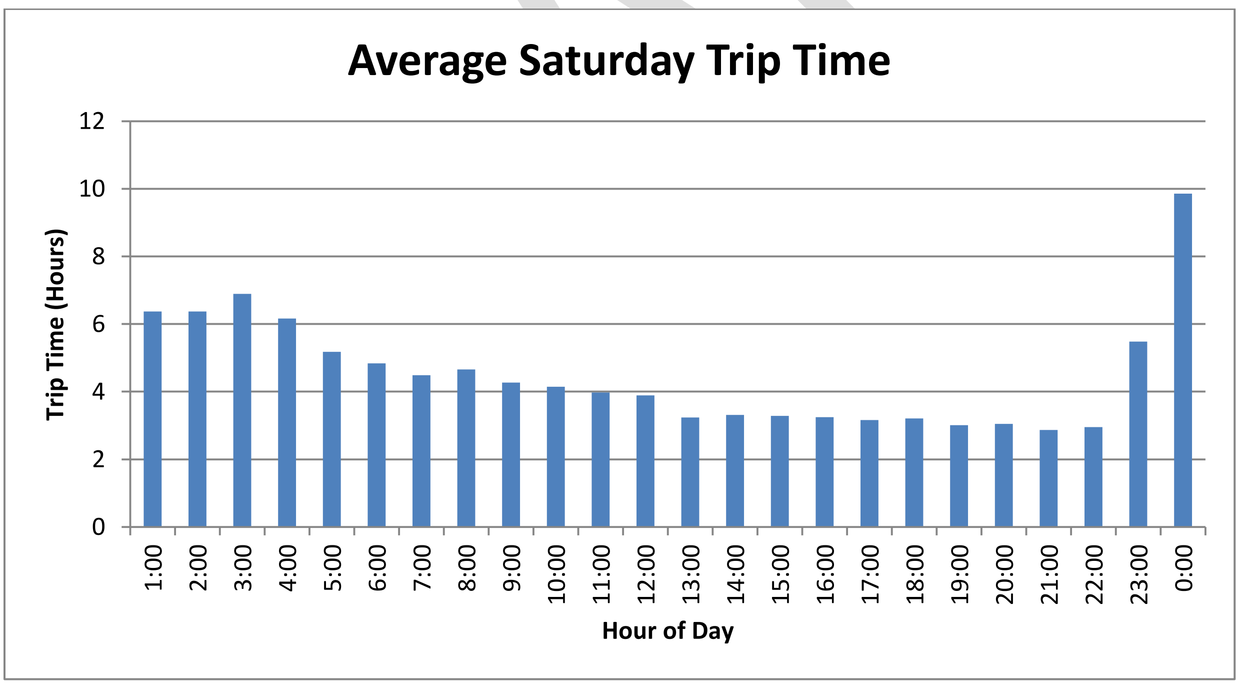


Figure 25: Average Saturday Trip Time

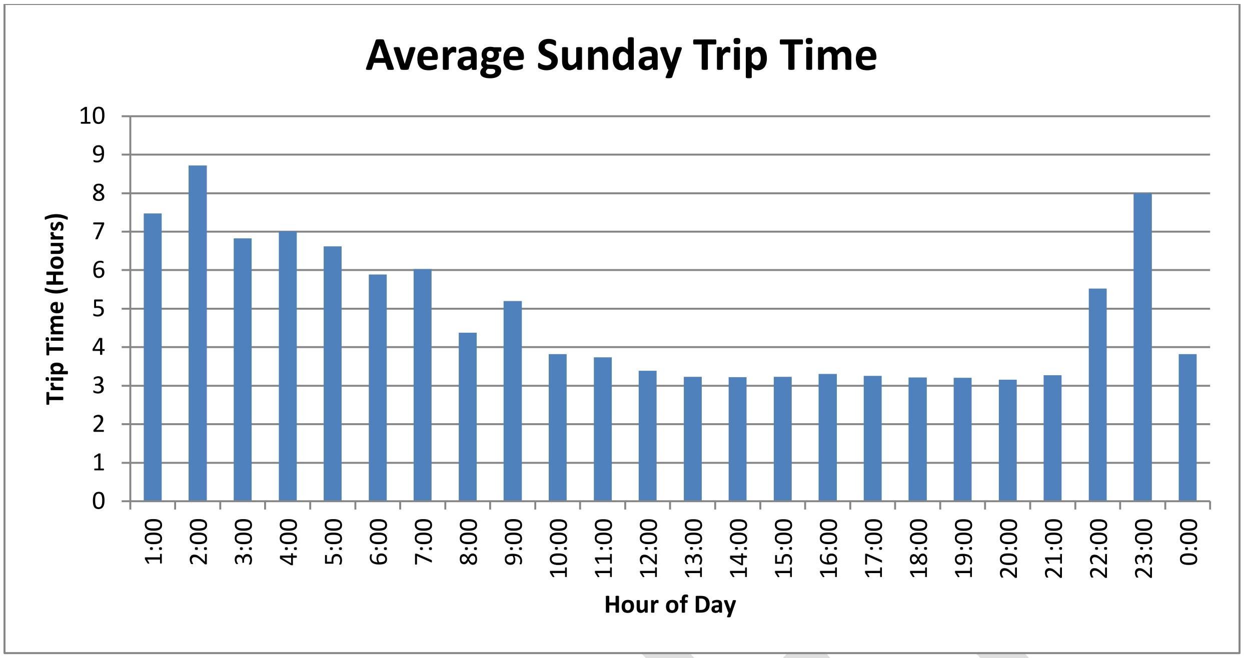


Figure 26: **Average Sunday Trip Time**

Further aggregation of data is shown in Figure 27. It shows the averages of all the weekdays' trip times. The pattern was very similar to the pattern that was observed during the individual days. Trip time between Memphis and Nashville was approximately equal to 5-7 hours during the early hours of the morning. Trip times decreased relatively steeply until the midday hours (11AM-4PM) where trip times averaged out to about 3.5 hours. During the early evening hours (8PM-10PM), trip times decreased more to about 3 hours. A significant increase in trip times (7-8 hours) during the late hours of the day was observed.

Similar conclusions can be reached for the average weekend trip times (Figure 28) as the corresponding patterns were approximately the same.

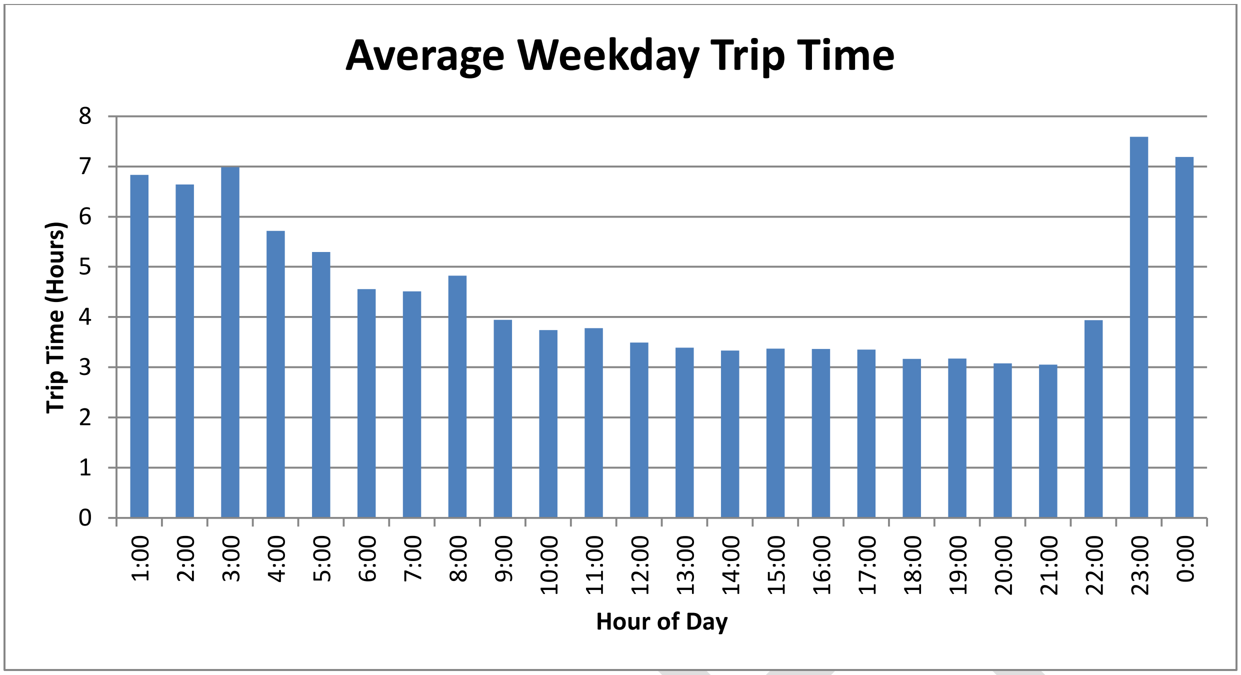


Figure 27: Average Weekday Trip Time

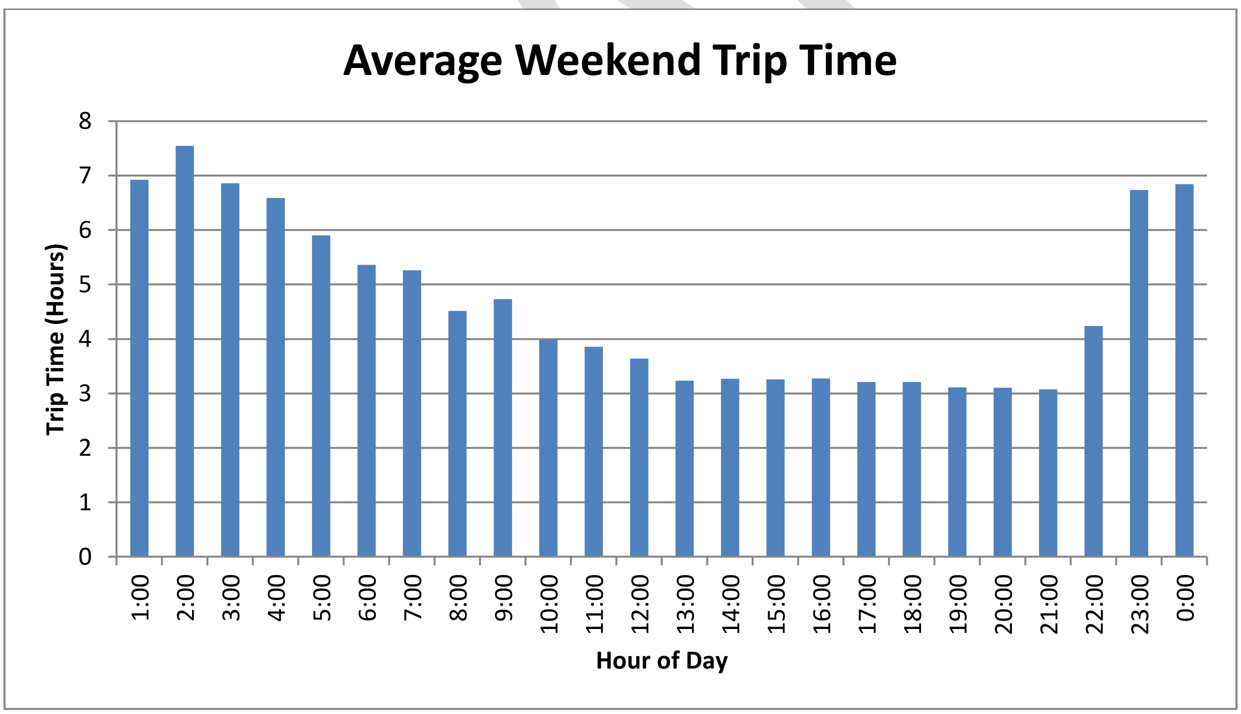


Figure 28: Average Weekend Trip Time

4.3 HOS Rules - Congestion Impact

New HOS rules impact on congestion levels was identified by tracking the potential effects of additional trucks volumes on LOS. The results from a case study which were produced after modifying the suggested methodology of the HCM are presented in figures 29 to 32.

Additional trucks volumes were defined by analyzing the existing truck patterns and focused on the truck trips which were taking place during the early hours of Monday, between 1:00 and 5:00 a.m. These trips were considered to be more affected by new rules restrictions.

Considering the average trip times between Memphis and Nashville area, analysis focused on the potential impact of these additional truck volumes on traffic conditions during peak hour period from 7:00 to 10:00 a.m. Due to data limitation, different scenarios which corresponded to which proportion (proportions were considered on a 25% rates-base) of the additional trucks affected the case study road segment during specific time periods, were analyzed. In more details, the case study roadway link in our analysis could be affected by five different proportions of additional truck volumes (0, 25, 50, 75 and 100%) during the time period from 7:00 to 10:00 a.m. The basic alternative combinations which reflect the impact on LOS and congestions levels during a.m. peak period are presented through figures 29 to 32 (all the different permutations of additional truck rates and their corresponding effects on traffic conditions are included in the appendix report).

These graphs were developed after summarizing the results from 1944 different cases which corresponded to all the different combinations of parameters values. The value ranges of the different parameters are described as follows:

Dtot: is the directional split and refers to the directional distribution of total hourly volume (Values range: 40%-60%)

Dtr: is the directional split and refers to the directional distribution of trucks hourly volume (Values range: 40%-60%)

CF: is an adjustment factor and corresponded to the proportion of the total truck data population (Values range: 3%-8%)

PDT: is the percent of hourly AADT and refers to the corresponding daily traffic demand pattern (Values range: 5%-10%)

TPDT: is the truck percentage of TAADT and refers to the corresponding daily truck traffic demand pattern (Values range: 5%-10%)

The corresponding results from the analysis regarding the impact of new HOS rules on traffic conditions as described above are summarized in figures 29 to 32:

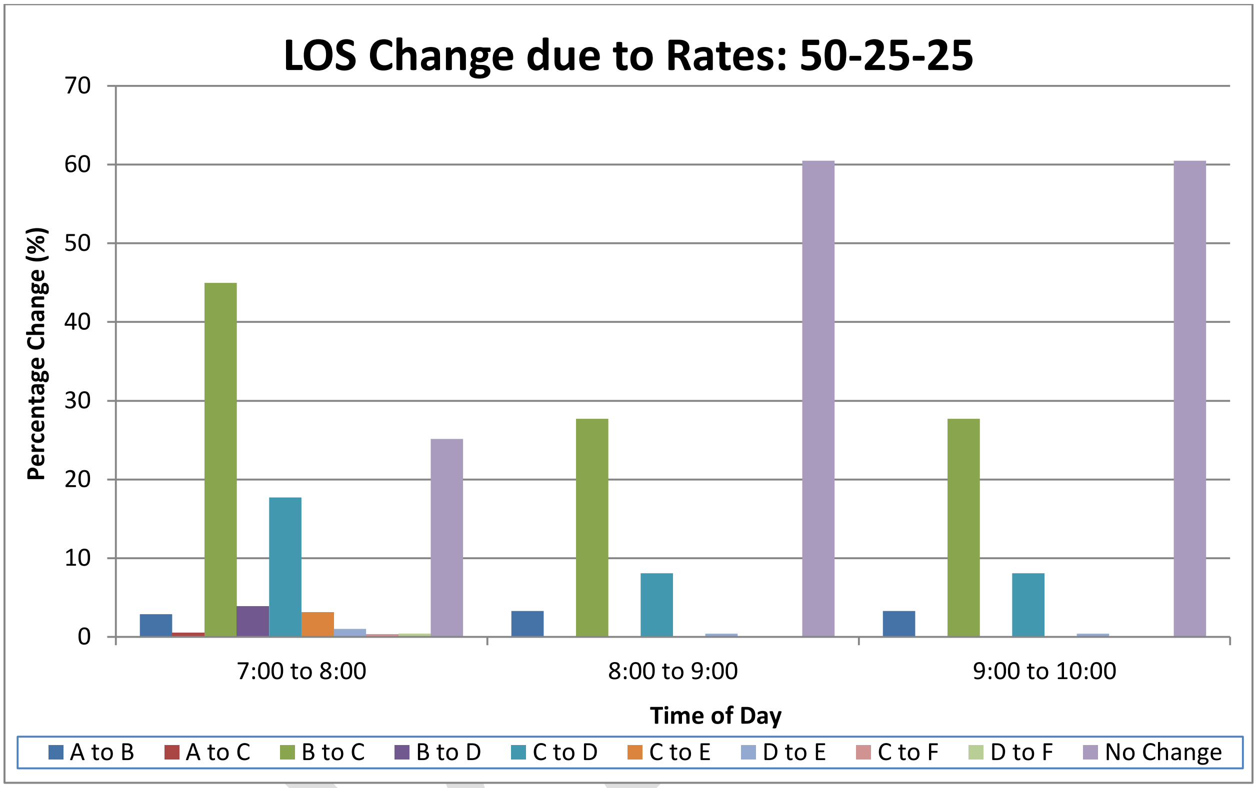


Figure 29: LOS Change due to Scenario 50-25-25

Figure 31 refers to the scenario 50-25-25 which describes the case where 50% of the additional trucks affect the case study link during 7:00 to 8:00 a.m., 25% from 8:00 to 9:00 a.m. and 25% from 9:00 to 10:00 a.m. Regarding the scenario where 25% of the additional truck volumes affect a specific link, it was found that in 60% of the cases LOS remained the same. However a notable negative impact on traffic conditions was identified as LOS was impaired in the rest of the cases. Especially, LOS was modified from level B to C in 28% and from C to D in 8% of the corresponding cases.

