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Efficient Utilization of the Existing ITS System and the Viability of a Proactive Traffic Management System for the Orlando-Orange County Expressway Authority System

Contract # DTRT12GUTC12 with USDOT Office of the Assistant Secretary for Research and Technology (OST-R)

Final Report

September 2014

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EFFICIENT UTILIZATION OF THE EXISTING ITS SYSTEM AND THE VIABILITY OF A PROACTIVE TRAFFIC MANAGEMENT SYSTEM FOR THE CENTRAL FLORIDA EXPRESSWAY AUTHORITY SYSTEM

Final Report

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Submitted to
Central Florida Expressway Authority
and UTC
National Center for Transportation System Productivity and Management

September 2014

EXECUTIVE SUMMARY

The rapid development of Intelligent Transportation Systems (ITS) has triggered new traffic detection technologies to capture the traffic flow characteristics. The data acquired from these systems provide traffic operators and researchers with different perspectives to evaluate their system, pinpoint the potential problems and make targeted improvement. This report documents the efforts to explore the efficient utilization of the ITS systems on the expressway network operated by Central Florida Expressway Authority (CFX). On CFX's system, multiple ITS systems are in deployment. In this report, detailed work using the traffic data from these existing ITS systems has been conducted to identify the potential applications of current ITS systems on CFX's expressways. The applications include evaluation of current expressway operation and potential improvement using the ITS systems. In addition, since traffic safety is another important indicator of system performance and is closely related to operation. Traffic safety performance on the expressways has also been examined.

To achieve these goals, comprehensive database including traffic detection data from Automatic Vehicle Identification (AVI) system and Microwave Vehicle Detection System (MVDS), Dynamic Message Signs (DMS) data, roadway geometric data and crash data have been prepared. Currently, AVI and MVDS sensors have been installed along the expressways in large quantity over the whole system to provide real-time traffic information of the five expressways under CFX's management. Based on the traffic detection data, multiple congestion measures were proposed to determine the mainline segments and ramps that experience congestion. The suggested congestion measures have the advantages of reflecting traffic congestion in real-time manner at numerous locations because of the continuous monitoring of the detection system and high deployment density of sensors along the expressways. Consequently, congestion intensity, time duration and locations have been identified. According to the conclusions of congestion evaluation, congestion mitigation via DMS for queue warning was discussed. The current DMS that can be used for queue warning and potential locations of DMS in the future were identified.

In addition to congestion evaluation and improvement, ramp closure practice in extreme cases such as total shut-down on the mainline has been investigated through a survey. Both domestic and international toll and turnpike authorities have been included in this survey to share their experience in ramp closure practice and procedures. Detailed information about how these

authorities close their on-ramps, how they communicate with their road users and the ITS systems they implemented in this process provide valuable insights into the emergency response in case of mainline shut-down.

Traffic safety is evaluated using the crash data during the past three and half years to be able to both reflect the most recent safety conditions on the expressways and the trend of changes. More detailed crash statistics based on the characteristics of crashes have been calculated to explore whether specific safety issues exist on certain expressways. Finally, crash data visualization is provided to illustrate the spatial and temporal patterns of the crashes on CFX's system. The spatial and temporal patterns of crashes clearly point out to the relationship between congestion and crashes especially rear end crashes. Moreover, lighting related crashes, weather and wet pavement related crashes also have their significant characteristics on the expressways for which future improvement projects should consider their effects.

To get insights about the ramp crashes at interchanges, a case study focusing on SR 528 – SR 417 interchange was conducted. Individual crash reports were scrutinized. The most important finding in this study is that the wet road surface condition could contribute to crashes on ramps. Most of the crashes on the ramps were single-vehicle crashes and the vehicles hydroplaned on the wet surface. Potential treatments including warning messages, high friction surface treatment, providing guardrail and shoulders on ramps have been proposed to reduce the crashes.

Overall, the current ITS systems on the CFX expressway network could be efficiently used for congestion measurement and queue warning. They are proved to be able to reflect the dynamics of traffic flow for which the traditional Average Annual Daily Traffic (AADT) or Level of Service (LOS) could not. The real-time nature of the traffic detection data enables traffic operators to understand their system at the microscopic level, locate the spots experiencing specific issues and make the most of limited resources for effective improvement. Efficient utilization of the ITS system could benefit both traffic operation and safety, enhancing overall performance of expressways. Nevertheless, their applications are not limited to the topics discussed in this report. Potential applications include travel time estimation, micro-simulation, incident and closure duration, DMS optimum locations, etc. that can be further explored in future.

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LIST OF ACRONYMS

ATIS -- Advanced Traveler Information System

AVI -- Automatic Vehicle Identification

Caltrans -- California Department of Transportation

CFX -- Central Florida Expressway Authority

CI -- Congestion Index

DelDOT -- Delaware Department of Transportation

DMB -- Digital Multimedia Broadcasting

DMS -- Dynamic Message Signs

DUI -- Driving Under the Influence

ETC -- Electronic Toll Collection

FDOT -- Florida Department of Transportation

FHWA -- Federal Highway Administration

FITM -- Freeway Incident Traffic Management

GIS -- Geographic Information

HFST -- High friction surface treatment

HOT -- High Occupancy Lane

ICS -- Incident Command System

ITS -- Intelligent Transportation System

KEC -- Korean Expressway Corporation

LCS -- Lane Control System

M&E -- Monitoring and Evaluation

MDTA -- Maryland Transportation Authority

MDXWay -- Miami-Dade Expressway Authority

MP -- Milepost

MVDS -- Microwave Vehicle Detection System

MnDOT -- Minnesota Department of Transportation

MOT -- Maintenance of Traffic

MUTCD -- Manual on Uniform Traffic Control Devices

MVMT -- Million Vehicle Miles Traveled

NH Turnpike Bureau -- New Hampshire Department of Transportation Bureau of Turnpikes

ORT -- Open Road Tolling

PDO --Property Damage Only

PRT -- Perception-Response Time

PSV -- Polished Stone Value

RCI -- Road Characteristics Inventory

RISC -- Rapid Incident Scene Clearance

RTMS -- Remote Traffic Management Sensors

MVDS -- Microwave Vehicle Detector Sensor

SOP -- Standard Operating Procedure

STARR -- Specialty Towing and Roadside Repair

TMC -- Traffic Management Center

TTI -- Travel Time Index

UCF -- University of Central Florida

WV Parkways Authority -- West Virginia Parkways Authority

1 INTRODUCTION

1.1 Overview

Traffic detection technology is the main spine of any Intelligent Transportation System (ITS); there are a wide range of vehicle detection devices in use than ever before on freeways and expressways, starting from the popular inductive loops and magnetometers to video and radar-based detectors. The Central Florida Expressway Authority (CFX) System utilizes Automatic Vehicle Identification (AVI) system for Electronic Toll Collection (ETC) as well as for the provision of real time information to motorists within the Advanced Traveler Information System (ATIS). Recently CFX also introduced Microwave Vehicle Detection System (MVDS) for more precise traffic detection. These ITS systems can provide services include but not limited to fleet management systems, emergency response services, congestion pricing, pay-as-you-drive insurance services and navigation capabilities. Efficient use of the traffic data from these systems is therefore essential to fulfill the services above.

Despite that the detection technologies for each traffic detection system can be distinct, they share several common features. These systems monitor the traffic flow continuously and archive the traffic data on short time interval (e.g., 30 seconds, 1 minute). In addition, they are often installed with relatively short spacing on the managed freeways and expressways especially in urban areas. Thus they have the advantage of reflecting the traffic states along the roadways in real-time. The availability of real-time traffic data has transformed the outlook of numerous aspects of traffic operation and safety, both in research and practice. They allow operators to evaluate the traffic conditions at extremely microscopic level (i.e., specific locations at specific time). Researchers use the data to restore traffic conditions prior to individual crashes and summarize the common patterns leading to unsafe traffic conditions. As a result, proactive traffic management strategies can be developed to improve overall performance of roadway networks. To realize the envisioned improvement, the authority needs a medium to communicate with motorists on their system. Dynamic Message Signs (DMS) serve as an ideal tool since they can convey the required message to drivers in a timely manner. Nevertheless, only proper emplacement of them ensures their effectiveness.

The main objective of this research study is to identify potential applications of the current ITS infrastructure on CFX's system. The applications are focused on real-time traffic operation (congestion) and safety evaluation and improvement. The applications depend on efficient use of the AVI, MVDS and DMS systems. Consequently, the viability of using the AVI and MVDS for high quality data and DMS for timely warning will be investigated carefully. Expected contributions from this study are guidelines to adapt the existing ITS systems in the context of a proactive traffic management strategy.

1.2 Objectives

There are 4 general objectives of this research for the short and long terms. The research will try to answer the questions raised in each objective:

1. How well do the current ITS systems on CFX's expressways perform? How can the authority achieve more effective use of the data from these systems?
2. Based on the ITS infrastructure, how to evaluate the current operational performance of expressways? How can CFX improve their DMS deployment?
3. How are the current traffic safety conditions on the expressways? How can the ITS systems help operators improve their understanding about the safety on their system? How to achieve a safer expressway system through more proactive management?
4. What potential applications can CFX do to improve their ITS applications in future?

To achieve these objectives, several tasks have been conducted at different phases of the project and are described in the following report.

1.3 Research Organization

The organization of this report is as follows: following this chapter, the efforts related to the data collection are summarized in Chapter 2. This chapter covers an overview of the expressway system managed by CFX, the current deployment of ITS systems and detailed description about different types of data to be used in the report. Chapter 3 to Chapter 5 are about traffic operation on CFX's system. Chapter 3 focuses on overall traffic conditions on the expressways and congestion evaluation. Chapter 4 discusses the use of DMS in congestion management. Chapter 5 offers insights about another perspective in traffic operation, which is ramp closure practice in case of total shut-down on the mainline. Chapter 6 to Chapter 7 give a comprehensive analysis about the traffic safety on the expressways. Chapter 6 offers comprehensive analysis of expressway safety conditions and their trends. Chapter 7 is a case study about the traffic safety of an interchange on the expressway system especially asked by CFX. Chapter 8 summarizes the findings in the previous chapters and raises a real-time traffic management strategy intended for operation and safety improvement. Chapter 9 sheds some light on potential ITS implementation for the CFX system in future regarding micro-simulation and travel time estimation.

2 DATA PREPARATION

2.1 Expressway System Overview

The Central Florida Expressway Authority (CFX) operates and maintains the region's 109-miles of expressway networks as shown in Figure 2-1 (*1*). Currently, there are five toll roads under or partly under the management of CFX. Although future extensions have been planned, this project only focuses on existing CFX system. The five expressways connect Orlando and neighboring areas, serving both residents and visitors.

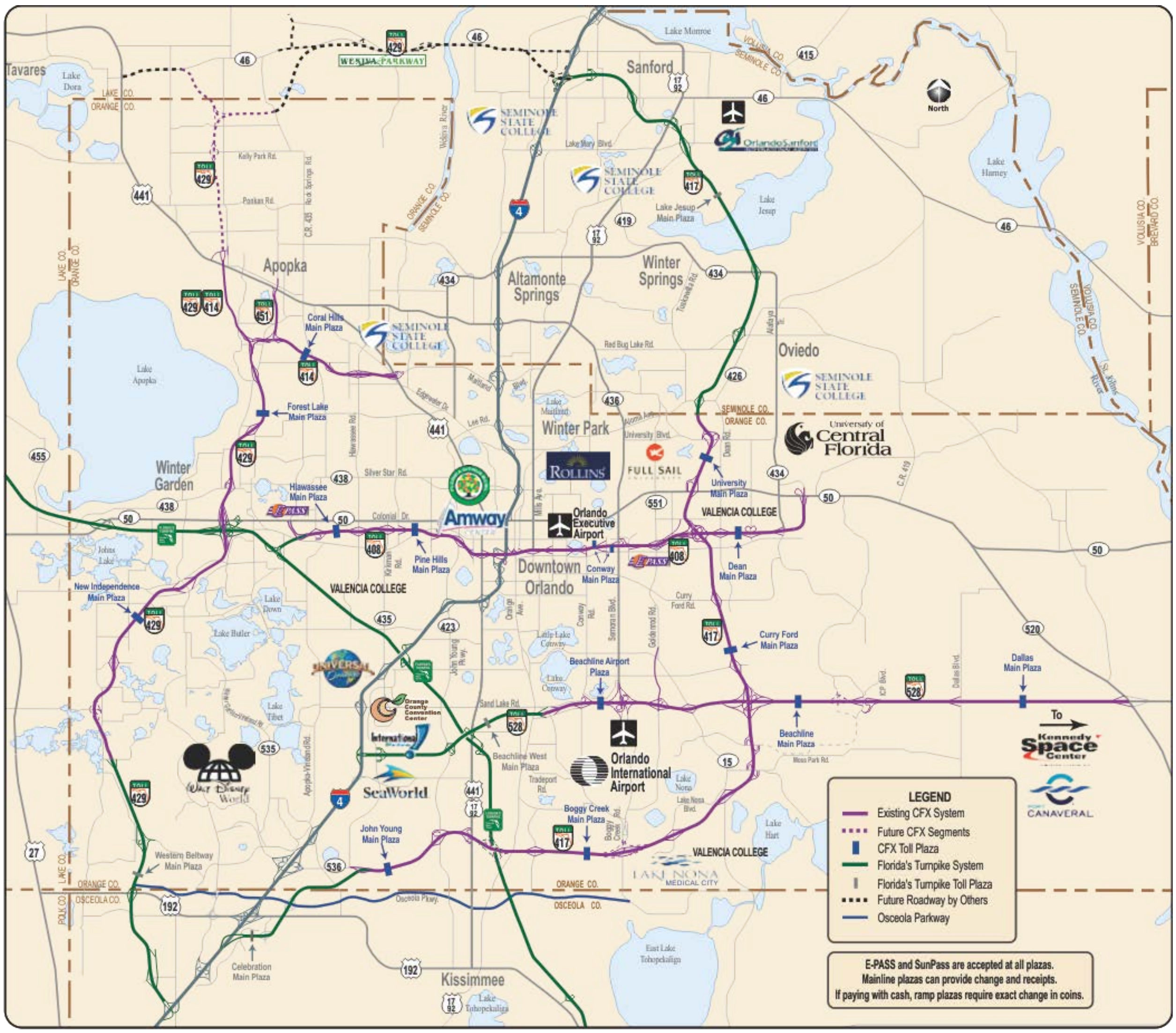


Figure 2-1 Expressways under CFX Management (*2*)

According to CFX, State Road 408 (Spessard L. Holland East-West Expressway) is the backbone of the Expressway Authority's 109-mile network. Except for the westernmost mile, the expressway is owned and operated by CFX. An estimated 125,000 - 135,000 vehicles a day travel the 21-mile expressway through downtown Orlando. Land uses along the expressway include residential, commercial and services, transportation (airport), academic institutions (*3*).

State Road 414 (John Land Apopka Expressway) is a 9-mile east-west corridor and is relatively new in the system. It improves access to SR 429 which is another expressway in CFX system, Interstate 4 and many local roads in the greater Apopka area (*4*).

A segment of 33 miles of the State Road 417 located in Orange County is under CFX management. This segment is also known as the GreeneWay. It provides the suburban areas near Orlando with convenient access if motorists need to travel between Sanford, Oviedo, the University of Central Florida, East Orlando or Kissimmee. SR 417 was the first in the system to have all mainline toll plazas converted to Express Lanes, which keep traffic moving by allowing customers to pay tolls at the posted highway speed (*5*).

State Road 429 (Daniel Webster Western Beltway) was developed in partnership between the Expressway Authority and the Florida's Turnpike Enterprise. CFX operates 23 miles of the expressway. The function of the SR 429 is to provide West Orange and Osceola counties with an alternate north-south route to Interstate 4 (*6*).

State Road 528 (Martin B. Andersen Beachline Expressway) provides a crucial connection for residents and tourists between the attractions area, the Orlando International Airport and the East Coast beaches and Cape Canaveral. The Expressway Authority operates the 23 miles of the expressway (*7*).

For a thorough evaluation of current operation and safety performance of the network, comprehensive efforts have been made to collect data from different sources. Traffic data from two different detection systems, DMS message information, roadway geometric characteristics data, and crash data have been collected.

2.2 Traffic Detection Systems on the Expressways

When CFX converted mainline toll plazas to open tolling express lanes, they adopted the Automatic Vehicle Identification (AVI) system for Electronic Toll Collection (ETC). If vehicles traveling on CFX's expressways are equipped with E-PASS or SunPass, they don't have to stop to pay the tolls. The AVI detectors will keep records of the vehicle information and calculate the tolls according to the distance that the vehicles traveled. Although AVI detectors can archive traffic information, they are not designed for this objective. Since 2012, CFX has introduced Microwave Vehicle Detection System (MVDS) to their expressway network. These detectors are specifically installed for traffic monitoring. The two systems exhibit substantial difference between them, however, both of them could be leveraged to provide traffic professionals with valuable traffic information. In this study, both data were collected based on their availability.

2.2.1 AVI Traffic Data

AVI detectors are installed at toll plazas for Electronic Toll Collection (ETC) and at other locations for travel time estimation. The deployment of AVI system since 2005 and system updates afterwards were provided by CFX. The AVI traffic data were collected from September 2012 to July 2014. Table A-1 to A-10 in Appendix A show the active AVI sensors in each month during the study time period. Then the traveling speed for a segment can be calculated. The segmentation of expressways based on the AVI sensors is shown in Appendix B. Table 2-1 summarizes the number of AVI segments per direction and basic statistics on each of the five expressways.

Table 2-1 AVI Segments on CFX Expressway System

Route ID	Direction	No. of Segments	Segment Length			
			Mean	Std Dev	Min	Max
SR 408	EB	23	0.926	0.479	0.290	1.853
	WB	23	0.977	0.524	0.332	2.287
SR 414	EB	3	1.529	0.555	0.928	2.022
	WB	4	2.445	2.948	0.350	6.811
SR 417	NB	16	1.959	0.829	0.751	3.848
	SB	20	1.567	0.770	0.378	3.098
SR 429	NB	10	1.895	1.220	0.704	4.271
	SB	9	2.136	1.534	0.614	4.536
SR 528	EB	8	2.740	2.25149	0.329	7.058
	WB	9	2.578	2.129	0.861	7.597

Figure 2-2 illustrates the deployment of AVI sensors on the expressway network. SR 408 has the smallest AVI segment length of the five expressways. SR 528 has relatively short AVI segments near the international airport and west to SR 417. However, on the suburban segments leading to the coast area, the distance of adjacent AVI sensors could be above 7 miles. The distance of adjacent AVI tag readers are determined on two basic criteria: 1) the need for toll collection; 2) the need for travel time estimation. In urban areas, the accessibility of the expressway has to accommodate the travelers' demand of entering and exiting the expressways. This makes the toll collection for a relatively short spacing necessary on SR 408.

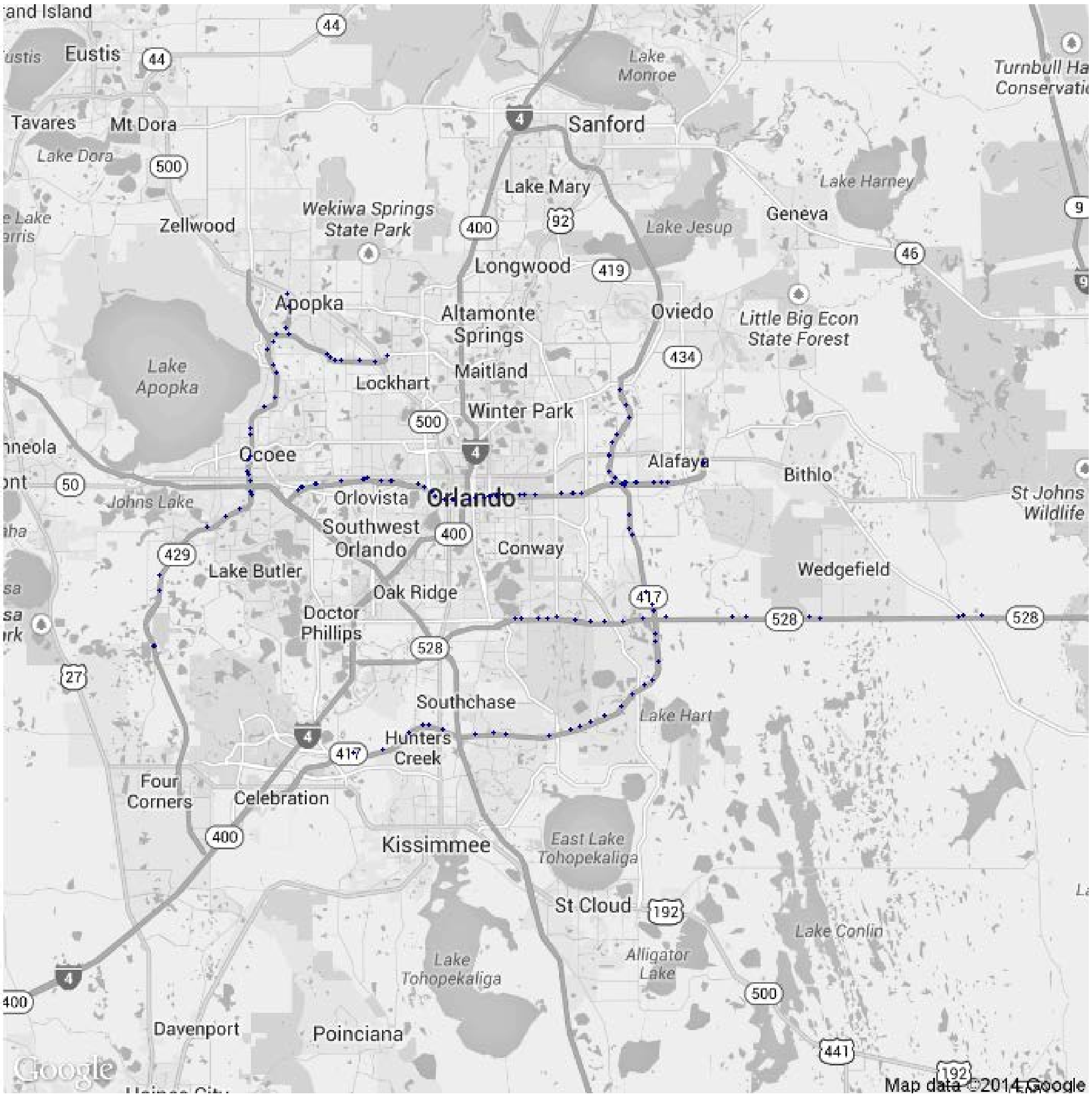


Figure 2-2 Deployment of AVI Sensors on Expressway Network

Traffic data generated from the AVI system can be categorized in two types, one is the more traditional capped AVI data and the other is the uncapped AVI data collected since the beginning of the project. The capped AVI data contain space mean speed information for each detection segment on one minute interval basis. The speed is capped at speed limit. Therefore, the AVI data during this time period are referred to as capped AVI data. While providing traffic information in real-time, the capped AVI data is not able to reflect the real situation as shown in Figure 2-3.