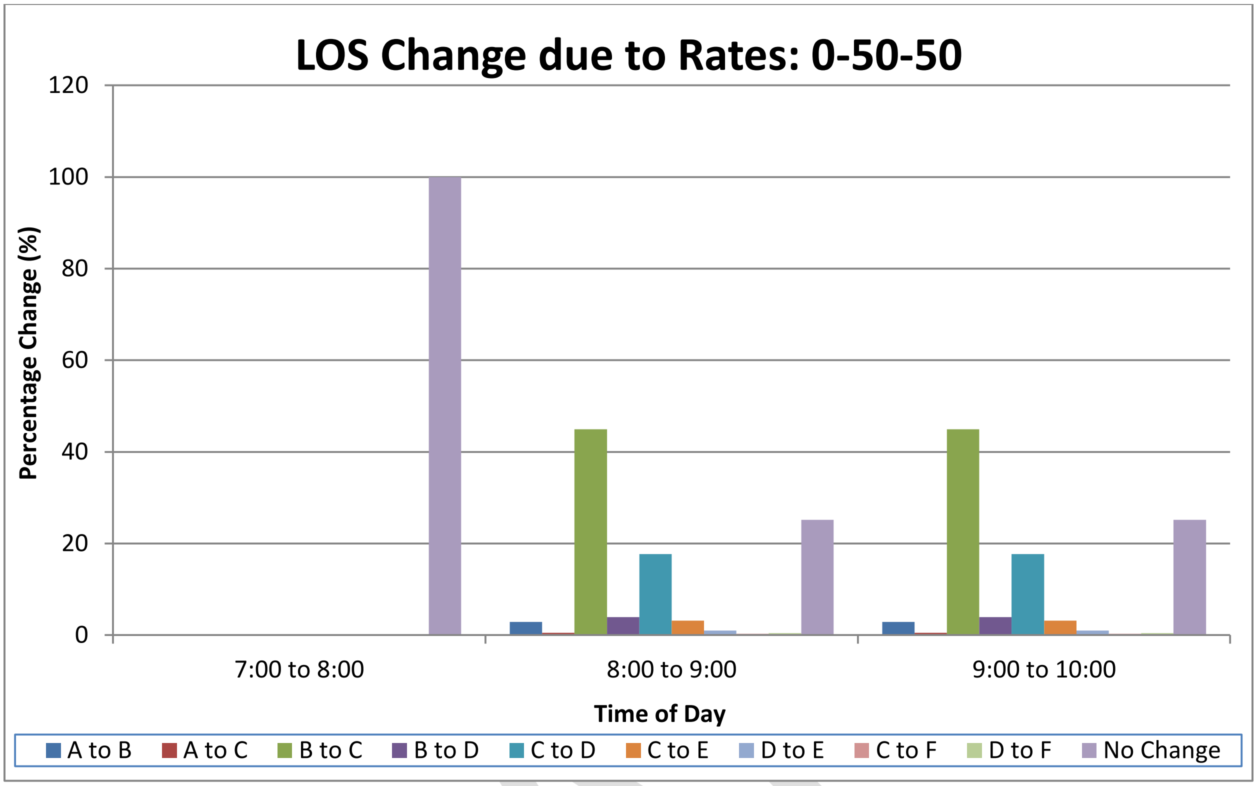


Figure 30: LOS Change due to Scenario 0-50-50

From Figure 29 and Figure 30 the impact of an additional 50% of trucks volumes during a specific time period is presented. These truck volumes would significantly affect traffic conditions and the corresponding congestion levels as LOS is worsened in many cases. In more details, analysis showed that a 50% increase in truck volumes resulted in a LOS modification from B to C in 45% of the cases while a worsening from LOS C to D in 18% of the cases was also observed. In approximately 3% of the cases, LOS changed from B to D and from C to E, something which revealed an even more intense negative impact.

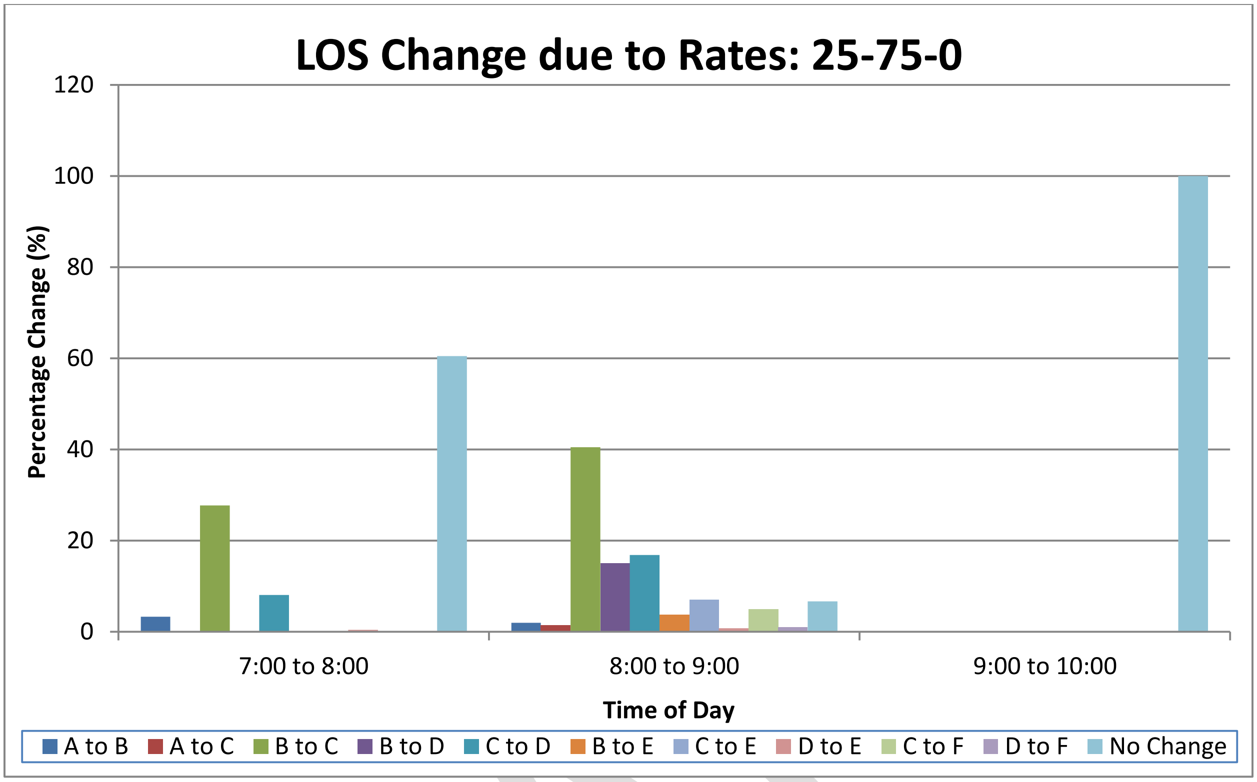


Figure 31: LOS Change due to Scenario 25-75-0

Figure 31 shows the significant impact on a link's traffic conditions if an additional 75% of trucks utilize this link during 8:00 to 9:00 a.m. The negative impact on traffic conditions is revealed through the fact that in almost 93% of the observations LOS worsened. Especially, in 40% of the analyzed cases LOS changed from B to C and in 17% of the cases from C to D. Additionally, 15% of the cases showed that LOS changed from B to D and a change from C to E by 7%.

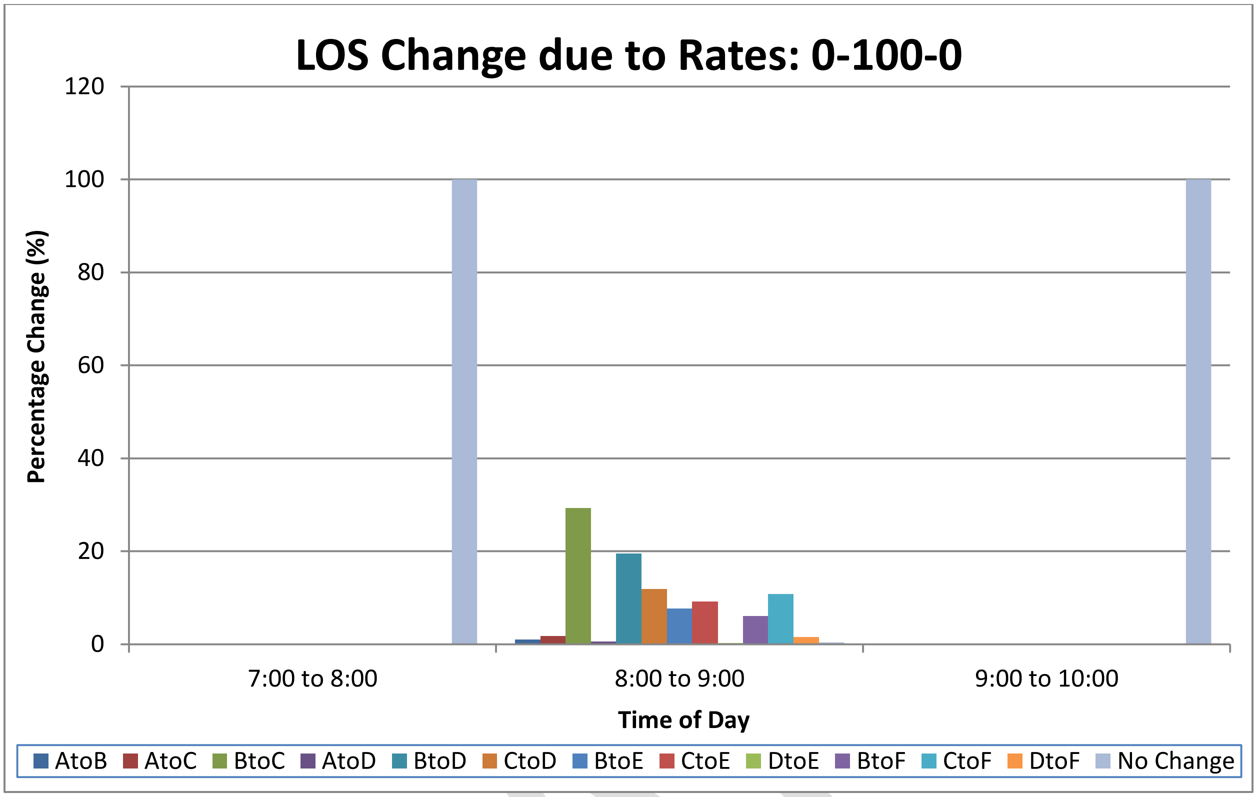


Figure 32: LOS Change due to Scenario 0-100-0

Error! Reference source not found. describes the worst case scenario where all the additional trucks affect a roadway segment during a specific time period, for example from 8:00 to 9:00 a.m. Traffic conditions and congestions levels on this link were highly affected as in almost 100% of the cases LOS became worse. In more details, in 30% of the cases LOS changed from B to C and in 20% from B to D. Other noticeable changes include a significant modification of the LOS from C to D in approximately 12% of the cases and from C to F in almost 11% of the cases.

5. CONCLUSIONS

Road safety has always been a constant issue for transportation agencies and authorities. Truck volumes and Commercial Motor Vehicles (CMV) in general can significantly increase crash rates due to the interaction of large vehicles with the rest of traffic. Driver fatigue has been identified as one of the major causes for truck-involved crashes.

Transportation authorities, in order to reduce driver fatigue levels and ensure efficient rest periods, regulated Hours of Service (HOS) rules for CMV drivers. HOS rules define the allowable working and driving hours along with the required corresponding rest periods and breaks. Recently, transportation agencies in order to improve road safety suggested an update of HOS rules. These new rules reduce the weekly allowable number of working hours and require additional night rest periods for CMV drivers.

However, new HOS regulation has created significant controversy among CMV drivers and the truck industry in general. The efficiency of new HOS rules is doubted and many concerns regarding the potential effects are expressed. Concerns focus on the potential impact on traffic conditions and mainly congestion levels during peak-hour periods due to the additional nights rest period provision.

The major objective of this research was to investigate the potential effects of the new HOS rules and model the corresponding impact on traffic conditions. Due to new rules, increased truck volumes were expected to utilize road networks during peak hour periods, which could significantly modify traffic conditions. Analysis focused on tracking the corresponding changes on the LOS of the related roadway segments as a measure of the potential impact on congestion levels.

Results from a case study indicated that new HOS regulation will significantly affect traffic conditions and consequently congestion levels. This was concluded as in the majority of the different cases that were analyzed, LOS which described traffic conditions on the case study link during peak hour periods was impaired. The levels of impact varied significantly depending on the proportion of the additional trucks which utilized a road link during specific time periods. However, a common fact was that all the different scenarios that were tested verified that traffic congestion will be negatively affected after applying new HOS rules.

6. ACKNOWLEDGEMENT

REFERENCES

Al-Kaisy, A., and Jung, Y., “Examining the Effect of Heavy Vehicles during Congestion Using Passenger Car Equivalents”. Proceedings 8th International Symposium on Heavy Vehicle Weights and Dimensions - Loads, Roads and the Information Highway, Johannesburg, South Africa (2004)

Altius Directory, “MATLAB Programming Language”. Retrieved 2010 (2010)

American Trucking Associations, “Federal Motor Carrier Safety Administration Responses to Questions Posed to Listening Session Participants Hours of Service of Drivers”. American Trucking Associations Inc. (2010)

Amundsen, A. H., and Sagberg, F., “Hours of Service Regulations and the Risk of Fatigue and Sleep-Related Road Accidents. A Literature Review”. Report, Institute of Transport Economics, Oslo, Norway (2003)

Arnold, P.K., Hartley, L.R., Cony, A., Hochstadt, D., Penna, F., and Freyer, A.M., “Hours of Work, and Perceptions of Fatigue among Truck Drivers”. Accident Analysis and Prevention, 29, pp. 471-477 (1997)

Aschauer, G., Flotzinger, C. W., and Starkl, F., “Time4trucks-Freight Transportation and Congestion Relationships in Urban Areas-Methodology Approach and Savings potentials”. Proceedings of the ITRN2011, University College Cork (2011)

Aschauer, G., Hofler, L., Starkl, F., and Keber, R., “Road Freight Transportation and Its Contribution to Congestion in City Regions Suggestions and Possibilities for Improvement”. European Transport Conference, 2010 Proceedings, Scotland, United Kingdom (2010)

Beilock, R., “Schedule-induced Hours-of-Service and Speed Limit Violations among Tractor-trailer Drivers”. Accident Analysis and Prevention, Vol. 27, No. 1, pp. 32–42 (1995)

Belzer, M. H., Fulton, G. A., Fulton, G. A., Grimes, D.R, Saltzman, G. M., Sedo, S., and Schmidt, L. G., “Proposed Changes in Motor Carrier Hours of Service Regulations: An Assessment”. Draft Report for Task under Contract No. DTFH61-96-C-00038, University of Michigan, Transportation Research Institute (2002)

Benstowe, S. J., “Long Driving Hours and Health of Truck Drivers”. Master Thesis, New Jersey Institute of Technology (2008)

Blanco, M., Hanowski, R. J., Olson, R. L., Morgan, J. F., Soccolich, S. A., Wu, S. and Guo, F., “The Impact of Driving, Non-Driving Work, and Rest Breaks on Driving Performance in Commercial Motor Vehicle Operations”. Final Report, RRR-11-017, FMCSA, U.S. Department of Transportation (2011)

Blanchard, D., "New Hours of Service Rules. Settle Nothing, Satisfy Nobody". Material Handling and Logistics, pp. 6-8 (2012)

Braver, E.R., Preusser C.W., Preusser, D.F., Baum, H.M., Beilock, R., and Ulmer, R. "Long Hours and Fatigue: A Survey of Tractor-Trailer Drivers". Journal of Public Health Policy, Vol. 13, No. 3, pp. 352 (1992)

Cambridge Systematics, "Freight Impacts on Ohio's Roadway System". Cambridge Systematics, Inc. (2002)

Cassidy, W. B., "Clock Ticks on Hours of Service". The Journal of Commerce, July 2010, pp. 23-24 (2010)

Clarke, K. C., "Advances in Geographic Information Systems, Computers, Environment and Urban Systems". Vol. 10, pp. 175–184 (1986)

Dick, V., Hendrix, J.W., and Knipling, R.R., "New Hours-of-Service Rules: Trucking Industry Reactions and Safety Outcomes". Transportation Research Record, No. 1966, pp. 103-109 (2006)

Edgeworth Economics, "Review of FMCSA'S Regulatory Impact Analysis for the 2010-2011 Hours of Service Rules". Prepared for the American Trucking Associations (2011)

Englert, B., and Lam, S., "The impact of Truck Repositioning on Congestion and Pollution in the L.A. Basin". Proposal to METRANS Transportation Center (2009)

Englert, B., and Lam, S., "The impact of Truck Repositioning on Congestion and Pollution in the L.A. Basin". Final Report, METRANS Project 10-26 (2011)

Federal Motor Carrier Safety Administration (FMCSA), "49 CFR Parts 350, 390, 394, 395 and 398 Hours of Service of Drivers; Driver Rest and Sleep for Safe Operations". Federal Register, Vol. 65, No. 85, pp. 25540-25611 (2000)

Federal Motor Carrier Safety Administration (FMCSA), "49 CFR Parts 385,386, 390, and 395 Hours of Service of Drivers," Federal Register, Vol. 76, No. 248, pp. 81134-81188 (2011)

Federal Motor Carrier Safety Administration (FMCSA) Analysis Division, "2010 – 2011 Hours of Service Rule Regulatory Impact Analysis". RIN 2126-AB26, FMCSA, Washington, DC (2010)

Fisk, C. S., "Effects of Heavy Traffic on Network Congestion". Transportation Research Part B: Methodological, Vol. 24, Issue 5, pp. 391-404 (1990)

Goel, A., "Truck Driver Scheduling and U.S. Hours of Service Regulations". Available at SSRN: http://ssrn.com/abstract=1407509 (2009)