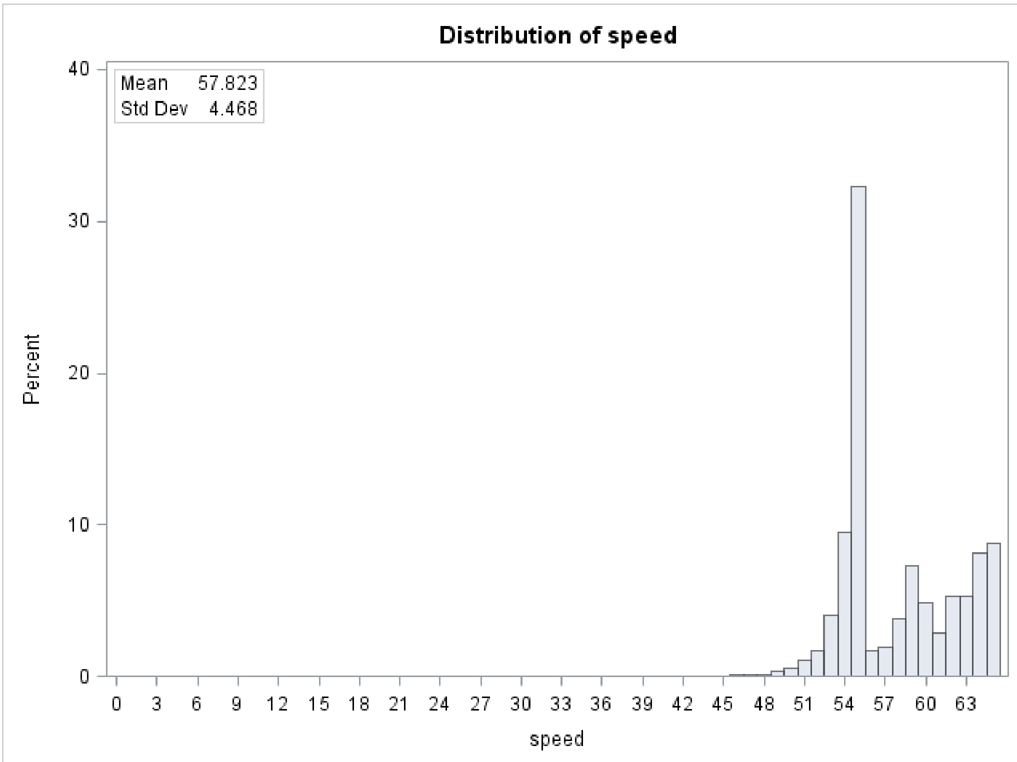


Figure 2-3 SR 408 Eastbound Capped AVI Data (Aug, 2013)

Since September 2012, CFX and Atkins have archived the raw readings by the AVI detectors. The raw readings contain the encrypted vehicle ID information and the timestamps of detection at each AVI detector location. Based on the information, the speed of individual vehicles can be derived using equation (1).

$$\text{speed} = \frac{|\text{milepost}_{\text{upstream}} - \text{milepost}_{\text{downstream}}|}{\text{timestamp}_{\text{downstream}} - \text{timestamp}_{\text{upstream}}} \quad (1)$$

Consequently, traffic information from the raw readings is referred to as the uncapped AVI data. Compared with capped AVI data, the uncapped data is not trimmed at speed limit, thus reflecting the speed of the segment at a specific time closer to the real traffic condition. In addition, the uncapped AVI data is based on individual vehicles, therefore providing some insights about the traffic volume on the expressways. Although the traffic count by AVI sensors is not complete traffic volume, they still offered precious information about real-time traffic volume before the introduction of MVDS sensors. Figure 2-4 is the distribution of speed for the same expressway during the same time period. The figure shows that the uncapped AVI data has its speed more normally distributed. Based on the comparison results, it is suggested to use the uncapped AVI data for more precise operation evaluation.

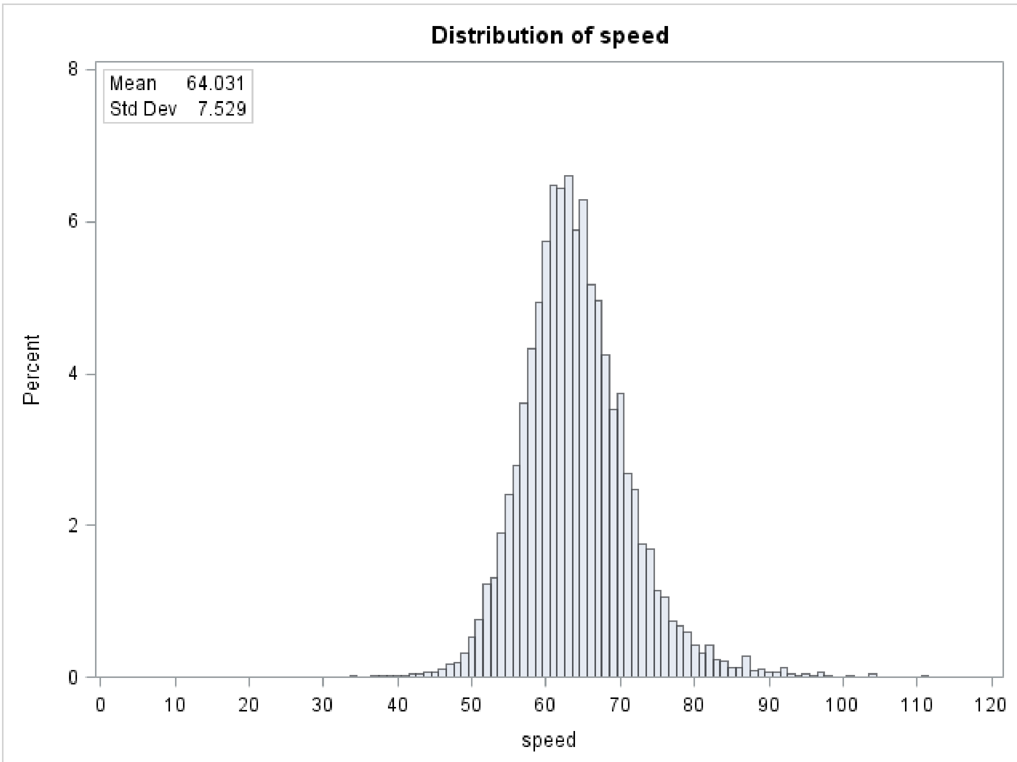


Figure 2-4 SR 408 Eastbound Uncapped AVI Data (Aug, 2013)

2.2.2 MVDS Traffic Data

MVDS was initially introduced to CFX's expressways since 2012. In 2013, the whole network operated by CFX was covered by MVDS as displayed in Figure 2-5. The system is specifically designed for traffic monitoring.

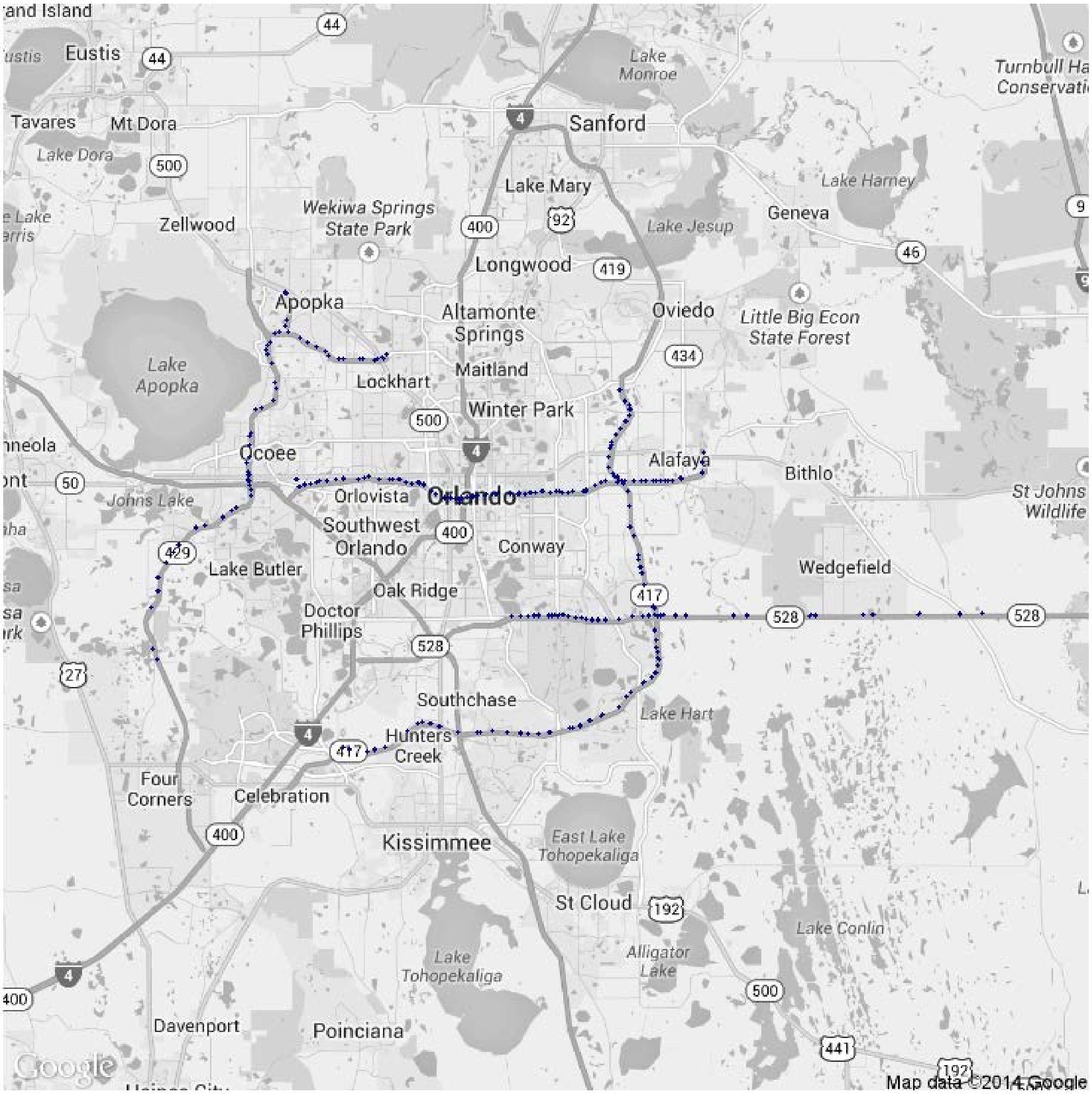


Figure 2-5 Deployment of MVDS Sensors on Expressway Network

For the purpose of this project, MVDS data have been collected since July, 2013. MVDS does not identify individual vehicles. They return aggregated traffic flow parameters for each lane of the cross-section where the MVDS detector is installed at one minute interval basis. The traffic parameters include traffic volume, time mean speed, lane occupancy and traffic volume by vehicle length. Four types of vehicles were defined by their lengths:

- Type 1: vehicles 0 to 10 feet in length
- Type 2: vehicles 10 to 24 feet in length
- Type 3: vehicles 24 to 54 feet in length

- Type 4: vehicles over 54 feet in length

Additional information from MVDS traffic data includes the timestamp when the sensor is polled. It has been mentioned above that the sensors are polled every one minute. Also, unique sensor identifier and lane identifier are contained within the data. The sensor identifier consists of the roadway (i.e., SR 408, SR414, SR 417, SR 429 and SR 528), milepost and direction. The lanes are counted from the roadway medium to the outside lane. The lanes fall into four categories, which are Mainline, Ramp, Mainline TP Express and Mainline TP Cash. Mainline TP Expressway indicates express lanes at mainline toll plazas; vehicles equipped with tags do not need to slow down on these lanes when they pass the toll plazas. Mainline TP Cash means toll booth at mainline toll plazas; vehicles need to stop and pay tolls. On the expressways, these two types of lanes are physically separated. The types of lanes and number of lanes at each MVDS detection location can be seen in Appendix C.

Compared with the AVI traffic data, MVDS data reflect the traffic states at their installed locations instead of a segment. They also have several advantages over AVI data. The first is the scale of MVDS system. As shown in Table 2-2, the MVDS sensors significantly outnumber the AVI sensors and average distance between adjacent detectors of MVDS is much smaller than that of the AVI system. The higher deployment density means traffic information from more locations is gathered and more detailed knowledge about the expressway system is available. The second advantage is traffic data for different types of lanes from MVDS system. Given that MVDS sensors monitor traffic conditions on each traveling lane, traffic data at toll plazas and on ramps can be collected. AVI data only provide traffic information of a cross-section on the mainline. However, to have a general understanding about the expressway performance, analysis of toll plazas and ramps are necessary as well. The third advantage is the richness of traffic information from MVDS data. Capped AVI data only has capped speed information which does not reflect real-world traffic conditions while uncapped AVI data has more realistic speed data and part of the traffic volume information. The traffic count from uncapped AVI data is not the complete traffic volume. MVDS data include speed, complete traffic volume, and lane occupancy as a surrogate measure of traffic density and the volume by vehicle lengths.

Table 2-2 MVDS on CFX Expressway System

Route	Length (mi)	Direction	MVDS Detectors							
			Total	Mainline (including TP Express)	TP Cash	Ramp	Distance between adjacent detectors			
							Mean	Std Dev	Min	Max
SR 408	21.4	EB	57	55	8	39	0.38	0.18	0.1	1
		WB	56	55	8	39	0.39	0.18	0.1	1
SR 414	9.5	EB	14	14	2	8	0.44	0.17	0.2	0.7
		WB	13	12	2	7	0.46	0.23	0.1	0.9
SR 417	31.5	NB	56	55	7	31	0.58	0.28	0.2	1.3
		SB	56	55	7	32	0.58	0.28	0.2	1.2
SR 429	22	NB	29	28	4	17	0.68	0.54	0.2	2.8
		SB	29	27	4	16	0.68	0.59	0.1	3.1
SR 528	22.4	EB	29	26	4	19	0.84	0.79	0.1	3
		WB	29	29	4	18	0.84	0.82	0.1	3.1

In conclusion, MVDS on CFX expressway network is more suitable for traffic monitoring. Nevertheless, AVI data will also be used in the report. It is expected that by using the two types of traffic data, better understanding about the expressways will be reached.

2.3 DMS Systems on Expressways

CFX installed numerous Dynamic Message Signs (DMS) on their expressways. The DMS are electronic signs on roadways to give motorists real-time information. As shown in Figure 2-6 and Table D-1 in Appendix D, in total 37 DMS are currently in use on CFX expressways and 35 of them are located on the five expressways involved in this study. The other two DMS are located on SR 451 and SR 520, respectively. The DMS data from September 2012 to September 2013 were collected. The DMS data record the DMS identifier information, the messages displayed on the boards, and the displayed time and duration of each message. SR 408 and SR 417 have the most DMS on the mainline according to Table 2-3. And SR 414, SR 429 and SR 528 have relatively fewer DMS installed. The differences are mainly affected by the traffic demand and the length of the segment. SR 408 has the highest traffic load among the five expressways. SR 417 on the other hand is the longest expressway in the system. However, the average distance between DMS on SR 408 is much smaller than the other roadways.

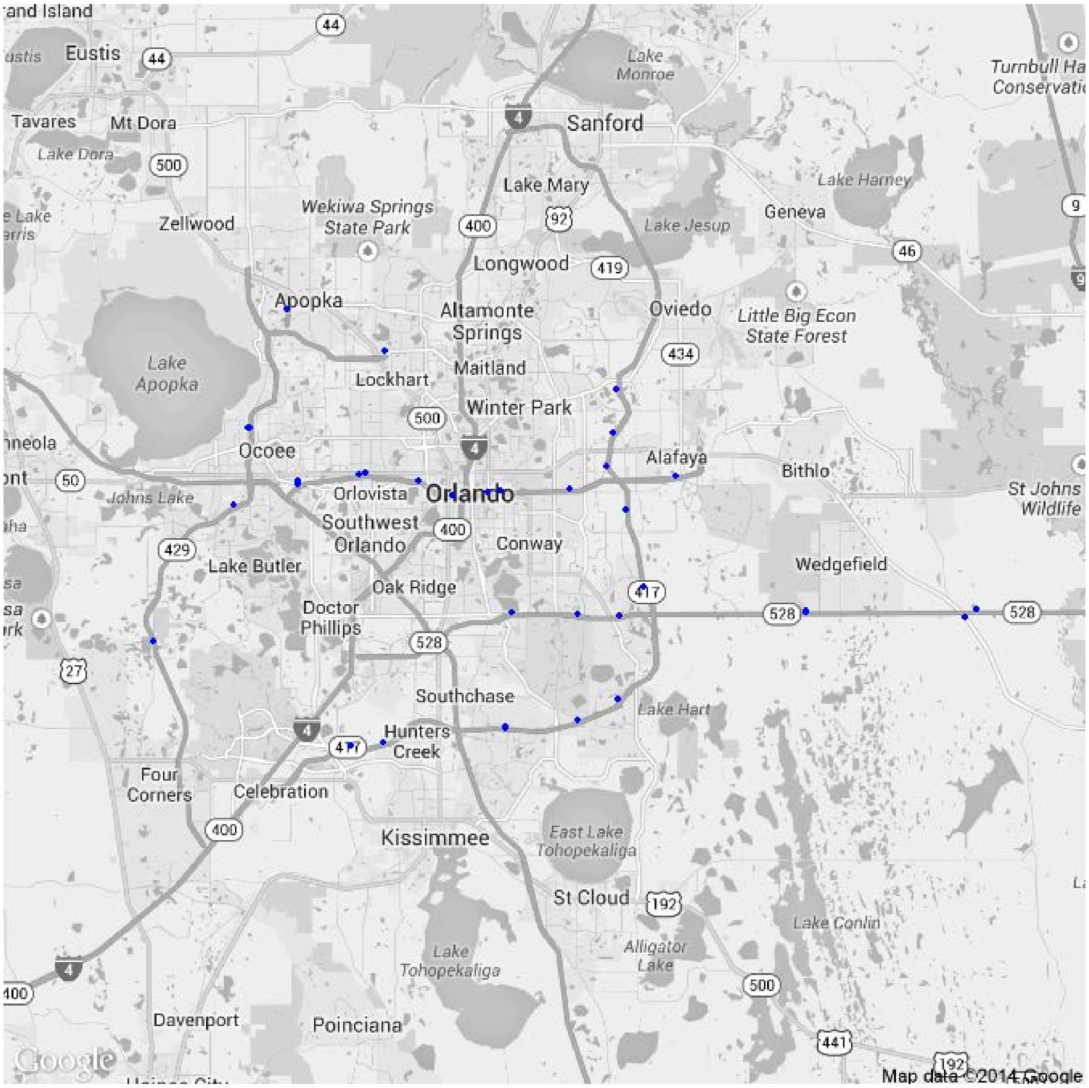


Figure 2-6 Deployment of DMS on Expressway Network

Table 2-3 DMS on CFX Expressway System

Route	Direction	Total Number	On Mainline	Average Distance between DMS (mi)	On Ramp
SR 408	EB	7	6	3.84	1
	WB	5	5	3.925	0
SR 414	EB	0	0	--	0
	WB	1	1	--	0
SR 417	NB	5	5	6.725	0
	SB	6	6	5.94	0
SR 429	NB	3	3	6.6	0
	SB	2	2	4.3	0
SR 528	EB	3	3	7.3	0
	WB	3	3	8.85	0

DMS is used to convey the messages from traffic operators to motorists on road. According to the messages displayed on the DMS board in the one year period, several types of messages could be summarized. Typical messages include:

- travel time estimation message (the most common type)
- alert message: silver alert, child abduction, LEO alert, traffic alert
- law enforcement message: safety belt use, moving over for emergency vehicle
- adverse weather warning message: fog, smoke, brush fire, low visibility
- congestion warning message: congestion, heavy congestion, expected congestion
- lane close/open message: lane block, all lanes block, ramp close, ramp open, planned close/open of lanes/ramps
- unexpected events warning message: incident, crash, debris, disabled vehicle
- planned events message
- road work warning message: construction, road work, planned road work, work zone, rolling road block

Among the listed types of messages above, several types of messages are not expected to alter motorists' behaviors, such as messages related to travel time estimation, alert, law enforcement and planned events. Other messages are displayed to heightened travelers' awareness of the traffic conditions, weather, incidents, etc. These types of messages are expected to reduce risks on the expressways and improve the traffic flow. Besides these commonly displayed messages, blank signs are also observed during the study period. In other cases signs under test will show "TEST" message. The DMS data will be used to evaluate current adequacy of DMS.

2.4 Road Geometric Characteristics Data for Expressways

Roadway geometry has been verified in previous research (*8-16*) to have significant impact on traffic operation and safety. In this project, we first collected the geometric characteristics data in 2012 and updated the data in 2013. Florida Department of Transportation (FDOT) maintained the Road Characteristics Inventory (RCI) database that has the complete roadway geometry and other relevant information. The RCI database has hundreds of variables. Only the most relevant variables were chosen for the data preparation. In sum 14 variables have been selected, including pavement condition, number of lanes, auxiliary lane type, shoulder type and width, median type and width, inside shoulder type and width, horizontal degree of curvature, speed limit, section AADT, D factor, K factor and truck percentage. The expressways are divided into homogeneous segments. If one of the geometric characteristics variables changes, a new segment will be generated. For the convenience of study, the smallest segment length is specified to be 0.1 mile. Segments smaller than 0.1 mile will be combined with adjacent segment which shares higher geometric similarity.

2.5 Crash Data on Expressways

In Florida, crashes are recorded in two formats of crash reports, namely the short form and long form. Long form crash reports are designed to keep records of more severe crashes, especially those involving injuries or fatalities. Short form crashes are mostly used for property damage only crashes. Two databases served as the crash data source. One is FDOT Crash Analysis Reporting (CAR) system and the other is Signal 4 Analytics (S4A) system. CAR database has longer history. However, they only archive the long form crashes. In contrast, S4A is newly developed and has both short and long form crashes. The issue with S4A database is that for the crashes occurred in early years (e.g., early 2000s), the short form crashes were not complete. After June 2012, S4A has the complete crash data from both types of reports for whole Florida. This current project covers two-year period since September 2012, thus having no problem with the crash data. For insurance, the research team still made a comparison between the CAR and S4A system using crash data from July 2012 to December 2013. All crashes recorded to occur on the expressways from CAR system were extracted as shown in Table 2-4. It should be noted that the crashes happening on the expressways are not necessarily on the segments operated by CFX. The number of crashes for each roadway that can be matched in S4A system was also retrieved. The results confirmed that S4A can replace CAR database in our research. As a result, in the safety analysis, the crash data were collected from S4A system.

Table 2-4 Crash in CAR and S4A

Expressways	Crash Count in CAR	Crash Matched in S4A
SR 408	731	730
SR 414	270	264
SR 417	401	401
SR 429	110	110
SR 528	592	590

3 TRAFFIC OPERATION EVALUATION

3.1 Overview

As stated in the system overview in section 2.1, the five expressways are located in Central Florida area. SR 408, SR 528 and SR 414 travel along east-west direction; SR 417 and SR 429 travel along north-south direction. SR 408 carries the most traffic in the expressway system, especially commuting traffic. By taking the merit of MVDS traffic data, traffic operation on the expressways can be examined at more microscopic level. MVDS data from July, 2014 was selected to represent the most recent traffic operation states on the expressways. As illustrated in Figure 3-1 and Appendix E, the spatial-temporal characteristics of hourly traffic volume on mainline could be easily captured.

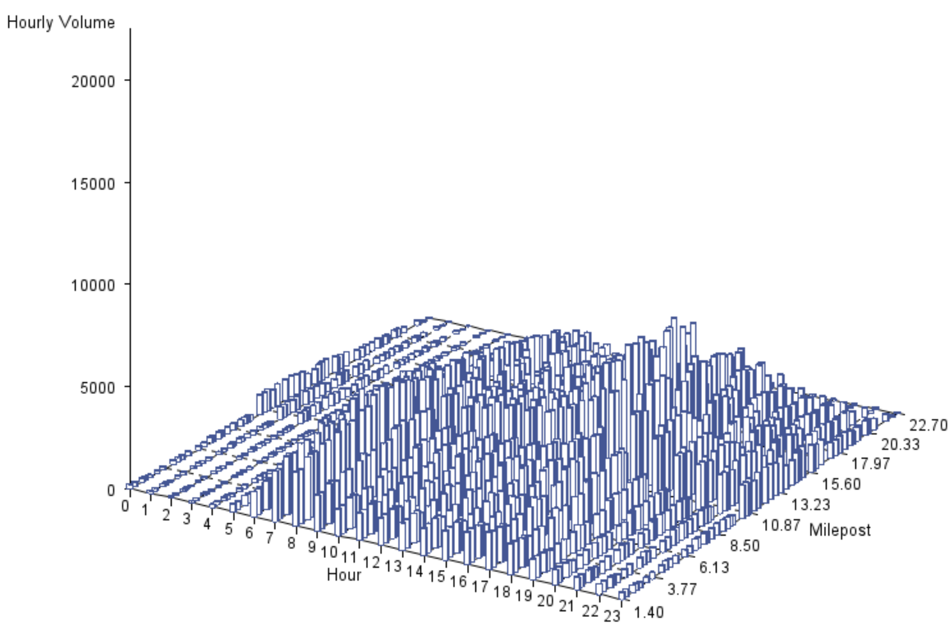
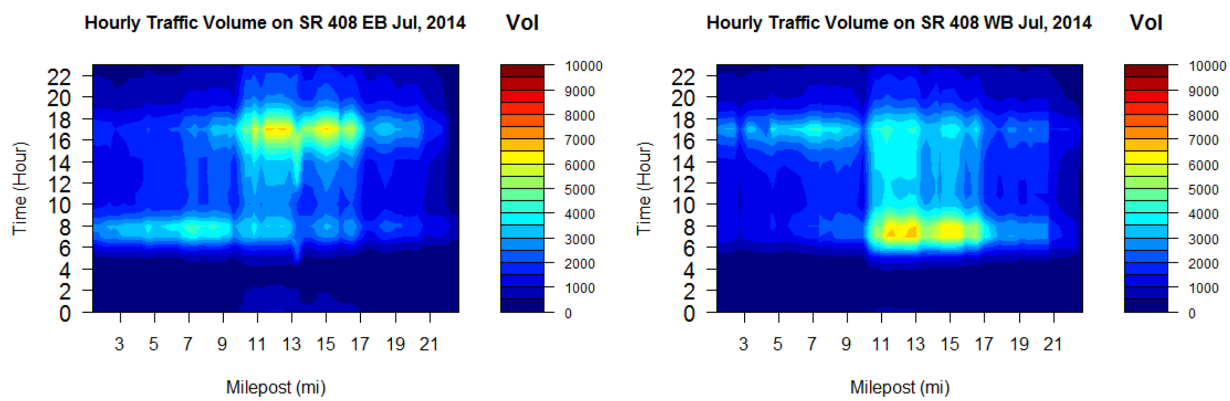


Figure 3-1 Weekday Hourly Volume along SR 408 Eastbound

For SR 408, Eastbound experiences significant high demand during evening rush hours while the traffic reaches its peak on Westbound during morning rush hours. With the contour plots in Figure 3-2 and in Appendix F, the pattern can be interpreted more clearly. Hourly traffic volume on SR 408 during peak hours can rise to about 7000 vehicles. The high demand exists around 6:00 to 9:00 AM in the morning and 16:00 to 19:00 PM in the afternoon. The segments that experience the high volume extend from around Milepost (MP) 11 to MP 17. For other segments and other time period, it can be seen that the traffic volumes are relatively stable and mostly below 3000 vehicles per hour. This preliminary review of SR 408 suggests when and where the congestion is likely to occur. Future congestion evaluation should focus on these segments during peak hours. By viewing the traffic demand at both spatial and temporal dimension, it has also been confirmed about how dynamic the traffic flow can be. Use of ITS traffic detection data enables operators and researchers to have precise and detailed knowledge about the performance of their roadways.



(a) (b)

Figure 3-2 Spatial-Temporal Hourly Volume Distribution on SR 408 (a) Eastbound and (b) Westbound

SR 414 has relatively low hourly volume even during the morning (for Eastbound) and evening (for Westbound) peak hours. In non-peak hours, the hourly volume is generally below 600 vehicles per hour. During peak hours, there will be moderate increase in traffic volume. However, the peak hour traffic volume on SR 414 is still below 2000 vehicles per hour, which is similar to non-peak hourly volume on SR 408. Moreover, since SR 414 has the shortest segment length of the five expressways, traffic increases on the whole roadway segment during the peak hours.

SR 417 shows the similar pattern during the peak hours. Nevertheless, from around MP 7 to MP 27, on the 20-mile segment, hourly traffic volume only increases mildly in the morning and evening peak hours. In contrast, from MP27 to MP 37, the hourly volume is significantly higher during the same time period. Especially for Northbound, hourly traffic can reach to about 5000 vehicles per hour around 17:00 PM.

SR 429 Northbound experiences mild traffic increase in the evening and Southbound in the morning. Peak hour volume is relatively low compared with SR 408, SR 417 and SR 528.

SR 528 accommodates most of its peak hour traffic on the segment from MP 8 to MP 13. Evening peak hours exert on SR 528 Eastbound while morning peak hours appear on Westbound. During peak hours, the hourly traffic volume can reach to 4000 vehicles per hour.

Synthesizing the mainline operation on the five expressways, it can be seen that SR 408 and SR 528 share similar traffic pattern and SR 417 and SR 429 share the similar traffic pattern. Considering the expressway locations in Figure 2-1, it can be seen that in the morning, traveling directions that experience higher demand is towards downtown Orlando while in the evening the direction is opposite. This pattern is straightforward considering the function of downtown area and should be taken into account for further analysis.

Table 3-1 Expressway System Operation Overview

Traveling Direction	Expressway	Direction of Morning Peak Hour	Segments with High Hourly Volume	Direction of Evening Peak Hour	Segments with High Hourly volume
EB – WB	SR 408	WB	MP 11 -- MP 17	EB	MP 11 -- MP 17
EB -- WB	SR 528	WB	MP 09 -- MP 13	EB	MP 09 -- MP 13
EB -- WB	SR 414	EB	MP 04 -- MP 09	WB	MP 04 -- MP 09
NB -- SB	SR 417	SB	MP 27 -- MP 37	NB	MP 27-- MP 37
NB -- SB	SR 429	SB	MP 24-- MP 30	NB	MP 24 -- MP 30

Besides mainline traffic conditions, toll plaza cash lanes and ramps were also examined. In most cases, one MVDS sensor will be installed at the beginning of the toll plaza and another one will be installed at the end. Figure 3-3 and figures in Appendix G show the traffic on the cash lanes at the toll plazas on each expressway. It was found that on the five expressways, if the toll plaza is located on the segments with high hourly volume as listed in Table 3-1, the cash lanes are much likely to have daily volume on weekend higher than that on weekdays. On other segments, either the daily volumes on weekday and weekend for the cash lanes are similar to each other or the weekday has relatively higher daily traffic volume. These patterns might be explained by the land use property of the nearby area. If the segment is located near office, commercial or business area, then on weekdays the most users are expected to be frequent users who will use the express lanes and on weekend there might be more users who only occasionally use the expressways. If the segment is near residential area, fewer trips are expected on weekend than on weekdays.