Goel, A., “Vehicle Scheduling and Routing with Drivers’ Working Hours”. Transportation Science, Vol. 53, pp. 17-26 (2009)

Goel, A., and Gruhn, V., “Drivers’ Working Hours in Vehicle Routing and Scheduling”. Proceedings of the 9th IEEE International Conference on Intelligent transportation Systems, Toronto, Canada, pp. 1280-1285 (2006)

Goel, A. and Vidal, T., “Hours of Service Regulations in Road Freight Transport: An Optimization-based International Assessment”. Working Paper. Available at SSRN: http://dx.doi.org/10.2139/ssrn.2057556 (2012)

Grenzeback, L. R., Reily, W. R., Roberts P. O., and Stowers, J. R. “Urban Freeway Gridlock Study: Decreasing the Effects of Large Trucks on Peak-period Urban Freeway Congestion”. Transportation Research Record, No. 1256, pp. 16-26 (1990)

Griffin, G., Rodriguez, J., and Lantz, B., “Evaluation of the Impact of Changes in the Hours of Service Regulations on Efficiency, Drivers and Safety”. Upper Great Plains Transportation Institute, North Dakota State University, Publication No. 93 (1992)

Gron, S., “Six Reasons Why Hours of Service Regulations for Truck Drivers Are Violated”. Safety Science Monitor, Issue 2, Vol. 13 (2009)

Hackman, K. D., Larson, E. E., Shinder, A. E., “Analysis of Accident Data and Hours of Service of Interstate Commercial Motor Vehicle Drivers”. Final Report, Bureau of Motor Carrier Safety, Washington, D.C. (1978)

Haldane, M. J., and Bunker, J. M., “Examining the Impact of Large Freight Vehicles on Signalized Intersection Operation”. AITPM National Conference-2002-Travelator, Perth (2002)

Hall, R. W., and Mukherjee, A., “Bounds on Effectiveness of Driver Hours-of-Service Regulations for Freight Motor Carriers”. Transportation Research Part E: Logistics and Transportation Review, Vol. 44, pp. 298–312 (2008)

Hanowski, R.J., Hickman, J., Fumero, M.C., Olson, R.L., Dingus, T.A, “The Sleep of Commercial Vehicle Drivers under the 2003 Hours-of-Service Regulations”. Accident Analysis and Prevention 39 (6), pp. 1140–1145 (2007)

Hanowski, R.J., Olson, R.L., Bocanegra, J., Hickman, J.S., “Analysis of Risk as a Function of Driving-Hour: Assessment of Driving Hours 1 Through 11. Report No. FMCSA RRR-08-002. Federal Motor Carrier and Safety Administration, USDOT, Washington, DC. (2008)

Harris, G., and Anderson, M., “Modeling Truck Traffic Volume Growth Congestion”. UTCA Report Number 07304, University Transportation Center for Alabama (2009)

Harris, W., and Mackie, R.R., “A Study of the Relationships among Fatigue Hours of Service, and Safety of Operations of Truck and Bus Drivers”. Final Report, BMCS RD 71-2, Washington: U.S. Department of Transportation, Federal Highway Administration, Bureau of Motor Carrier Safety (1972)

Heaton, K., “Truck Driver Hours of Service Regulations: The Collision of Policy and Public Health”. Policy Politics Nursing Practice, Vol. 6, No. 4, pp. 277-284 (2005)

Jasny, H., “Reform of the Truck Driver Hours of Service Rule Is Essential for Highway Safety”. Advocates for Highway and Auto Safety, Testimony of Henry Jasny: Subcommittee on Regulatory Affairs, Stimulus Oversight and Government Spending (2011)

Jensen, A. and Dahl, S., “Truck Drivers Hours-of-Service Regulations and Occupational Health”. Work: A Journal of Prevention, Assessment and Rehabilitation, Vol. 33, No. 3, pp. 363-368 (2009)

Jones, C. B., Dorrian, J., S.M.W. Rajaratnam, and D. Dawson, “Working Hours Regulations and Fatigue in Transportation: A Comparative Analysis”. Safety Science, Vol. 43, pp. 225-252 (2005)

Jones, I.S., and Stein, H.S., “Effect of Driver Hours of Service on Tractor-Trailer Crash Involvement”. Washington, D.C.: Insurance Institute for Highway Safety (1987)

Jovanis, P.P., Wu, K.F., and Chen, C., “Hours of Service and Driver Fatigue: Driver Characteristic Research”. Washington, DC: Federal Motor Carrier Safety Administration, FMCSA-RRR-11-018 (2011)

Jovanis, P.P., Park, S.W., Chen, K.Y., and Gross. F., “On the Relationship of Crash Risk and Driver Hours of Service”. 2005 International Truck and Bus Safety and Security Symposium, Alexandria, Virginia (2005)

Knipling, R. R., “Peer Review Critique of Penn State Study: Hours of Service and Driver Fatigue: Driver Characteristics Research”. Prepared for the American Trucking Associations and Submitted to FMCSA HOS Docket FMCSA-2004-19608 (2011)

Knipling, R. R., “Peer Review Critique of VTTI Study: The Impact of Driving, Non-Driving Work, and Rest Breaks on Driving Performance in Commercial Motor Vehicle Operations”. Prepared for the American Trucking Associations and Submitted to FMCSA HOS Rulemaking Docket FMCSA-2004-19608 (2011)

Kockelman, K. and Shabih, R., “Effect of Light-Duty Trucks on the Capacity of Signalized Intersections”. Journal of Transportation Engineering, Vol. 126(6), pp. 506–512 (2000)

Lake, M., Ferreira, L. and Stewart, D., “The Effect of Multi-Combination Vehicles in Urban Traffic”. In: L. Sucharov and C.A. Brebbia Urban Transport and the Environment VIII. (Eds), pp. 233-244, Wessex Institute of Technology Press (2002)

Lin, T. D, Jovanis P.P., Yang C.Z., “Modeling the Effect of Driver Service Hours on Motor Carrier Accident Risk Using Time Dependent Logistic Regression”. Transportation Research Record 1407, Transportation Research Board, Washington, D.C., pp. 1-10 (1993)

McCartt, A.T., Hellinga, L.A., and Solomon, M. G., “Survey of Long-Distance Truck Drivers: Work Schedules before and after Hours-of-Service Rule Change in 2004”.Preliminary Report, Arlington, VA: Insurance Institute for Highway Safety. (2005)

McCartt, A.T., Hellinga, L.A., and Solomon, M. G., “Survey of Long-Distance Truck Drivers: Work Schedules before and after Hours-of-Service Rule Change in 2004”. Arlington, VA: Insurance Institute for Highway Safety. (2008)

Mackie, R.R, and Miller, J.C., “Effects of Hours of Service, Regularity of Schedules, and Cargo Loading on Truck and Bus Driver Fatigue”. Human Factor Research, pp. 229-234 (1978)

Maier-Speredelozzi, V., “the Impact of Truck Drivers Hours-of-Service regulations on Retail Warehouse Operations”. Prepared for the University of Rhode Island Transportation Center, Draft Report, URITC Project No.53000466 (2006)

Min, H., “Building a Model-Based Decision Support System for Solving Vehicle Routing and Driver Scheduling Problems under Hours of Service Regulations”. Final Report (2011)

Min, H., “Combined Truck Routing and Driver Scheduling Problems under Hours of Service Regulations”. Final Report, Bowling Green State University (2009)

Min, H., “The Impact of Hours-of-Service Regulations on Transportation Productivity and Safety: A Summary of Findings from the Literature”. Journal of Transportation Management, 21(2), pp. 49-64 (2009)

Moler, C., “The Origins of MATLAB”. MATLAB News & Notes (2004)

Monaco, K. and Willmert, J., "Wages and Hours of Truck Drivers: An Analysis across Data Sets". Journal of the Transportation Research Forum, Published in Transportation Quarterly, Vol. 57, No. 3, pp.167-177 (2003)

Mukherjee, A., Hall, R. W., "Cost Benefit Analysis of Driver Hours of Service Regulations for Long-Haul LTL Carriers". Metrans Center, University of Southern California Los Angeles (2005)

Mukherjee, A., Hall, R. W., and Shen, Z., "Bounds on Effectiveness, Cost and Benefits of Driver Hours of Service Regulations for Freight Carriers". Final Report, Metrans Project 05-10 (2006)

National Research Council, "Highway Capacity Manual". HCM2000, US Customary Units, Transportation Research Board, National Research Council, Washington D.C. (2000)

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

Park, S-W, and Jovanis, P.P., "Hours of Service and Truck Crash Risk: Findings from 3 National U.S. Carriers during 2004". Journal of the Transportation Research Board No. 2194, pp. 3–10 (2010)

Parker, J., "Resetting the Clock. New Hours-of-Service Rules for Truckers Will Raise Costs". The Journal of Commerce, Special Report Intermodal Transportation, pp. 26-30 (2003)

Ramsay, E. D., Bunker, J. M., and Bruzsa, L., "Management of Traffic-Related Effects of Heavy Vehicles on Urban Freight Corridors". In Proceedings 9th International Symposium on Heavy Vehicle Weights and Dimensions, Pennsylvania State University, Pennsylvania, United States (2006)

Rancourt, M. E., Cordeau, J. F., and Laporte, G., "Long-Haul Vehicle Routing and Scheduling with Working Hour Rules". CIRRELT (2010)

Robbin-Vergeer, B. I., "Hours-of-Service: Missed Opportunities, Illegal Shortcuts". Journal of Transportation Law, Logistics and Policy (2007)

Ross, J., "ATA Requests Hours of Service Compliance Delay". American Shipper (2013)

Saltzman, G. M., and Belzer, M. H., "The Case for Strengthened Motor Carrier Hours of Service Regulations". Transportation Journal, Vol. 41, No. 4, pp. 51-71 (2002)

Scribner, M., “In the Matter of Proposed Rulemaking on Hours of Service”. Comments of the Competitive Enterprise Institute and Submitted to Docket No. FMCSA 2004-19608 (2011)

Shah, V.D., “Time Dependent Truck Routing and Driver Scheduling Problem with Hours of Service Regulations. Operation Research Master’s Theses, Northeastern University (2008)

Smiley, A., and Heslegrave, R. J., “A 36-Hour Recovery Period for Truck Drivers: Synopsis of Current Scientific Knowledge”. Transport Canada Publication No. TP 13035E, p. 90 (1997)

Soccolich, S. A., Blanco, M., Hanowski, R. J., Olson, R. L., Morgan, J. F., Guo, F., and Wu, S., “An Analysis of Driving and Working Hour on Commercial Motor Vehicle Driver Safety Using Naturalistic Data Collection”. Accident Analysis and Prevention (2012)

Tomlinson, R., “GIS Hall of Fame – Roger Tomlinson". URISA. Retrieved 2007-06-09

U.S Department of Transportation (USDOT), “Weight of Shipments by Transportation Mode: 2007, 2011, and 2040”. Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework, version 3.4 (2012)

U.S Department of Transportation (USDOT), “Value of Shipments by Transportation Mode: 2007, 2011, and 2040”. Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework, version 3.4 (2012)

U.S Department of Transportation (USDOT), “Traffic Safety Facts, 2010 Data”. National Highway Traffic Safety Administration, National Center for Statistics and Analysis (2012)

U.S Department of Transportation (USDOT), “Summary of HOS Regulations”. Federal Motor Carrier Safety Administration (2013)

U.S Department of Transportation (USDOT), “Summary of changes of HOS Final Rule Published in December 2011”. Federal Motor Carrier Safety Administration (2013)

U.S Department of Transportation (USDOT), “Who Must Comply”. Federal Motor Carrier Safety Administration (2013)

Vierth, I., Bereel, H., McDaniel, J., Haraldsson, M., Hammarstrom, U., Yahya, M. R., Lindberg, G., Carlsson, A., Ogren, M., and Bjorketun, U., “The Effects of Long and Heavy Trucks on the Transport System. Report on a Government Assignment Project”. Long and Heavy Vehicle Combinations, VTI Rapport 605A, VTI, Sweden (2008)

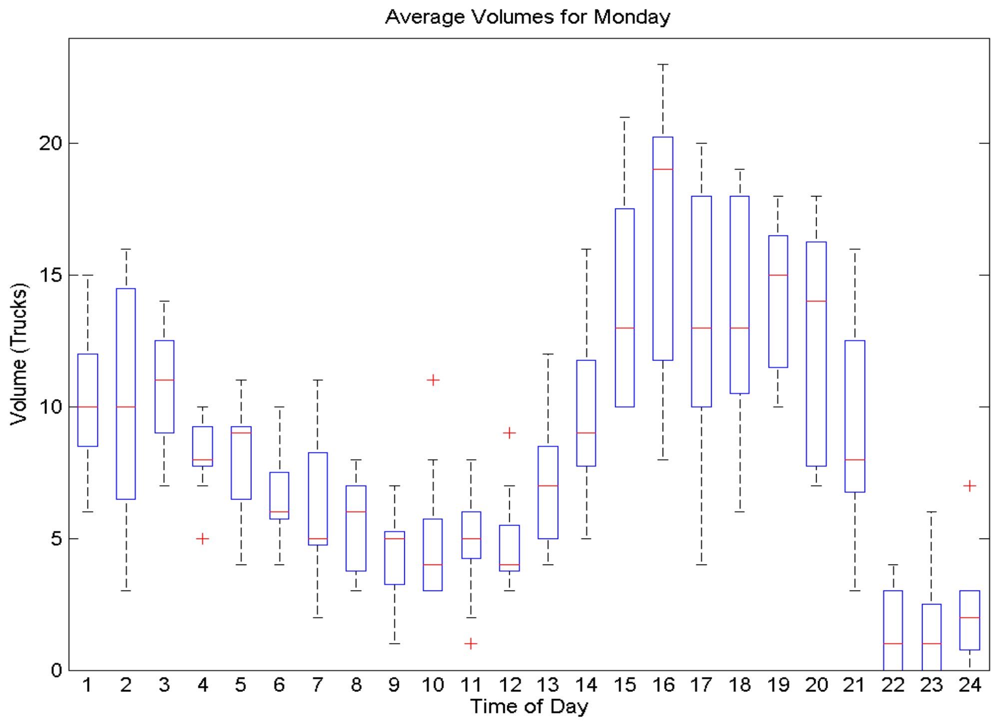
Washburn, S. S., and Cruz-Casas, C. O., “Impact of Trucks on Arterial LOS and Freeway Work Capacity (Part A)”. Final Report to the Florida Department of Transportation Systems Planning Office, UF Project 00054954, University of Florida Transportation Research Center, (2007)

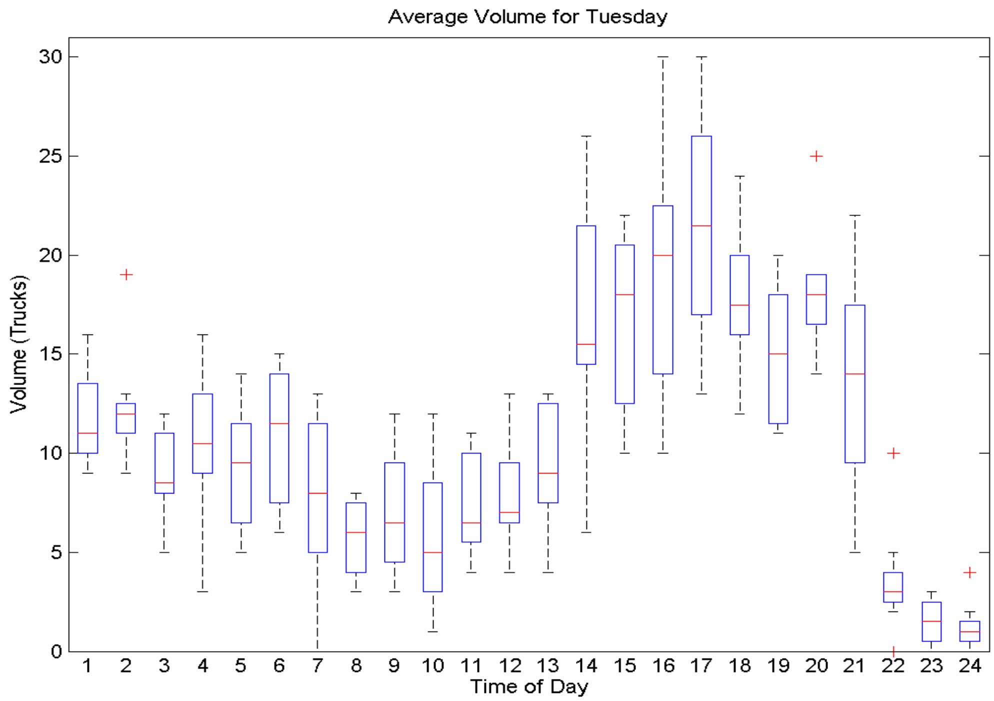
Williams, E., and Monaco, K., “Accidents and Hours-of-Service Violations among Over-the-Road Drivers”. Journal of the Transportation research Forum, Vol. 40, No. 1, pp. 105-115 (2001)