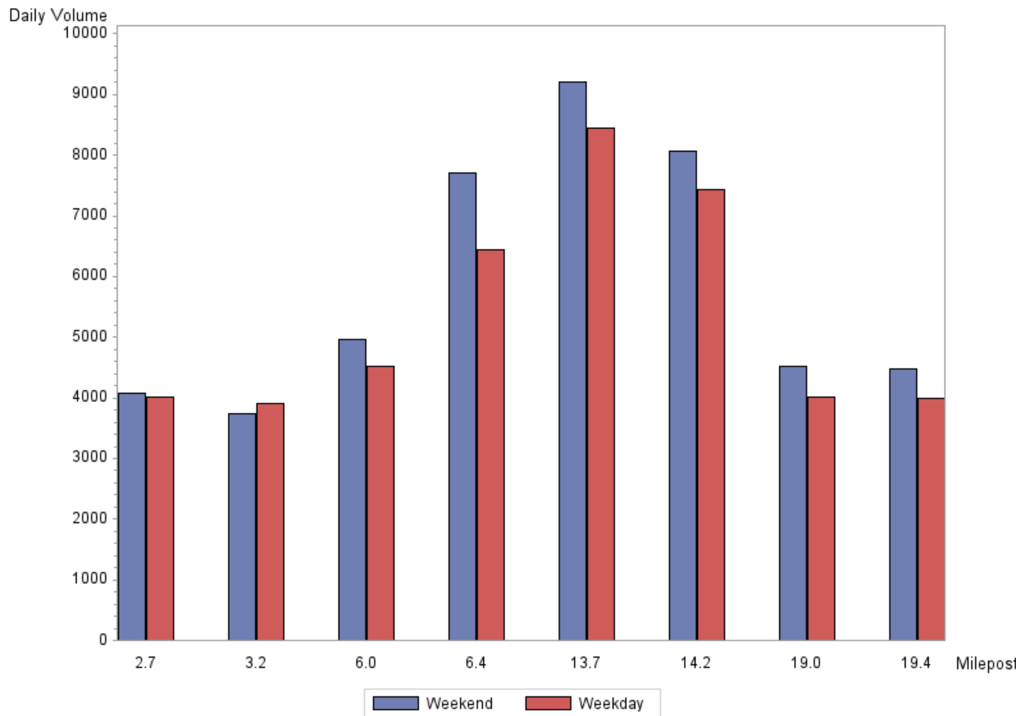


Figure 3-3 SR 408 Eastbound Toll Plaza Cash Lanes Traffic Volume

As shown in Figure 3-4 and in Appendix H, if a ramp is on-ramp, then its volume will be represented as a positive value. If a ramp is off-ramp, the volume will be negative indicating the traffic leaves the expressway system. SR 408 has several ramps with daily volume above 25000 vehicles per day on weekdays. On other expressways, high volume on ramps usually ranges from 10000 to 20000 vehicles per day. Considering the milepost of the ramps with high traffic volume, it can be found that most of these ramps are located near interchanges with other arterials that also have high traffic demand on weekdays.

By reviewing the traffic on expressway mainline, toll plaza cash lanes and ramps, a general impression of current expressway operation can be gained. For further evaluation, mainline operation will be thoroughly investigated. Ramps with daily volume higher than 10000 vehicles per day will also be studied. Since the toll plaza cash lanes are physically separated from the mainline and vehicles need to stop and pay tolls at the toll stations, they won't be the focus on this study.

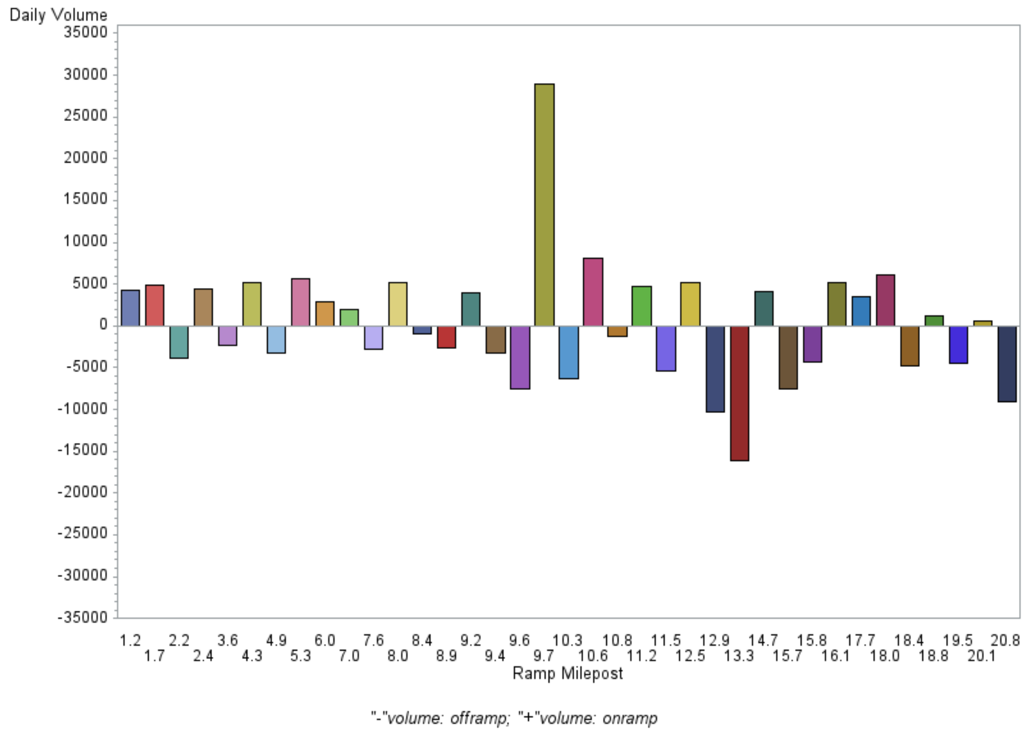


Figure 3-4 SR 408 Eastbound Weekday Ramp Traffic Volume

3.2 Congestion Measurement

Traffic operation on expressways focuses on providing motorists with efficient movement to their destinations. To achieve this goal, reducing congestion is the most important task. Measuring congestion accurately is a prerequisite in congestion management. Traditionally, volume-to-capacity (V/C) ratios and level of service (LOS) are implemented by transportation authorities as indicators of congestion intensity (*17*). Nevertheless, traffic demand can vary considerably in both temporal and spatial dimensions and roadway capacity can be reduced by incidents as discussed above. In such cases, V/C ratios and LOS lack the capability to capture the variability of congestion. With the fast development of ITS technology, real-time congestion measurement is becoming an urgent call. On the expressways, AVI and MVDS traffic detection systems are employed. Both of these systems archive the traffic data in real-time manner. In this project, multiple congestion measures were introduced and compared based on these two systems.

3.2.1 AVI-based Congestion Measurement

Congestion can be measured from three aspects, namely density, travel time and travel speed. AVI system is able to calculate the travel time of vehicles on a segment. Therefore, congestion measured by travel-time was introduced for the AVI system.

Travel time index (TTI) is the commonly accepted measure used to evaluate traffic congestion. It is defined as the ratio of actual travel time to an ideal (free-flow) travel time (*18*) as shown in Equation (2)

$$\text{TTI} = \frac{\text{actual travel time}}{\text{free flow travel time}} \tag{2}$$

It indicates the additional time spent on a trip made during peak traffic hours compared to an ideal trip on the same corridor. On CFX expressway system, free flow travel time for each segment is offered in AVI traffic data. Free flow travel time is calculated based on segment length and average speed limit. Average speed limit of a segment accounts for that speed limits may vary within the segment. From the Enhancing Expressway Operations Using Travel Time Performance Data (*19*), the levels of congestion and the corresponding travel time index for the studied expressways are listed in Table 3-2:

Table 3-2 Travel Time Index and Congestion Levels

Functional Class	Travel Time Index for different Congestion Levels		
	Below congestion threshold	Moderate Congestion	High Congestion
Freeway	Less than 1.25	1.25 – 1.99	Higher than 2.00

3.2.2 MVDS-based Congestion Measurement

Different from AVI system, MVDS sensors reflect the traffic conditions at the installed points rather than segments. Speed, volume and lane occupancy will be archived on one-minute interval basis.

Multiple congestion measures can be developed from the MVDS traffic data. Occupancy is defined as the percent of time a point on the road is occupied by vehicles (*20*). Gerlough and Huber (*21*) referred to occupancy as a surrogate for density. Compared with traditional V/C Ratio or LOS, occupancy has the advantage that it could be monitored in real-time.

The speed detected by MVDS detector is spot speed and the rate of reduction in speed caused by congestion from the free flow speed condition is adopted as congestion index (*12; 22*). The congestion index (CI) is expressed as

$$\mathrm{CI} \; = \frac{\text{free flow speed} - \text{actual speed}}{\text{free flow speed}} \times 100\% \text{ when CI} > 0; \qquad (3)$$

$$= 0 \text{ when CI} \leq 0$$

The CI is a continuous congestion indicator ranging from 0 to 1. The free flow speed is the 85^{th} percentile speed at the corresponding detection point. From equation (3) above it can be seen that when the actual speed is above free flow speed, CI will be recorded as 0. When CI increases, the congestion becomes more severe.

Currently, for the congestion measures calculated from MVDS data, no specific relationship between occupancy/CI and level of congestion is available. However, the TTI value of 1.25 and 2 are approximately equivalent to CI value of 0.2 and 0.5. And According to the congestion plots, when CI reaches 0.2 and 0.5, the corresponding occupancy (%) is about 15 and 25. Therefore, the research team set up the following congestion levels defined by occupancy and CI as displayed in Table 3-3. Nevertheless, further refinement of these thresholds might be possible.

Table 3-3 MVDS-Based Congestion Measures and Congestion Levels

Congestion Measure	Expressway Congestion Levels		
	Below congestion threshold	Moderate Congestion	High Congestion
Occupancy (%)	≤ 15	15 – 24.99	≥ 25
CI	≤ 0.2	0.2 – 0.499	≥ 0.5

In conclusion, expressway mainline congestion will be evaluated using the three congestion measures using traffic data from the two traffic detection systems. For ramps, only occupancy and CI could be used since no AVI segment is available on ramps.

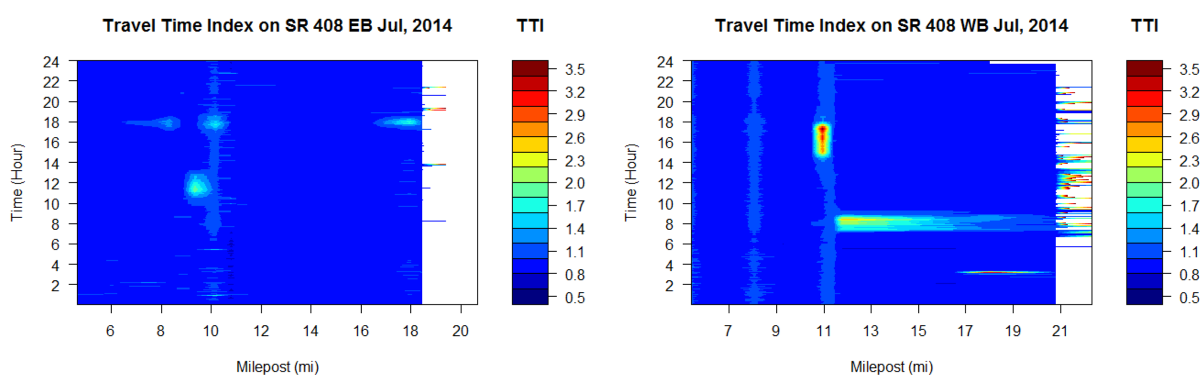
3.3 Expressway Congestion Evaluation

3.3.1 Mainline Congestion

Two major efforts of have been made to evaluate the congestion for the expressways. One is the evaluation of spatial-temporal distribution of current congestion on the expressways. The other effort is to identify the trend of congestion during the past one year to determine whether congestion is worsened or alleviated on the expressways. For this longitudinal comparison, five months during the past year was selected considering the availability of traffic data.

To measure current expressway congestion conditions, the traffic data were aggregated at five-minute interval and averaged by the weekdays for each month. Contour plots were generated to illustrate the spatial-temporal property of the congestion.

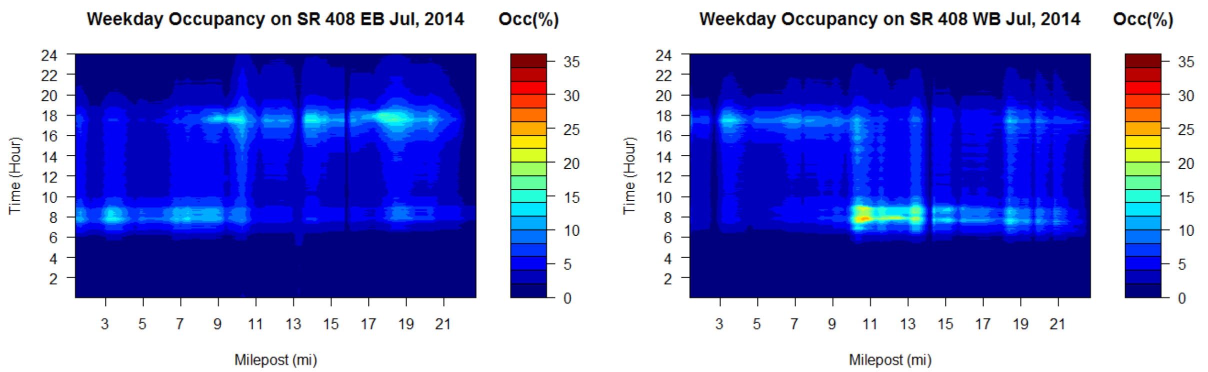
The TTI congestion plot shown in Figure 3-5 show a proportion of data near MP 3.0 and MP 20 were missing for both directions in July, 2014. As mentioned in the section about AVI system, the expressway system undertook major update in April, 2014. As a result, in the recent three months (May, 2014 – July, 2014) the AVI traffic data have the similar issues. For specific segments, no records were available during specific time period. Despite the incompleteness of the AVI data, some patterns could still be found from Figure 3-5, on SR 408 Eastbound, congestion is found near MP 9.0 and MP 18 in the evening peak hours. On SR 408 Westbound, morning congestion is observed from MP 11 to MP 15. These congestion patterns could also be found in Figure 3-6 and Figure 3-7, indicating that AVI data could reflect congestion to certain extent. However, it is still important to have the complete data to evaluate the performance of AVI-based congestion measure. In the following analysis, TTI won't be used to evaluate the current congestion on the system due to this data completeness issue.



(a) (b)

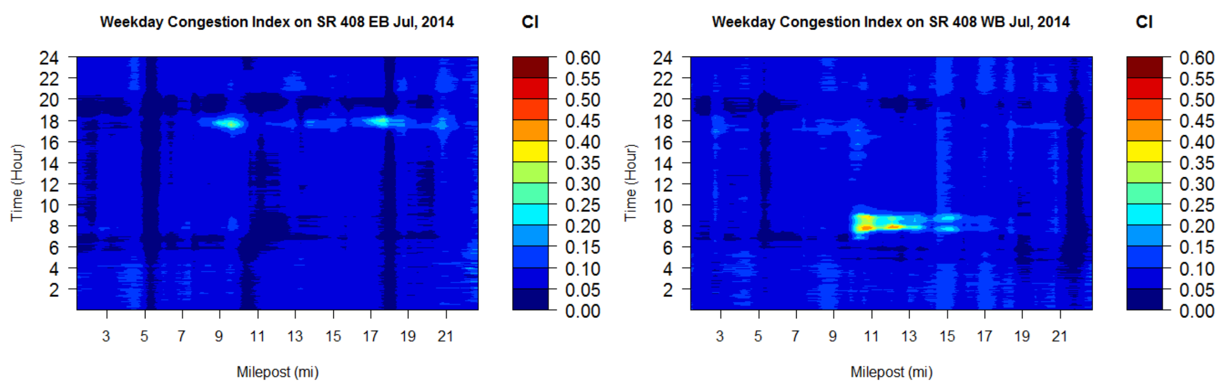
Figure 3-5 Mainline Weekday Travel Time Index of SR 408 (a) Eastbound and (b) Westbound

The congestion plots derived from occupancy and CI (Figure 3-6, Appendix I, Figure 3-7 and Appendix J) exhibit comparable congestion patterns for the expressways. As mentioned above, the number of MVDS sensors installed along the expressways is significantly more than that of the AVI sensors. In addition, the MVDS system is stable in terms of active sensors during the study time period. Therefore, the MVDS data is relatively complete and stable.



(a) (b)

Figure 3-6 Mainline Weekday Occupancy of SR 408 (a) Eastbound and (b) Westbound



(a) (b)

Figure 3-7 Mainline Weekday Congestion Index of SR 408 (a) Eastbound and (b) Westbound

Based on occupancy and CI, congestion conditions on the five expressways can be summarized. SR 408 experiences moderate congestion on Eastbound in morning peak hours and high congestion on Westbound in the evening peak hours. However, it should be noticed that the congestion intensity changes with time. When it is approaching peak hours, the congestion intensity gradually increases. Once the peak time is passed, the congestion becomes less severe. The congested area for SR 408 is approximately from MP 17 to MP 19 on Eastbound and from

MP 10 to MP 13 on Westbound. For SR 414, only the Eastbound experiences moderate congestion during morning peak hours, the congested segment is near MP 9.3. For SR 417, both directions experience moderate congestion during evening peak hours, the congested segments are short, only near the interchanges with University Blvd which leads to University of Central Florida. No congestion was detected on SR 429. On SR 528, congestion is detected on Eastbound in the evening and on Westbound in the morning.

In conclusion, based on the most recent MVDS data, the five expressways show distinct congestion patterns. SR 408 is affected by congestion most significantly. SR 528 also experience high congestion on the segment near MP 10 to MP 12. SR 417 and SR 528 only expect moderate congestion on specific locations for short time intervals. SR 429 has no congestion either in the morning or evening peak hours.

In the above congestion evaluation, the three candidate congestion measures were all applied. For a more detailed assessment of their performance, one segment on SR 408 Westbound with traffic data from February 2014 was extracted for the comparison. The selected AVI segment runs from MP 16.488 to MP 15.245. Within the AVI segment, five MVDS sensors are installed at the locations as shown in Figure 3-8.

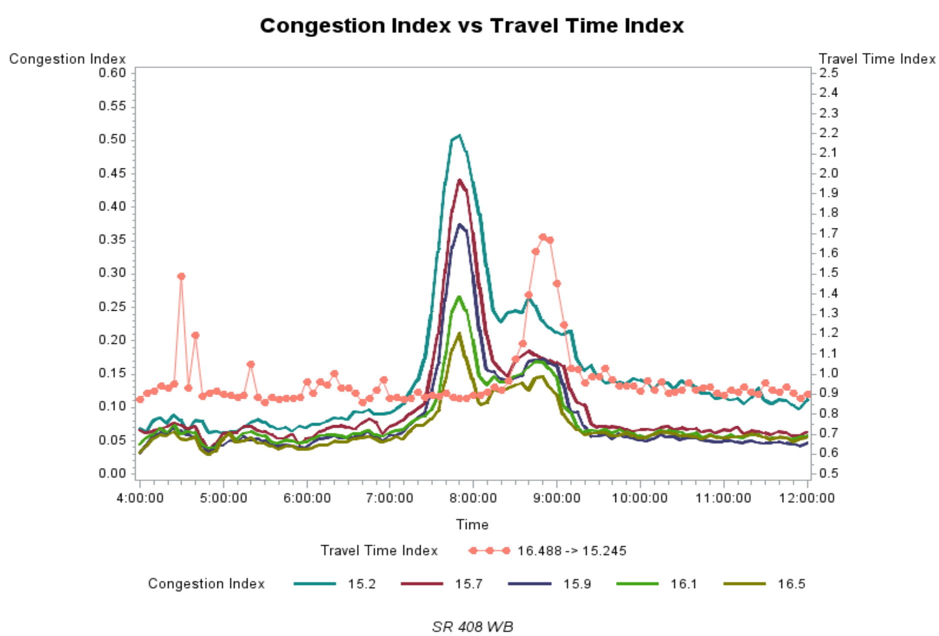


Figure 3-8 AVI-based TTI Profile vs MVDS-based Congestion Index Profile

The Figure 3-8 indicates that in the morning peak hours, both MVDS and AVI detect congestion on the segment. However, there is about one hour lag for the peak between the two types of data. The time period for congestion by the CI is considered more reliable since congestion was mostly found from 7:00 AM to 9:00 AM. On the other hand, congestion by TTI occurred from 8:30 AM to 9:30 AM. Furthermore, CIs from MVDS sensors within one AVI segment differ from each other. Downstream (MP 15.2) has the highest congestion intensity and upstream (16.5) has the lowest congestion intensity. However, the AVI data could not reflect this detail. The high deployment density of the MVDS system ensures better reflection of the congestion of at different locations within a queue.

Occupancy and CI are both derived from MVDS system. Therefore their performances in congestion detection are similar (Figure 3-9) according to several detectors. These findings imply that MVDS traffic data is more appropriate for congestion monitoring for several reasons: 1) MVDS system works in a more reliable manner, thus resulting in more complete data; 2) MVDS system has much more sensors than AVI system, consequently generating more detailed information about the expressways.