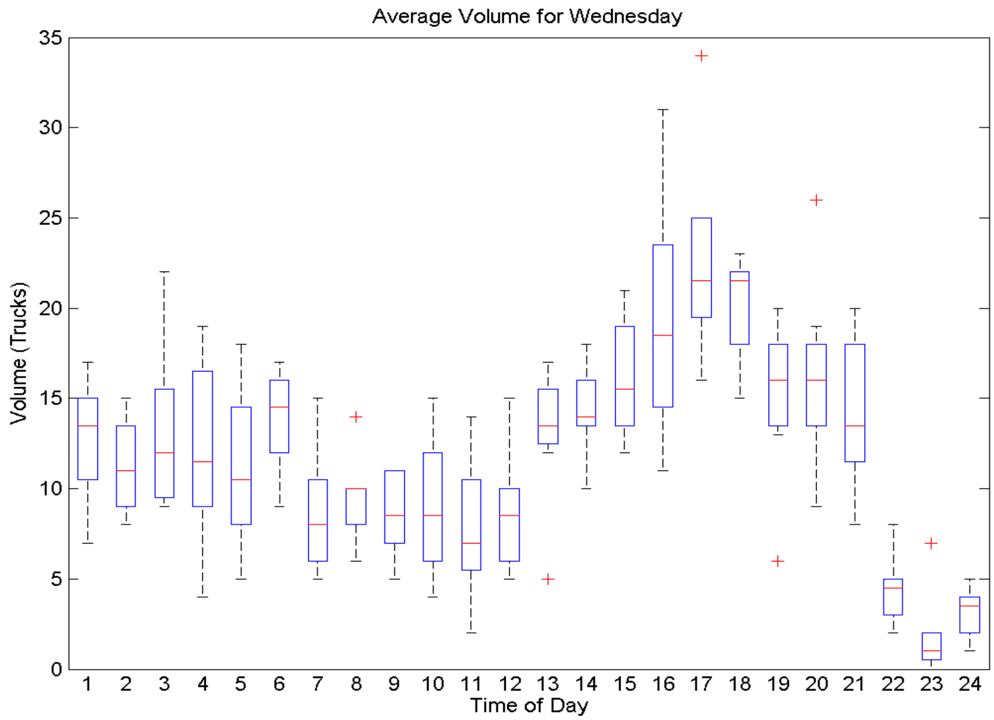
Wislocki, J., “New Hours Equal More Gridlock?”. Transport Topics, No. 3381, pp. 36 (2000)

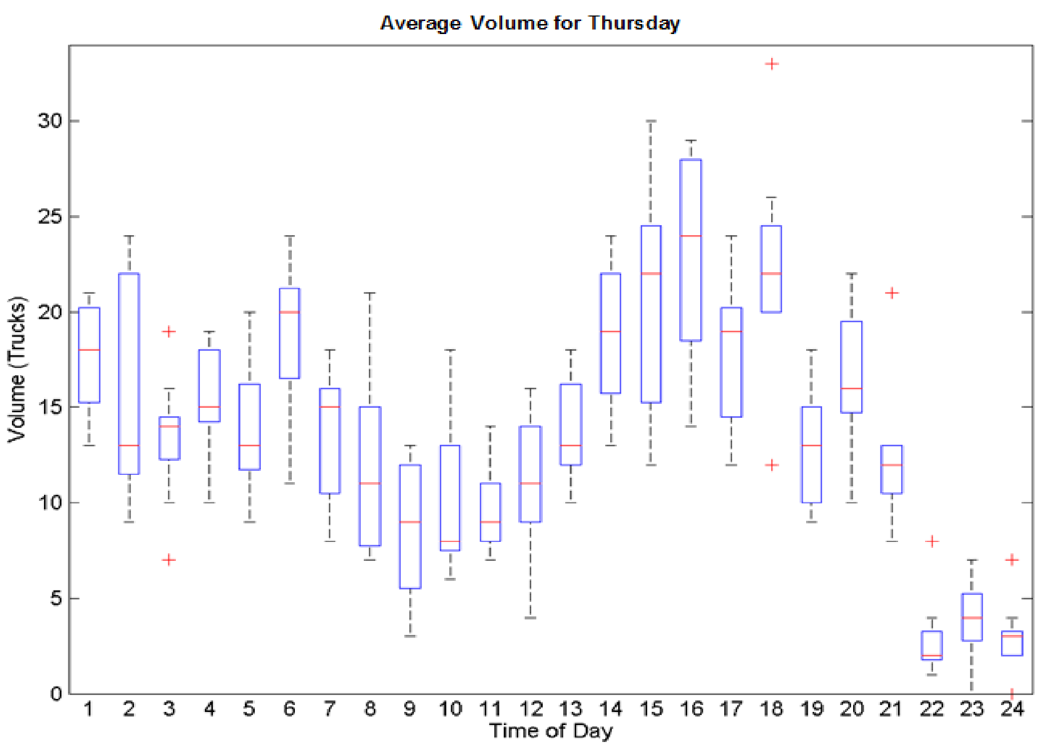
Wu, K., and Jovanis, P., “Effect of Driving Breaks and 34-Hour Recovery Period on Motor Carrier Crash Odds”. Driving Assessment 2011: 6th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design, pp. 606-613 (2011)

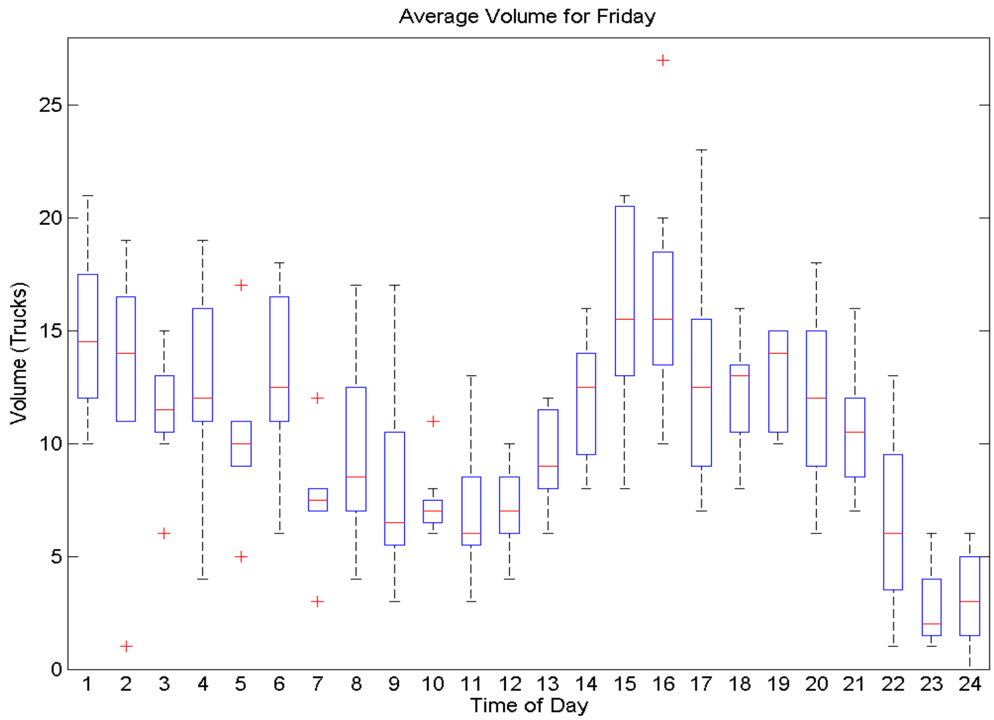
APPENDIX A. Truck Volumes Boxplots

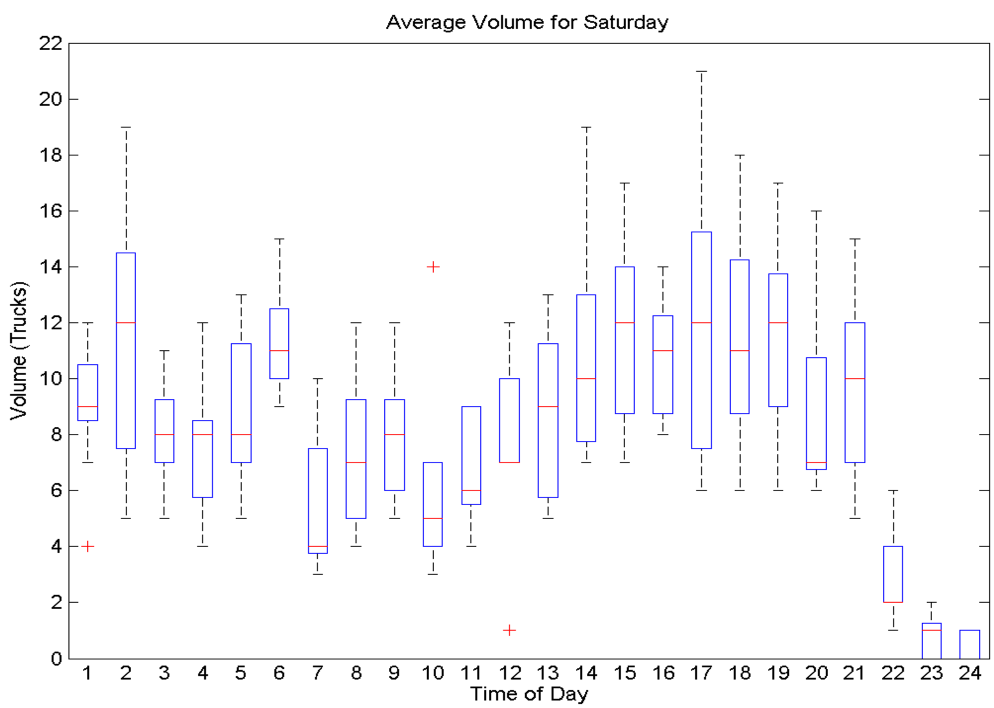


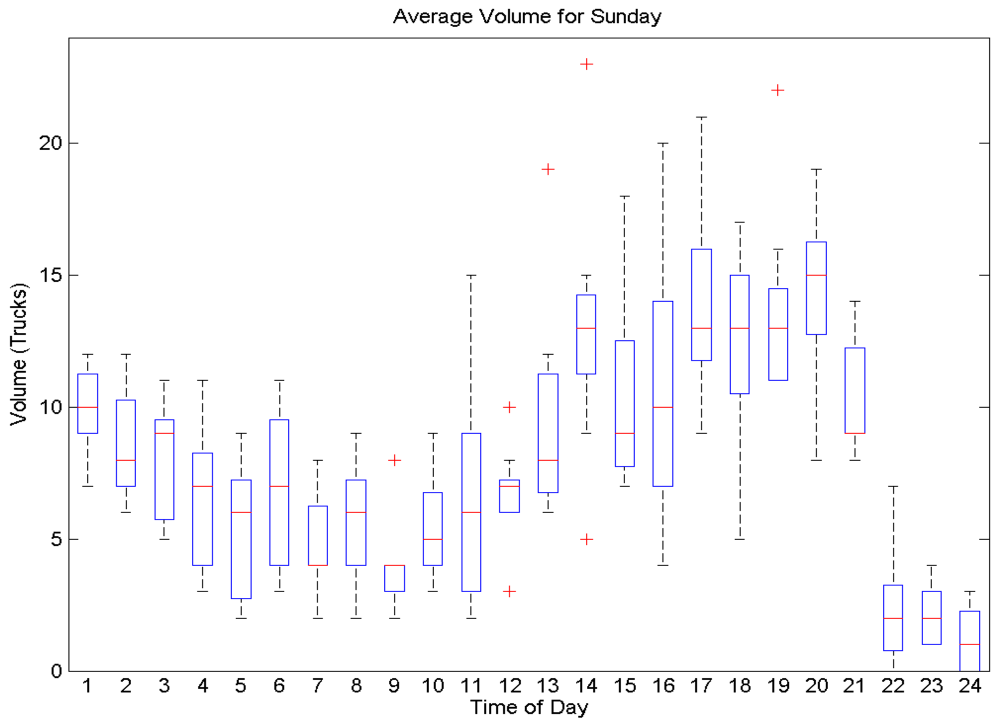


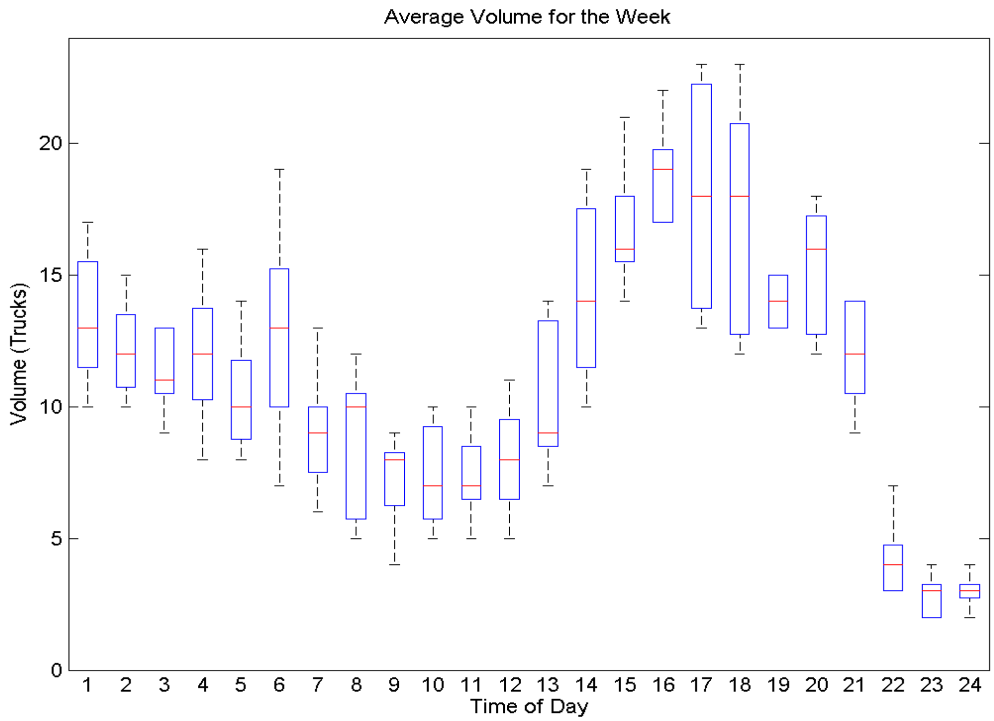

Average Volume for Wednesday
Volume (Trucks)
0
5
10
15
20
25
30
35
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time of Day

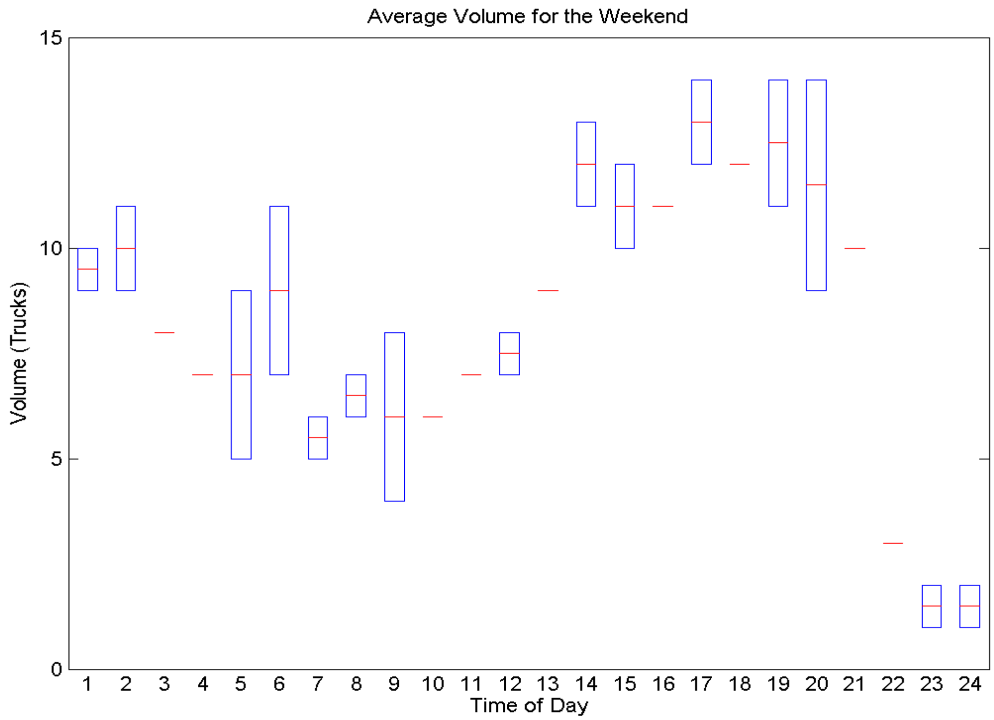

Average Volume for Thursday
Volume (Trucks)
0
5
10
15
20
25
30
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time of Day


Average Volume for Friday
Volume (Trucks)
0
5
10
15
20
25
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time of Day

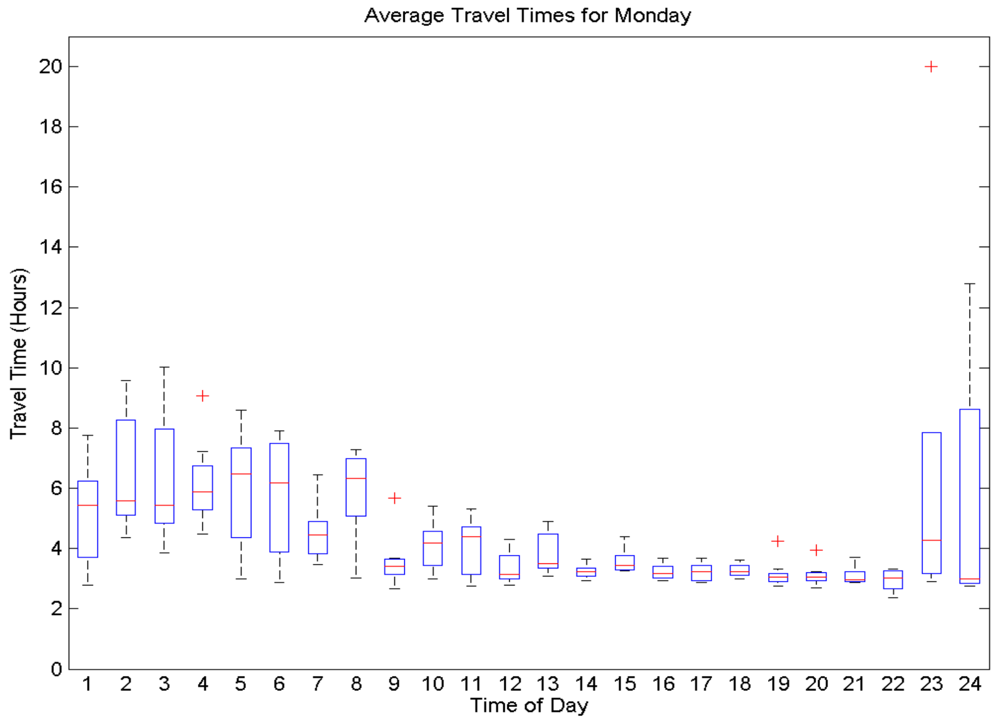

Average Volume for Saturday
Volume (Trucks)
0
2
4
6
8
10
12
14
16
18
20
22
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time of Day

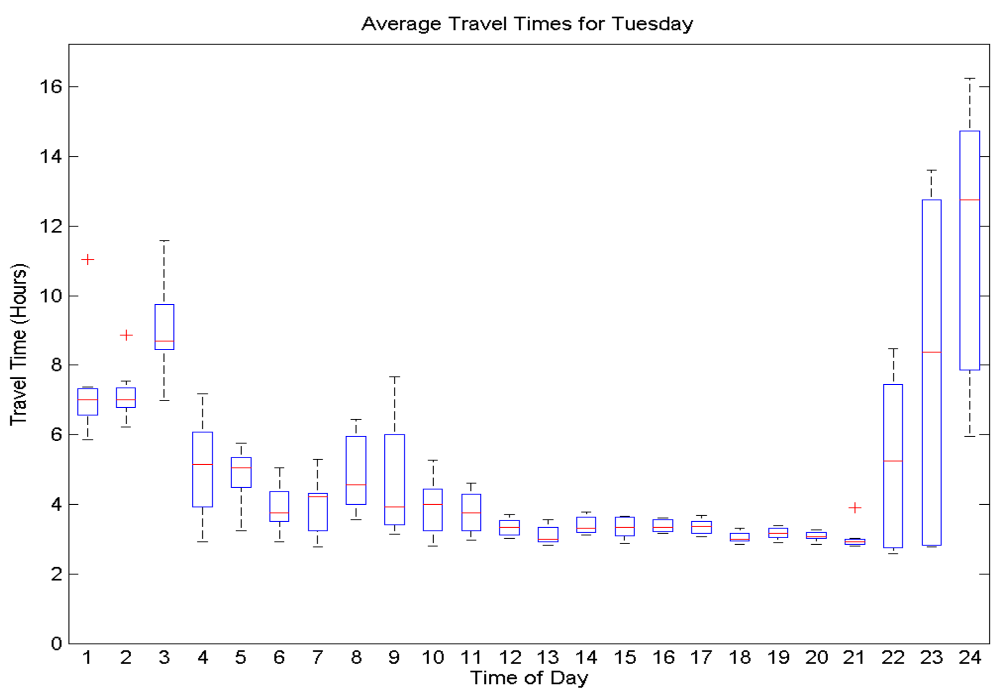

Average Volume for Sunday
Volume (Trucks)
0
5
10
15
20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time of Day

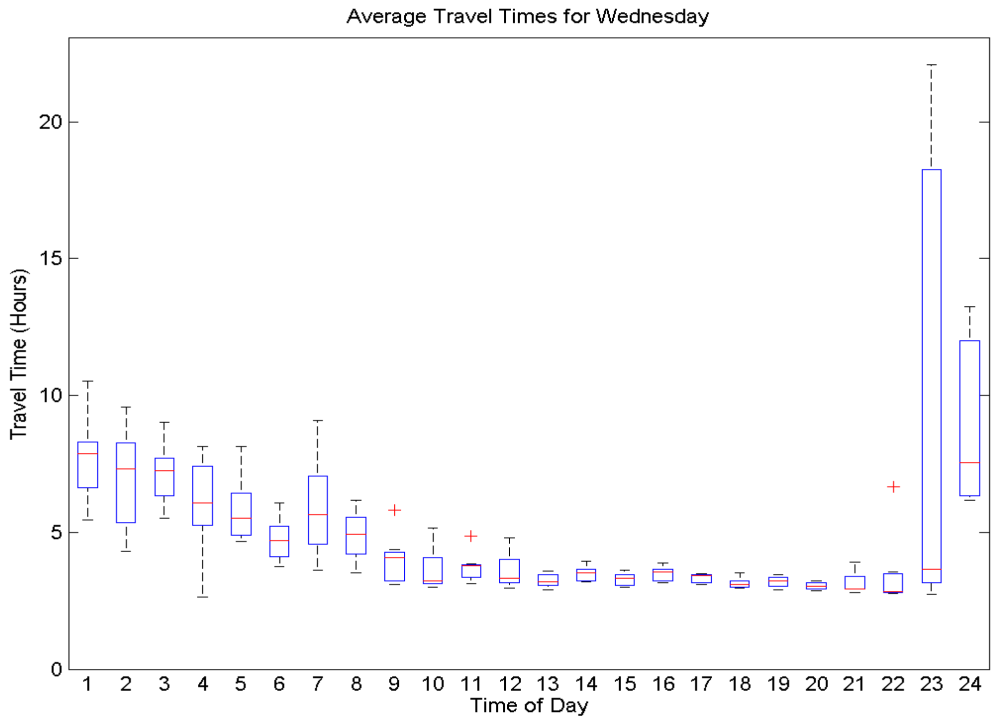

Average Volume for the Week
Volume (Trucks)
0
5
10
15
20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time of Day

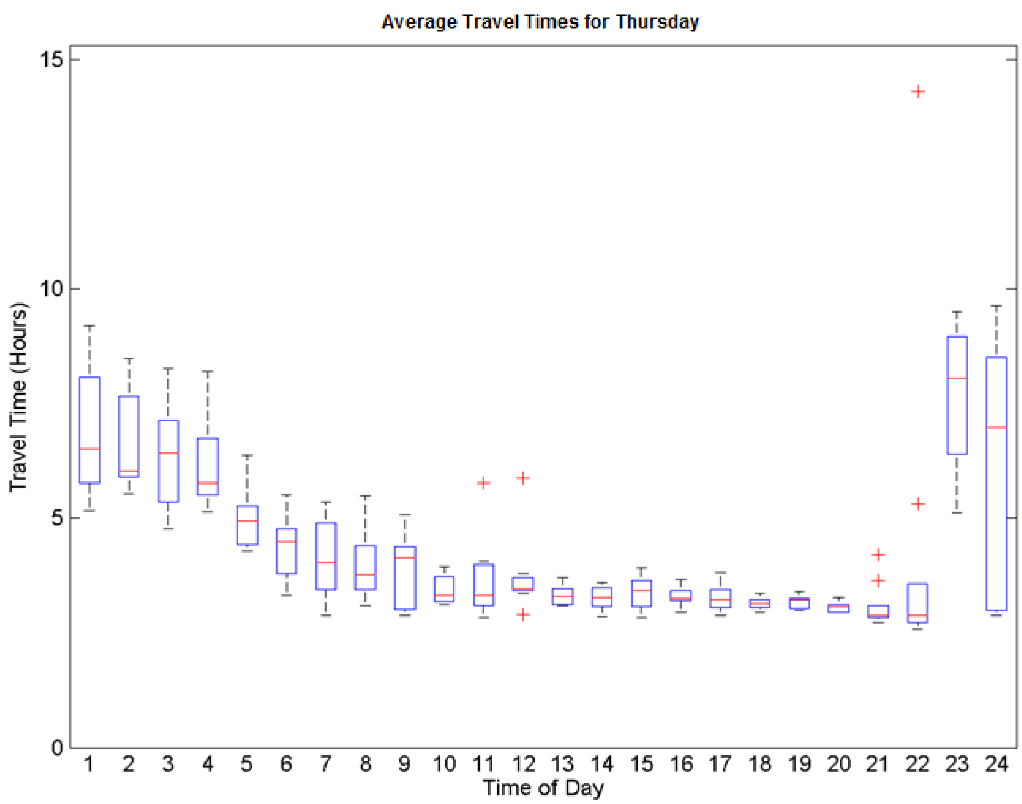

Average Volume for the Weekend
Volume (Trucks)
0
5
10
15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time of Day

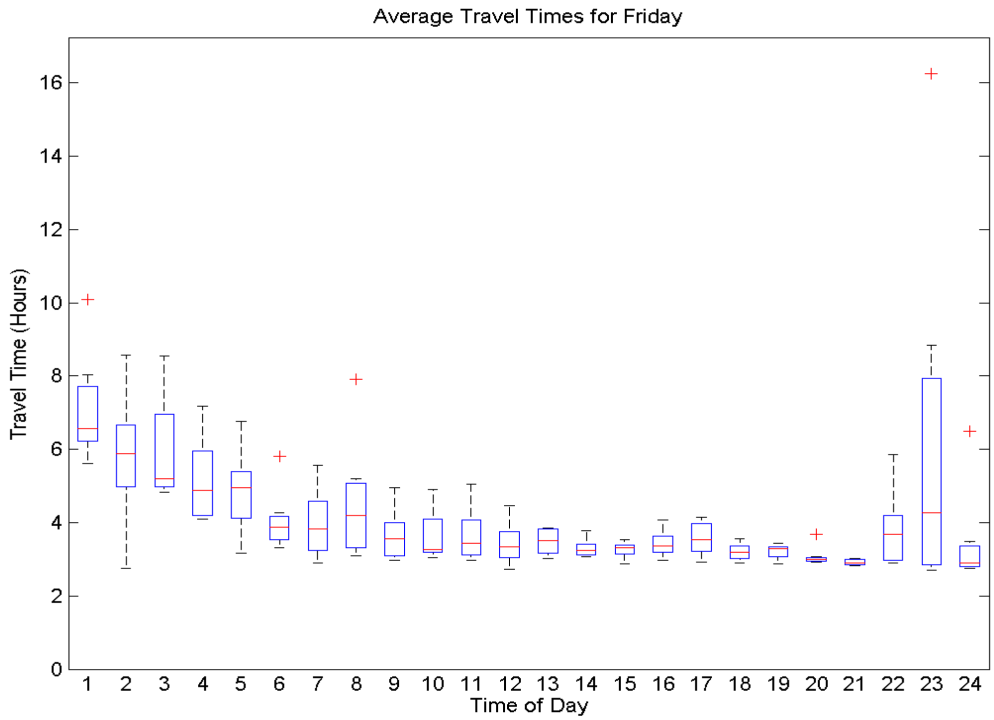
APPENDIX B. Trip Time Boxplots

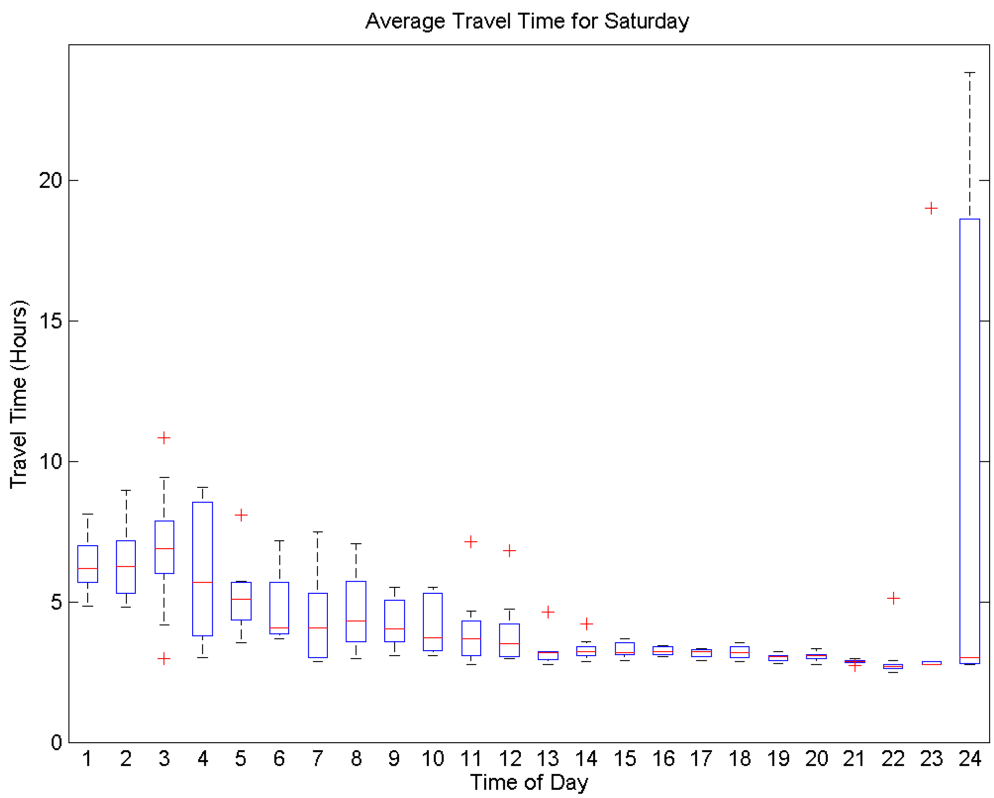


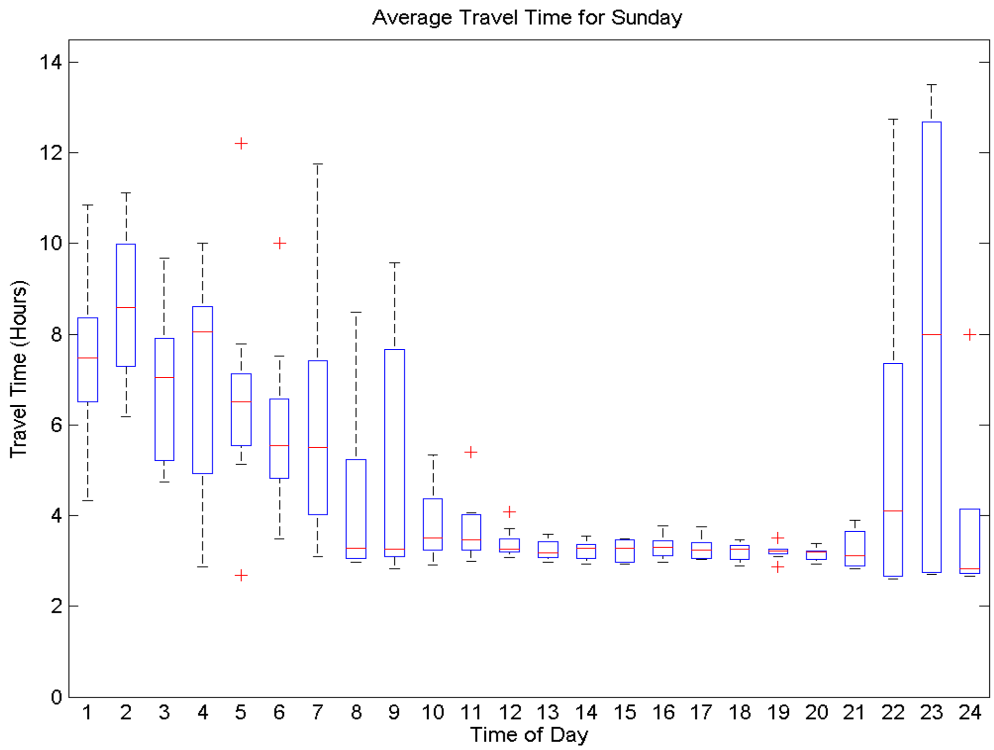


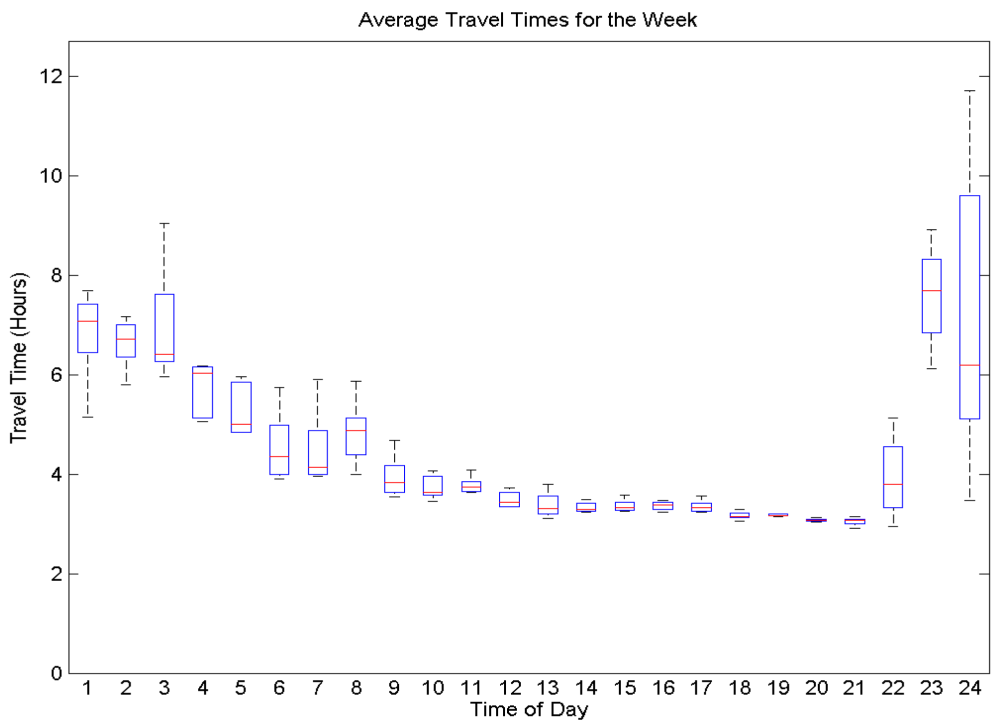

Average Travel Times for Wednesday
Travel Time (Hours)
0
5
10
15
20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time of Day

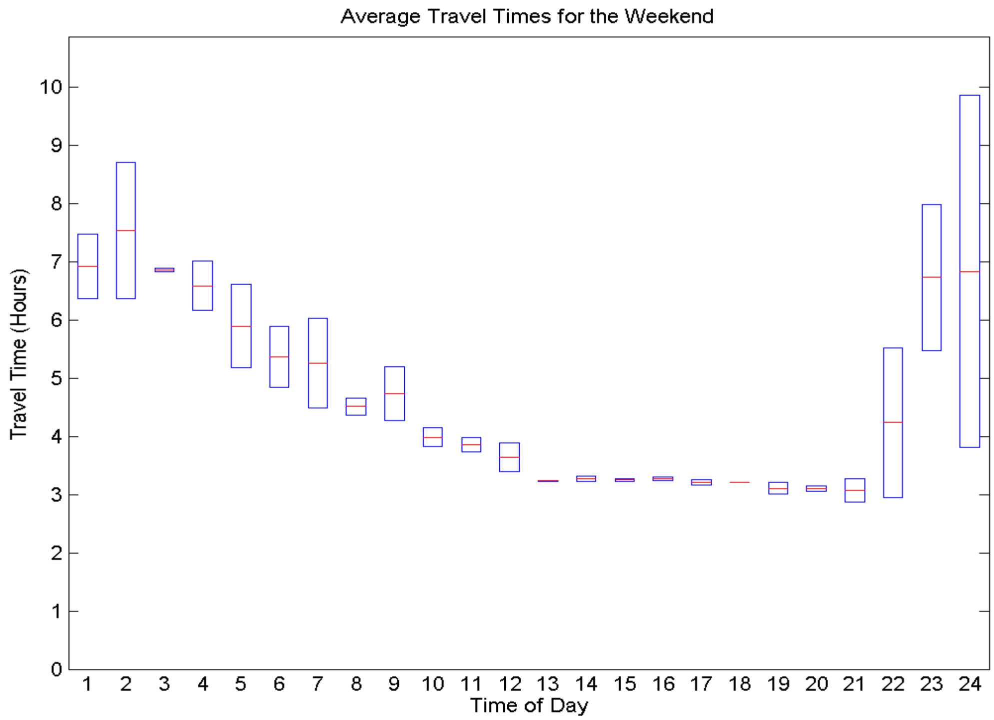

Average Travel Times for Thursday
Travel Time (Hours)
0
5
10
15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time of Day


Average Travel Times for Friday
Travel Time (Hours)
0
2
4
6
8
10
12
14
16
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time of Day

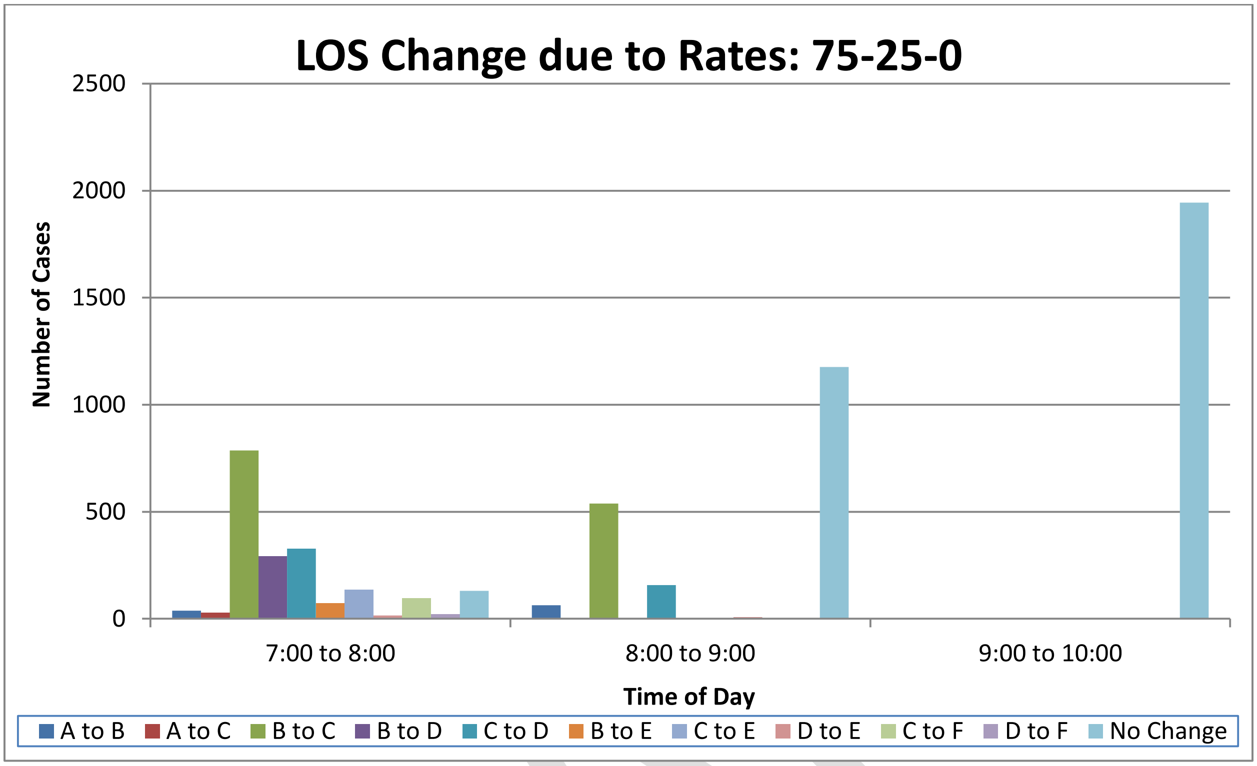

Average Travel Time for Saturday
Travel Time (Hours)
0
5
10
15
20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time of Day

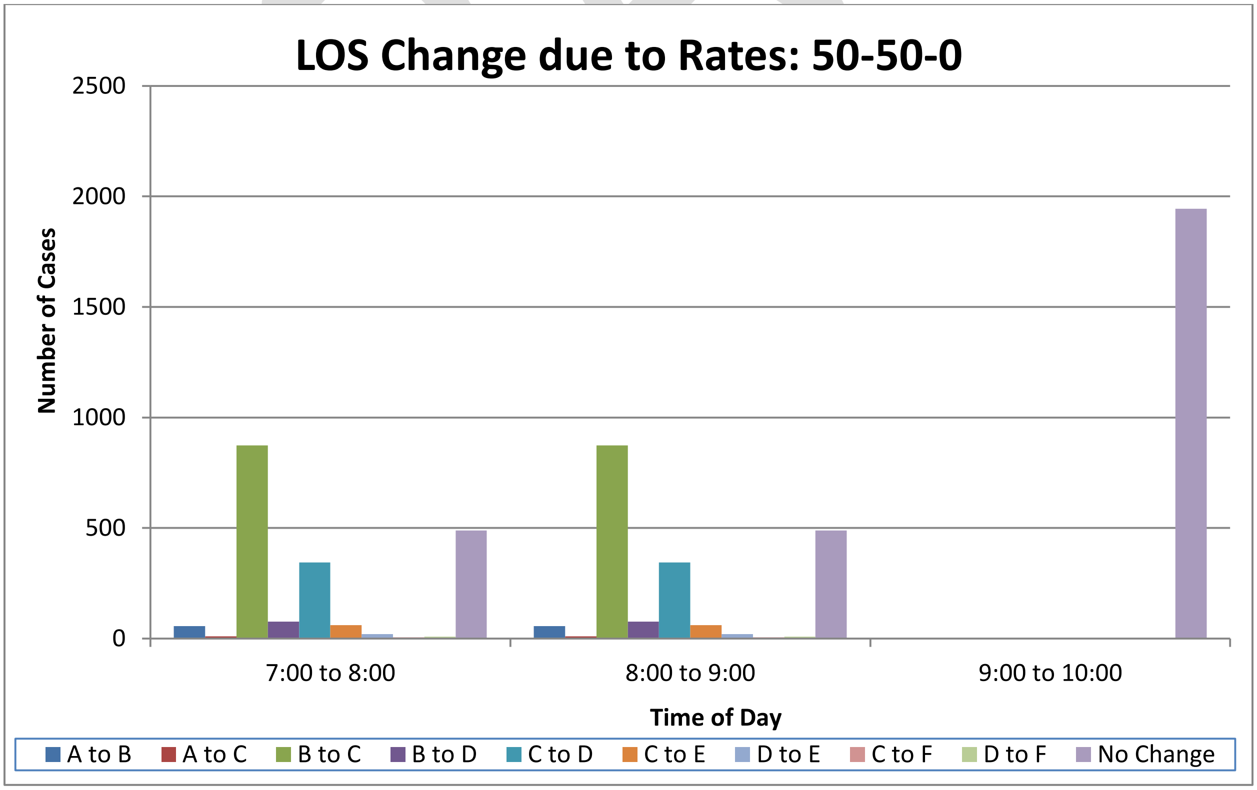

Average Travel Time for Sunday
Travel Time (Hours)
0
2
4
6
8
10
12
14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time of Day

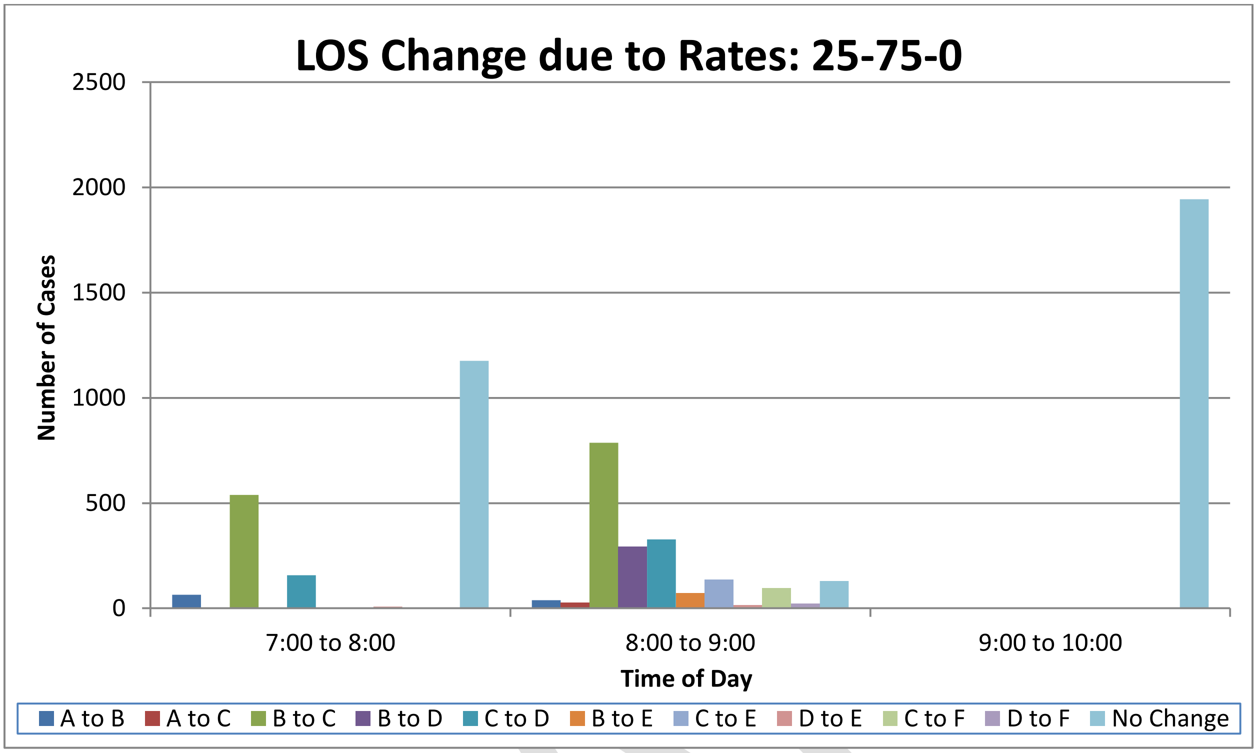

Average Travel Times for the Week
Travel Time (Hours)
0
2
4
6
8
10
12
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time of Day

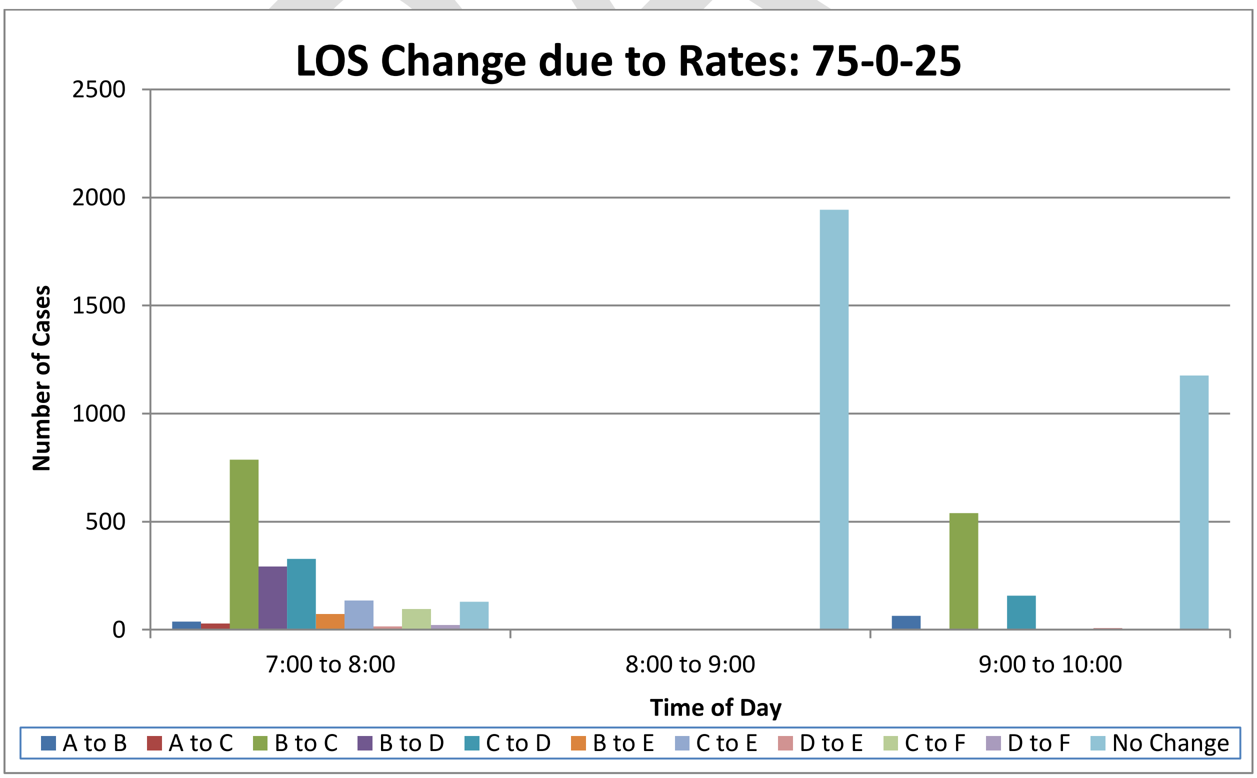

Average Travel Times for the Weekend
Travel Time (Hours)
0
1
2
3
4
5
6
7
8
9
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time of Day

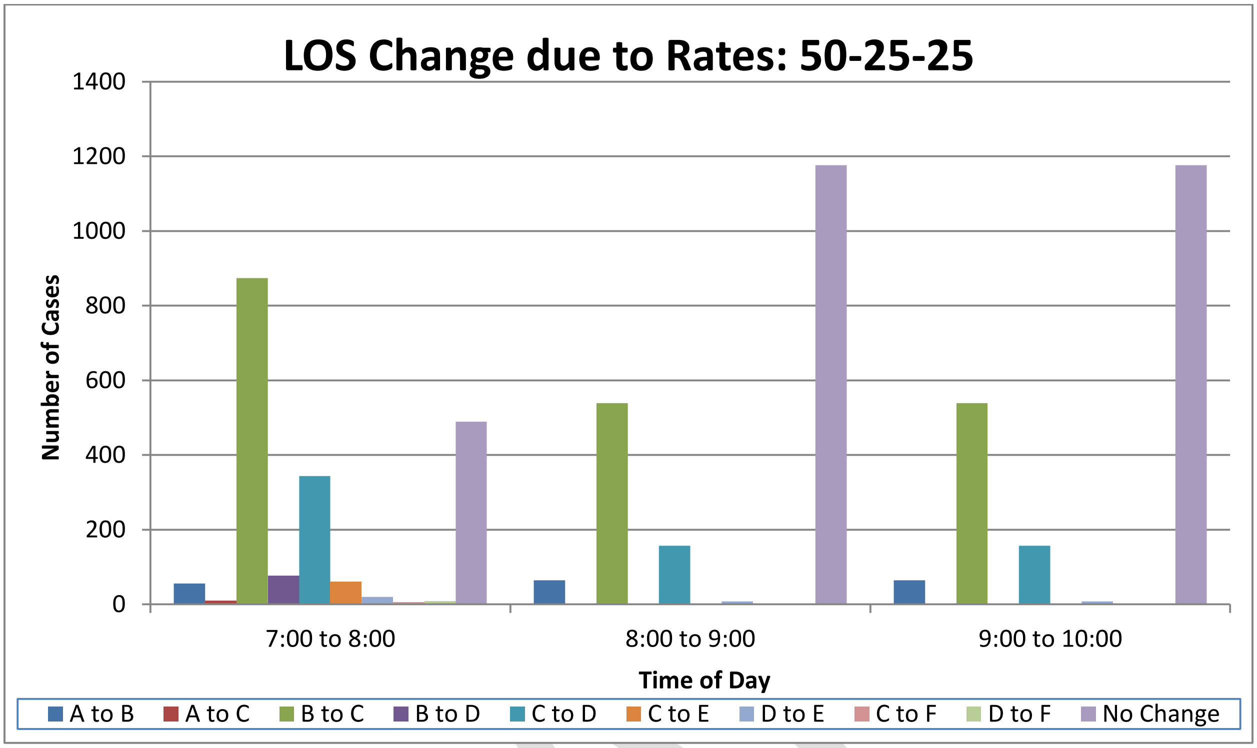
APPENDIX C. Impact on LOS

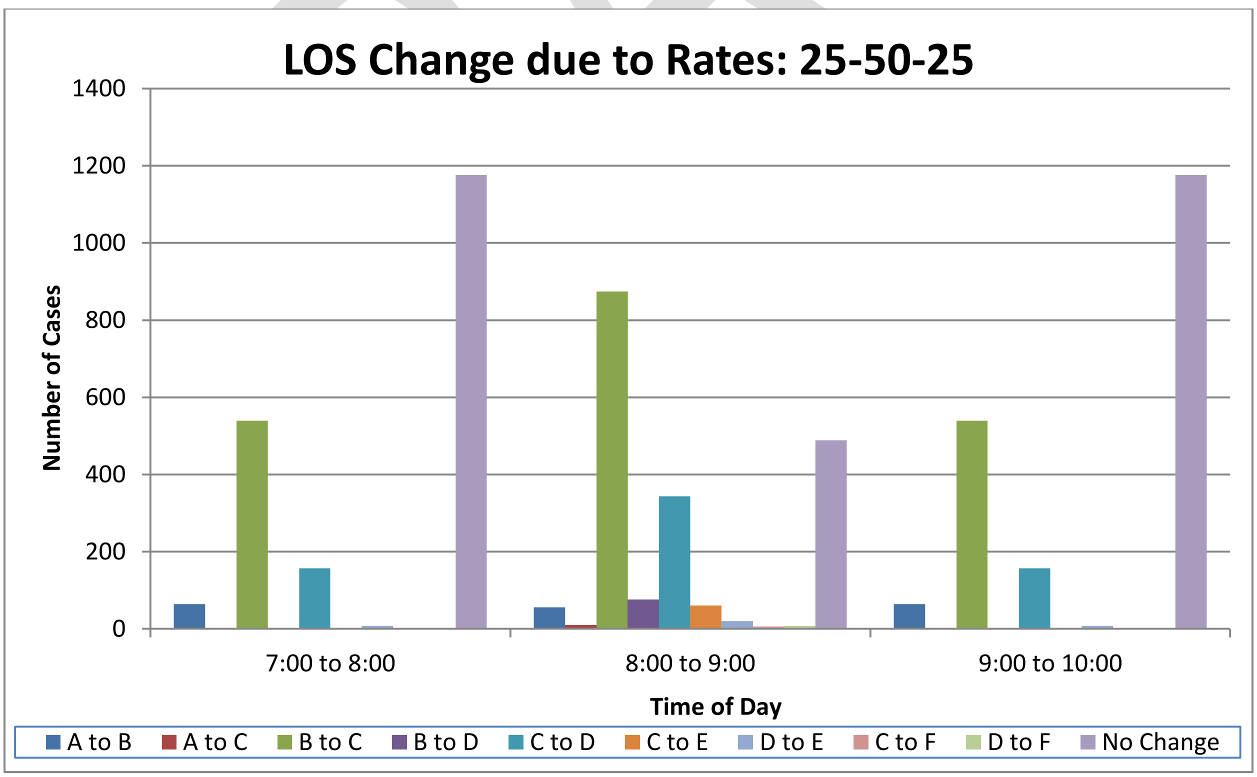


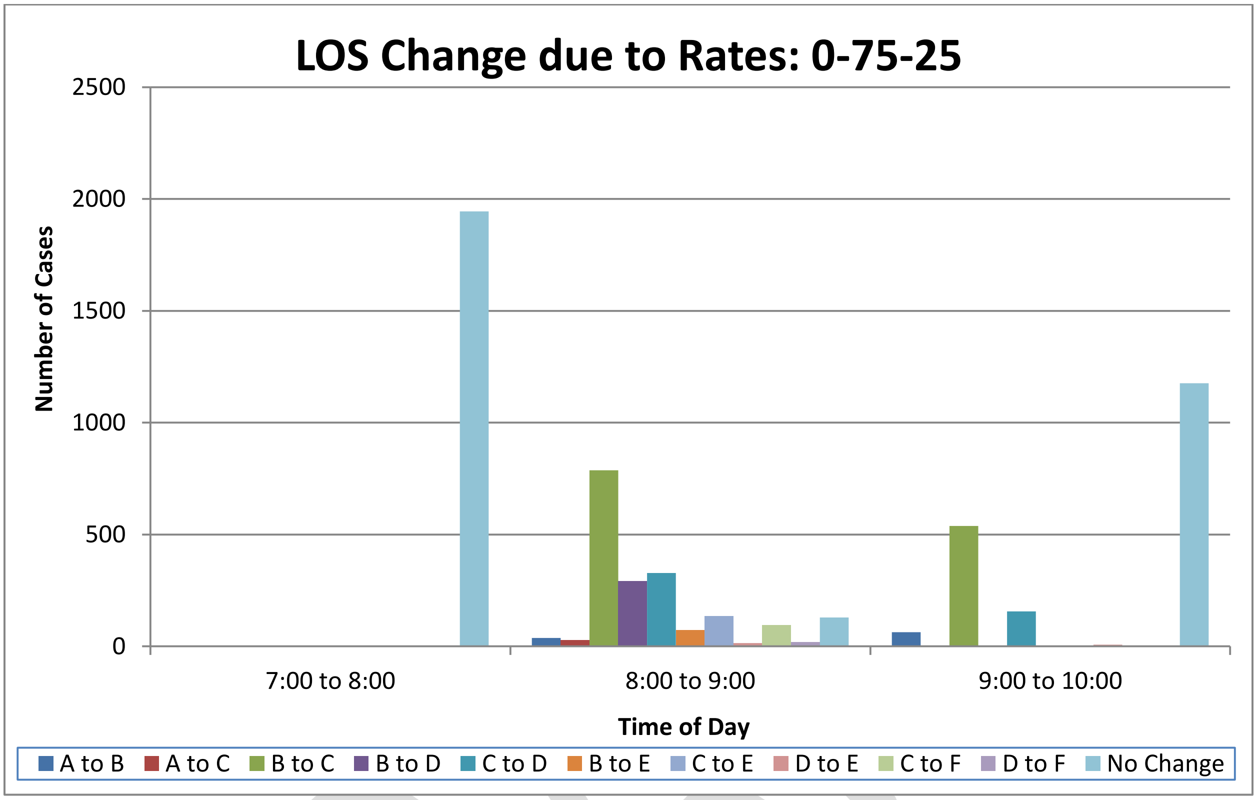


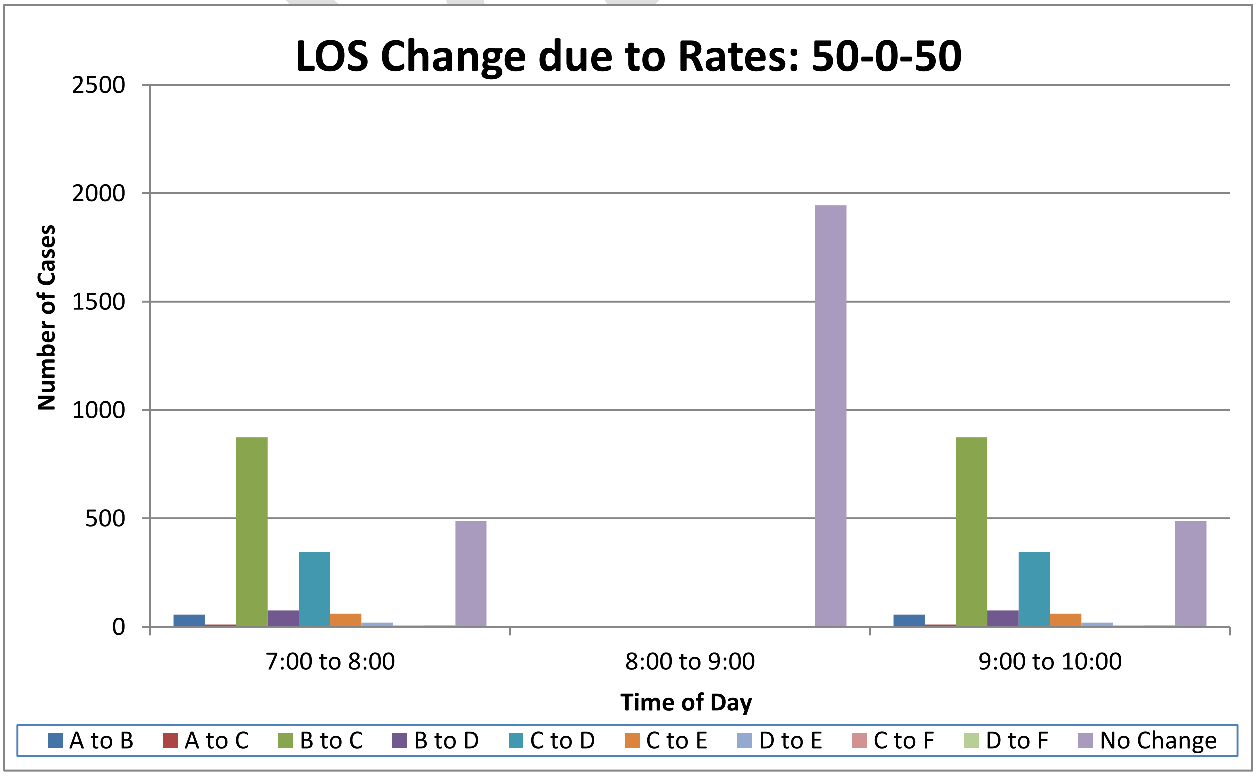

LOS Change due to Rates: 25-75-0
Number of Cases
2500
2000
1500
1000
500
0
7:00 to 8:00
8:00 to 9:00
9:00 to 10:00
Time of Day
A to B
A to C
B to C
B to D
C to D
B to E
C to E
D to E
C to F
D to F
No Change

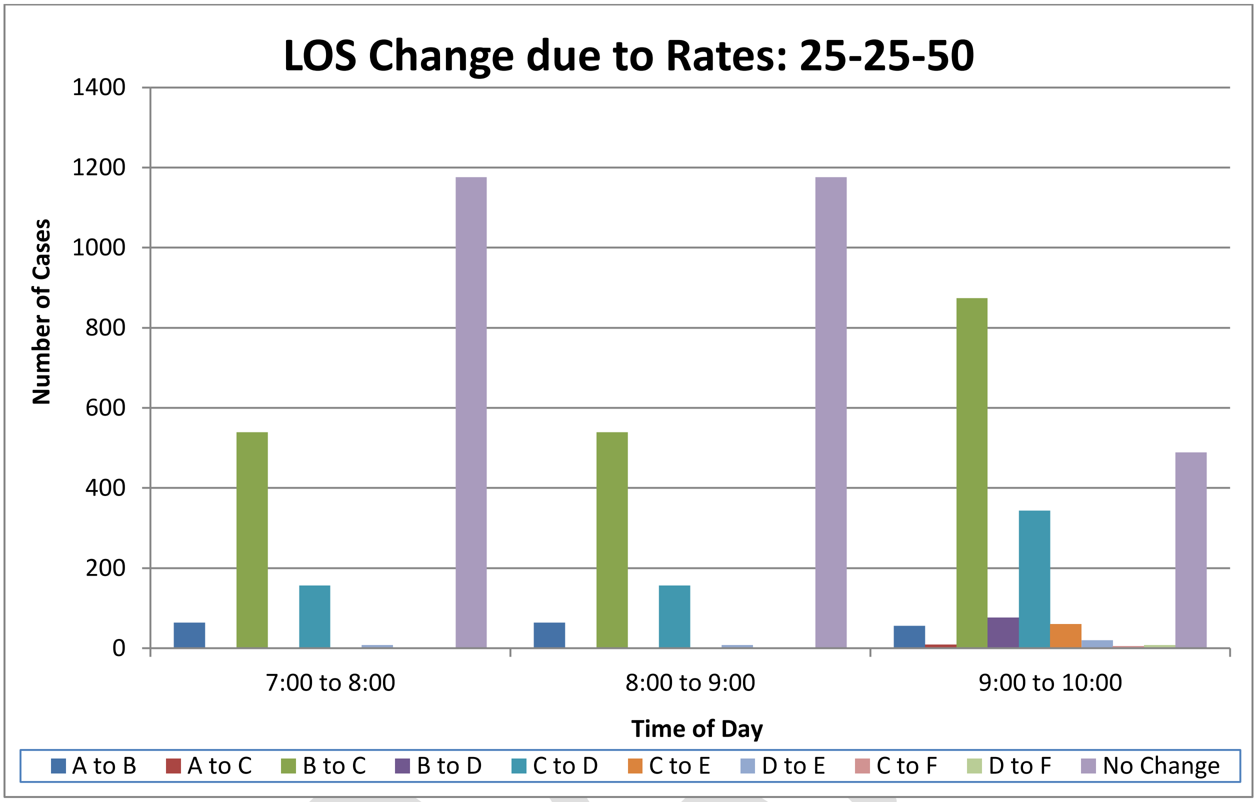

LOS Change due to Rates: 75-0-25
Number of Cases
2500
2000
1500
1000
500
0
7:00 to 8:00
8:00 to 9:00
9:00 to 10:00
Time of Day
A to B
A to C
B to C
B to D
C to D
B to E
C to E
D to E
C to F
D to F
No Change

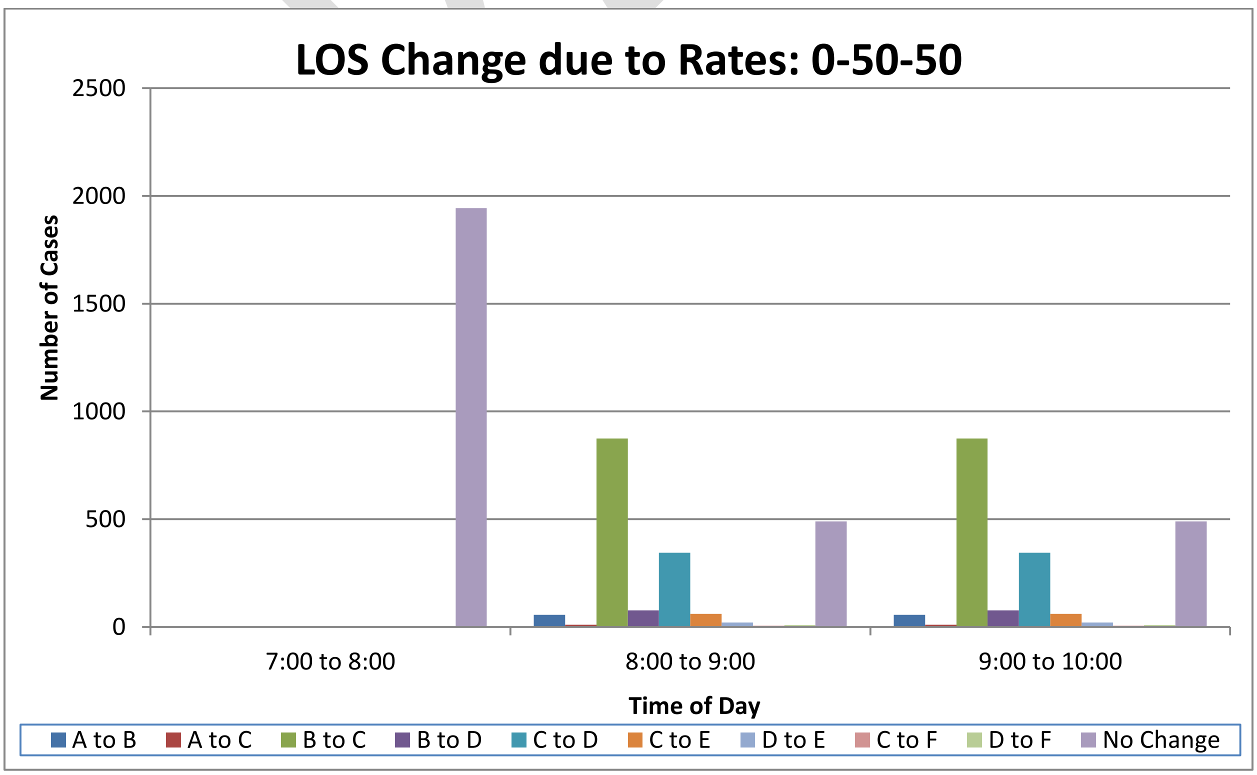

LOS Change due to Rates: 50-25-25
Number of Cases
0
200
400
600
800
1000
1200
1400
7:00 to 8:00
8:00 to 9:00
9:00 to 10:00
Time of Day
A to B
A to C
B to C
B to D
C to D
C to E
D to E
C to F
D to F
No Change

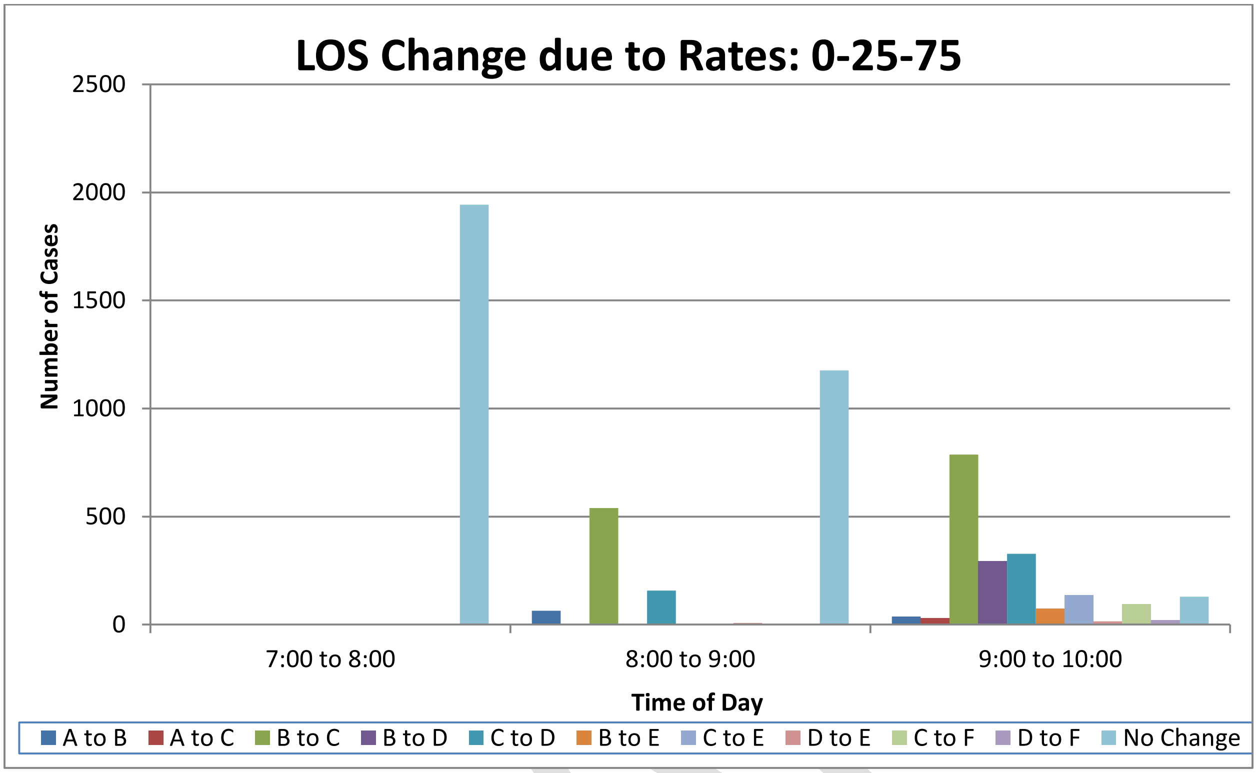

LOS Change due to Rates: 25-50-25
Number of Cases
0
200
400
600
800
1000
1200
1400
7:00 to 8:00
8:00 to 9:00
9:00 to 10:00
Time of Day
A to B
A to C
B to C
B to D
C to D
C to E
D to E
C to F
D to F
No Change

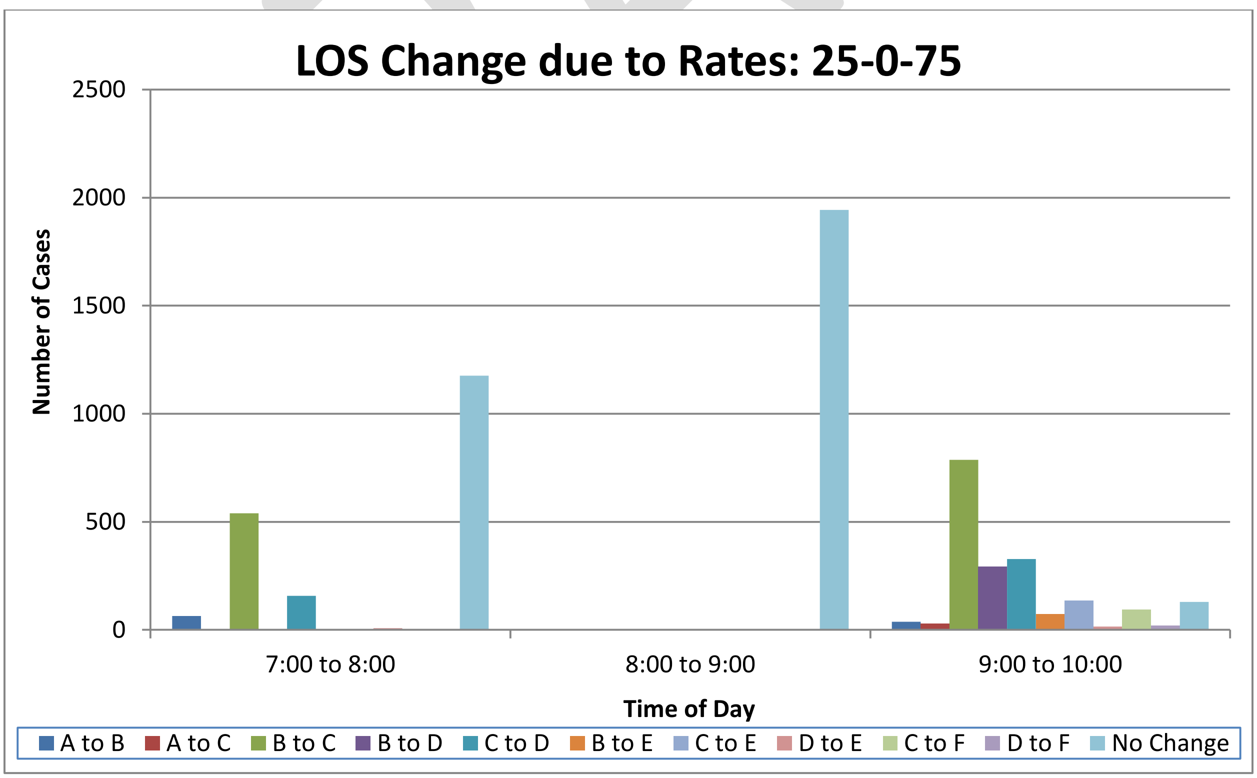

LOS Change due to Rates: 0-75-25
Number of Cases
2500
2000
1500
1000
500
0
7:00 to 8:00
8:00 to 9:00
9:00 to 10:00
Time of Day
A to B
A to C
B to C
B to D
C to D
B to E
C to E
D to E
C to F
D to F
No Change

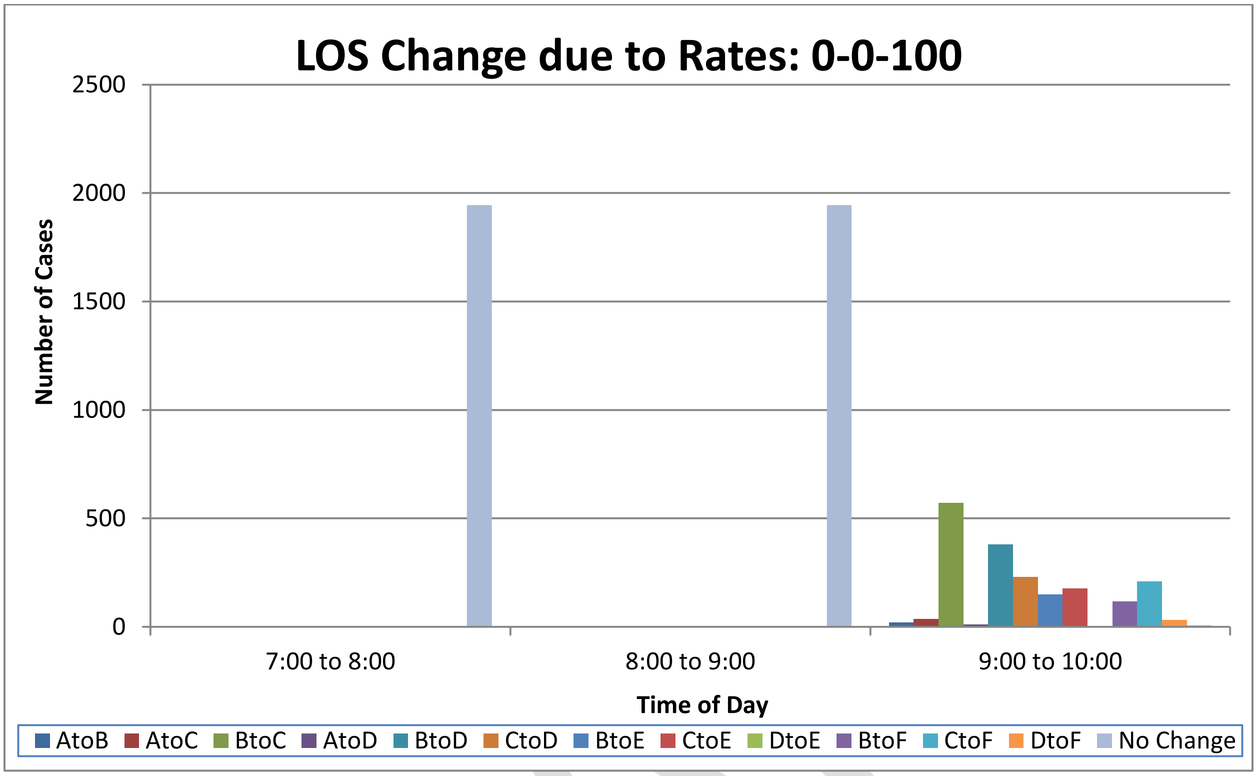

LOS Change due to Rates: 50-0-50
Number of Cases
2500
2000
1500
1000
500
0
7:00 to 8:00
8:00 to 9:00
9:00 to 10:00
Time of Day
A to B
A to C
B to C
B to D
C to D
C to E
D to E
C to F
D to F
No Change

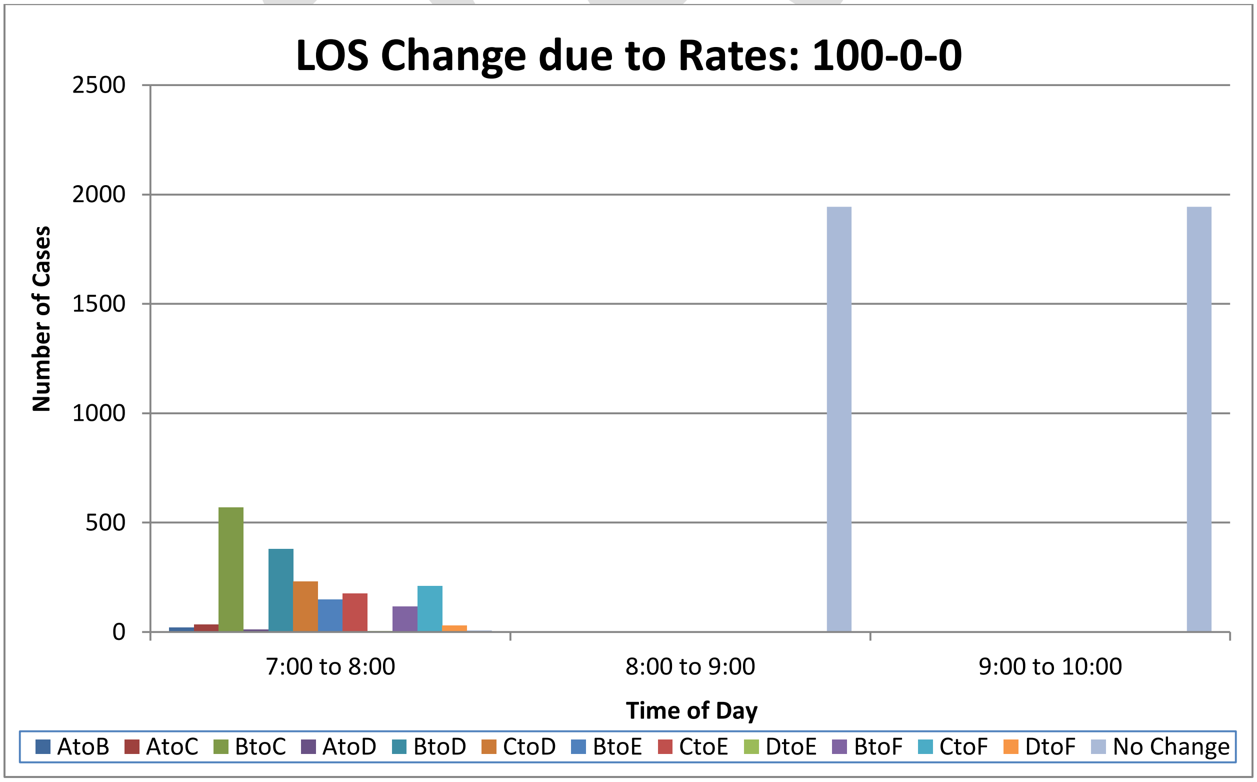

LOS Change due to Rates: 25-25-50
Number of Cases
1400
1200
1000
800
600
400
200
0
7:00 to 8:00
8:00 to 9:00
9:00 to 10:00
Time of Day
A to B
A to C
B to C
B to D
C to D
C to E
D to E
C to F
D to F
No Change

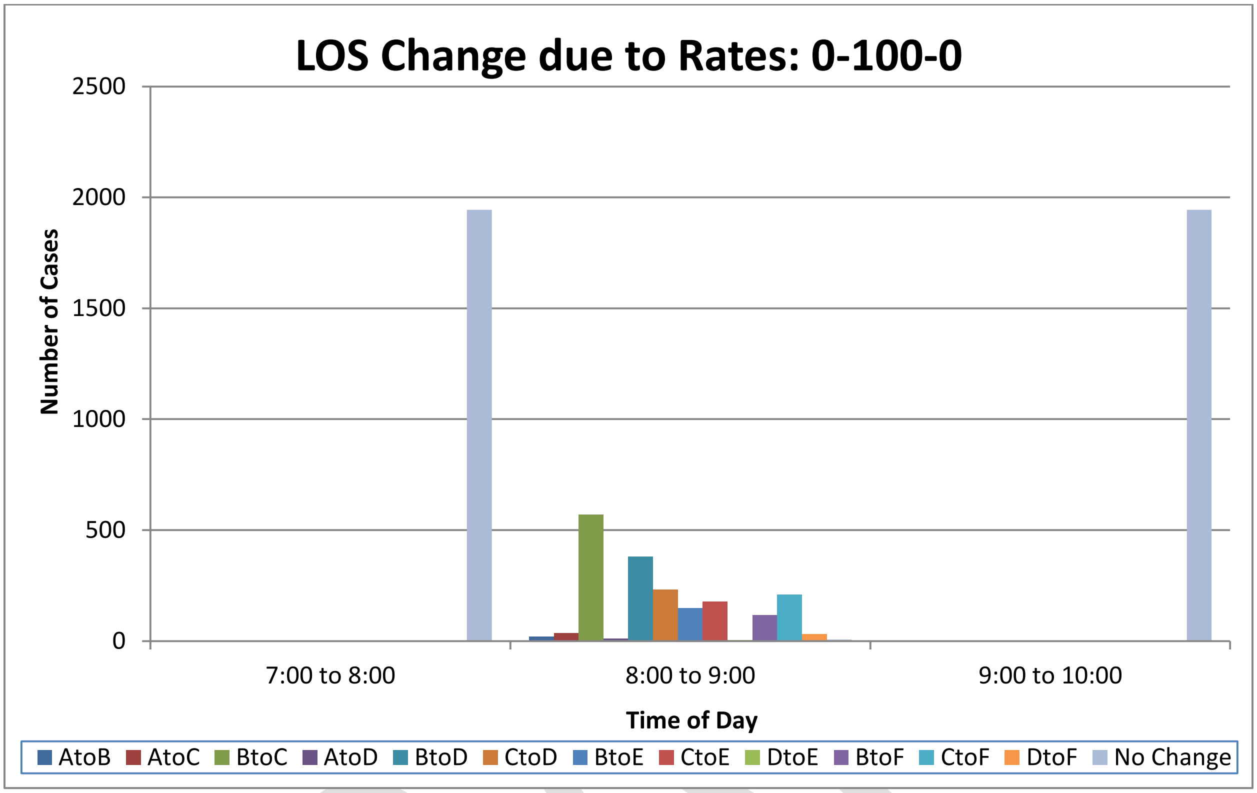

LOS Change due to Rates: 0-50-50
Number of Cases
2500
2000
1500
1000
500
0
7:00 to 8:00
8:00 to 9:00
9:00 to 10:00
Time of Day
A to B
A to C
B to C
B to D
C to D
C to E
D to E
C to F
D to F
No Change


LOS Change due to Rates: 0-25-75
Number of Cases
2500
2000
1500
1000
500
0
7:00 to 8:00
8:00 to 9:00
9:00 to 10:00
Time of Day
A to B
A to C
B to C
B to D
C to D
B to E
C to E
D to E
C to F
D to F
No Change


LOS Change due to Rates: 25-0-75
Number of Cases
2500
2000
1500
1000
500
0
7:00 to 8:00
8:00 to 9:00
9:00 to 10:00
Time of Day
A to B
A to C
B to C
B to D
C to D
B to E
C to E
D to E
C to F
D to F
No Change


LOS Change due to Rates: 0-0-100
Number of Cases
2500
2000
1500
1000
500
0
7:00 to 8:00
8:00 to 9:00
9:00 to 10:00
Time of Day
AtoB AtoC BtoC AtoD BtoD CtoD BtoE CtoE DtoE BtoF CtoF DtoF No Change


LOS Change due to Rates: 100-0-0
Number of Cases
2500
2000
1500
1000
500
0
7:00 to 8:00
8:00 to 9:00
9:00 to 10:00
Time of Day
AtoB AtoC BtoC AtoD BtoD CtoD BtoE CtoE DtoE BtoF CtoF DtoF No Change


LOS Change due to Rates: 0-100-0
2500
2000
1500
1000
500
0
Number of Cases
7:00 to 8:00
8:00 to 9:00
9:00 to 10:00
Time of Day
AtoB
AtoC
BtoC
AtoD
BtoD
CtoD
BtoE
CtoE
DtoE
BtoF
CtoF
DtoF
No Change