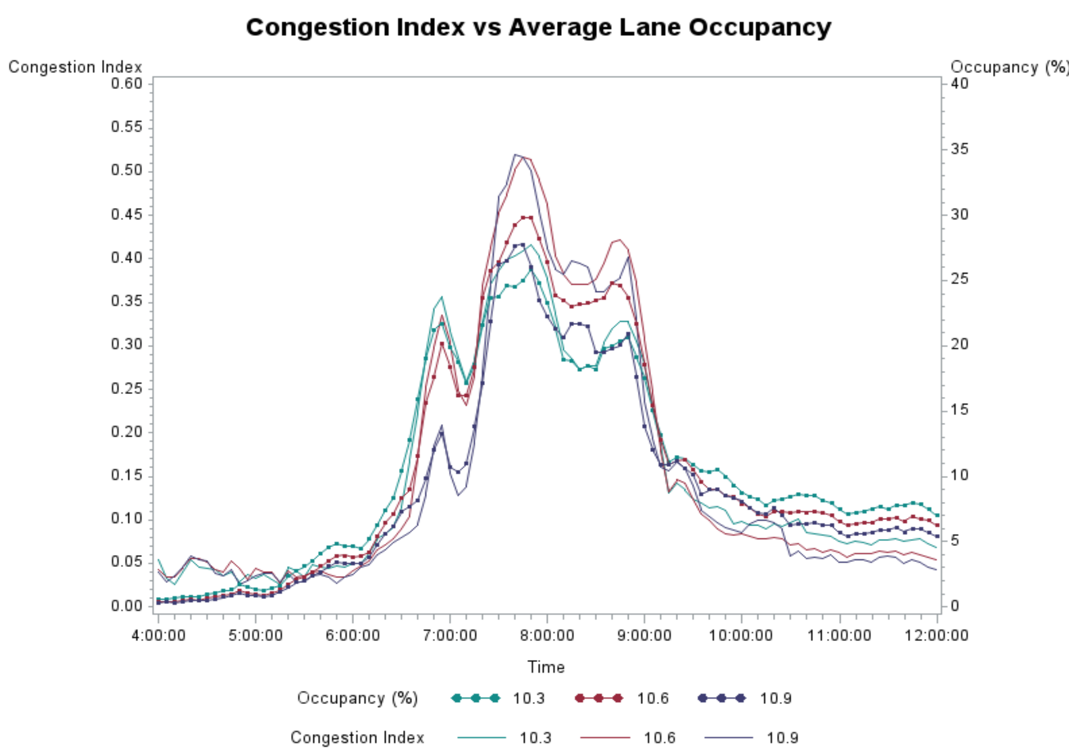


Figure 3-9 MVDS-based Congestion Index and Occupancy

In addition to the analysis of current congestion conditions on the expressways, the longitudinal trend of congestion during the past one year was also examined using the MVDS data. Five months, namely July 2014, May 2014, February 2014, November 2013 and August 2013 were selected. To see the trend of congestion, the system occupancy and CI were defined and calculated. The system occupancy and CI are the average occupancy and CI from all the MVDS sensors. They are used to represent the general congestion condition on the expressway (Figure 3-10, Figure 3-12, Appendix K and Appendix M). After the system congestion for each expressway is generated, the peak congested time can be identified. Then the detailed congestion information at different locations of the expressways at the time when the system congestion intensity is the highest can be evaluated (Figure 3-11, Figure 3-13, Appendix L and Appendix N). Overall, the longitudinal congestion evaluation consists of two parts, 1) whether the congestion has been alleviated during the last year for the whole expressway; 2) what are the changes for each specific location regarding to congestion intensity. The evaluation was conducted using both occupancy and CI.

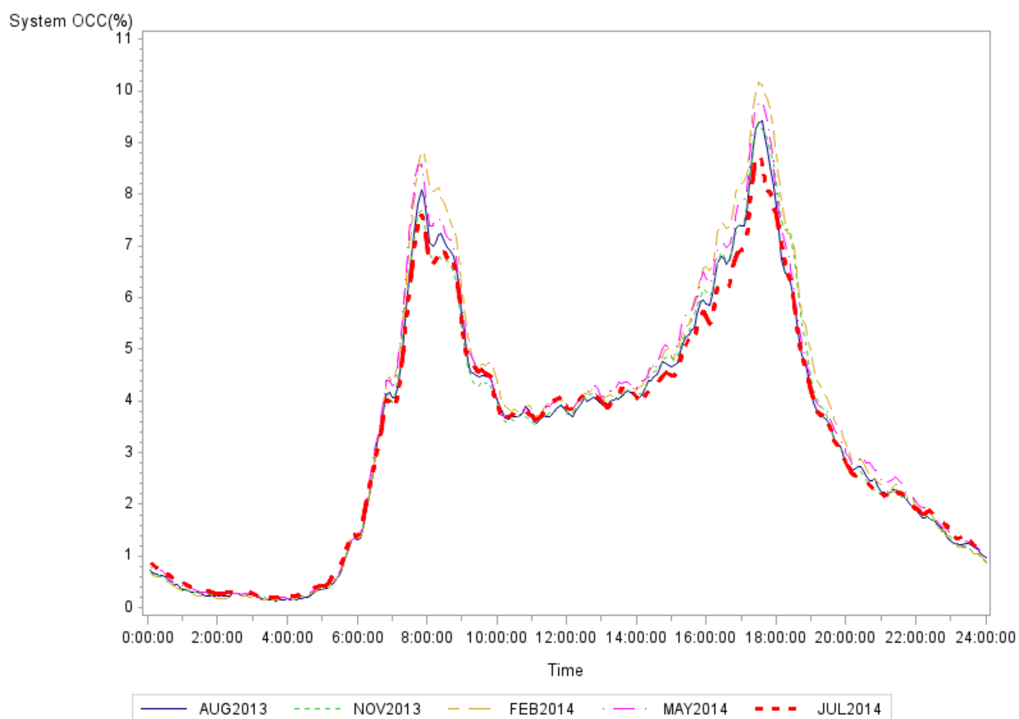


Figure 3-10 SR 408 Eastbound System Occupancy and Trend of Congestion

From a system point of view, Figure 3-10, Figure 3-12, etc. all confirmed that on SR 408, congestion is alleviated significantly in the recent month. Of the five months, both SR 408 Eastbound and SR 408 Westbound have the lowest system CI and occupancy. SR 408 is known as the spine of the expressway network since it carries the heaviest traffic load among the five expressways. Congestion on SR 408 is also the most severe compared with other expressways within the system. As a consequence, reduction in congestion intensity proves significant improvement in traffic operation. The same conclusion can be reached for SR 414. For SR 417 and SR 429, the improvement is not that significant yet congestion is not worsened. For SR 528, the conclusions from CI and occupancy diverge a little. According to the system occupancy, congestion conditions in the two months of 2013 were better than those in the three months of 2014. On the contrary, the system CI indicates that the three months in 2014 have less severe congestion than the two months in 2013. Nevertheless, at the system level, it cannot be judged that congestion on SR 528 has been improved significantly.

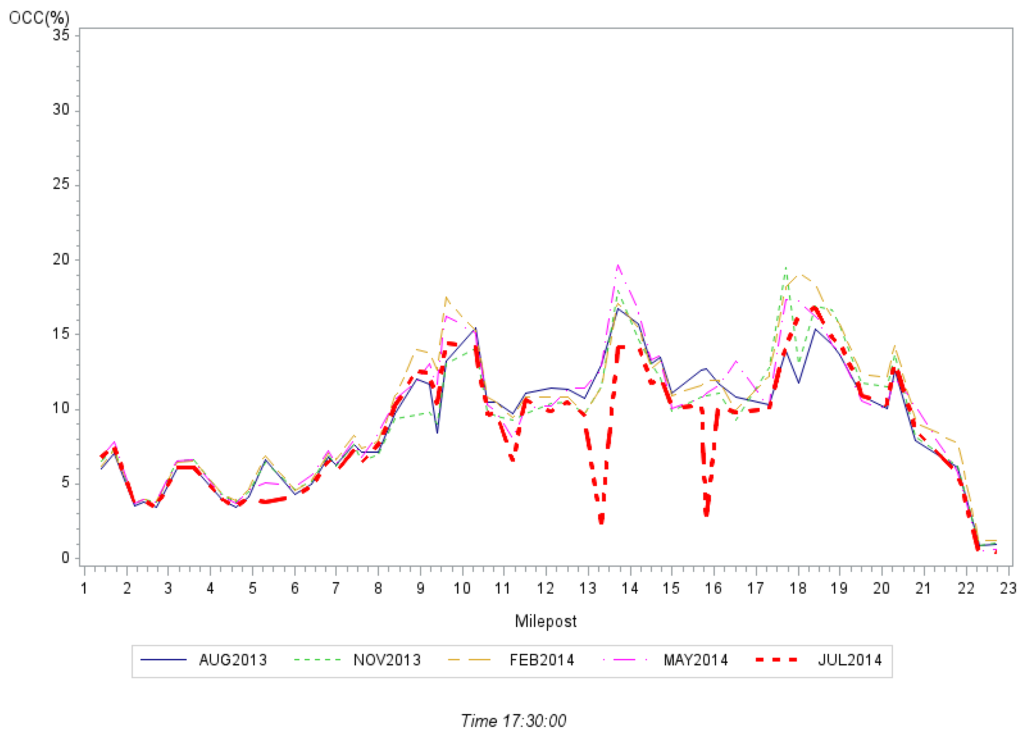


Figure 3-11 SR 408 Eastbound Peak Hour Occupancy and Trend of Congestion

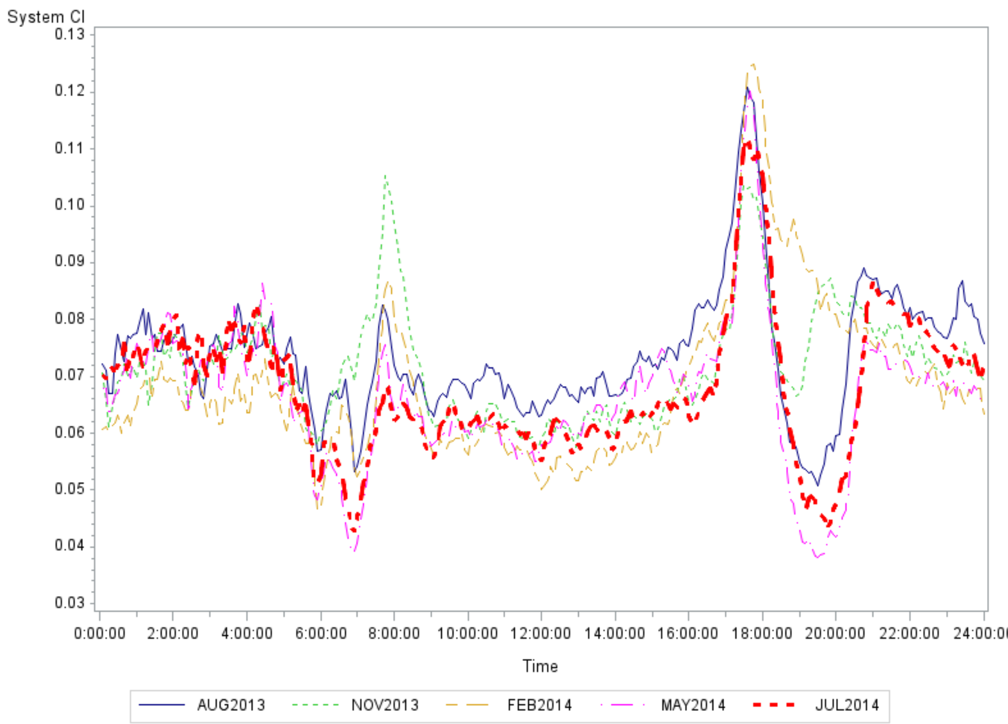


Figure 3-12 SR 408 Eastbound System Congestion Index and Trend of Congestion

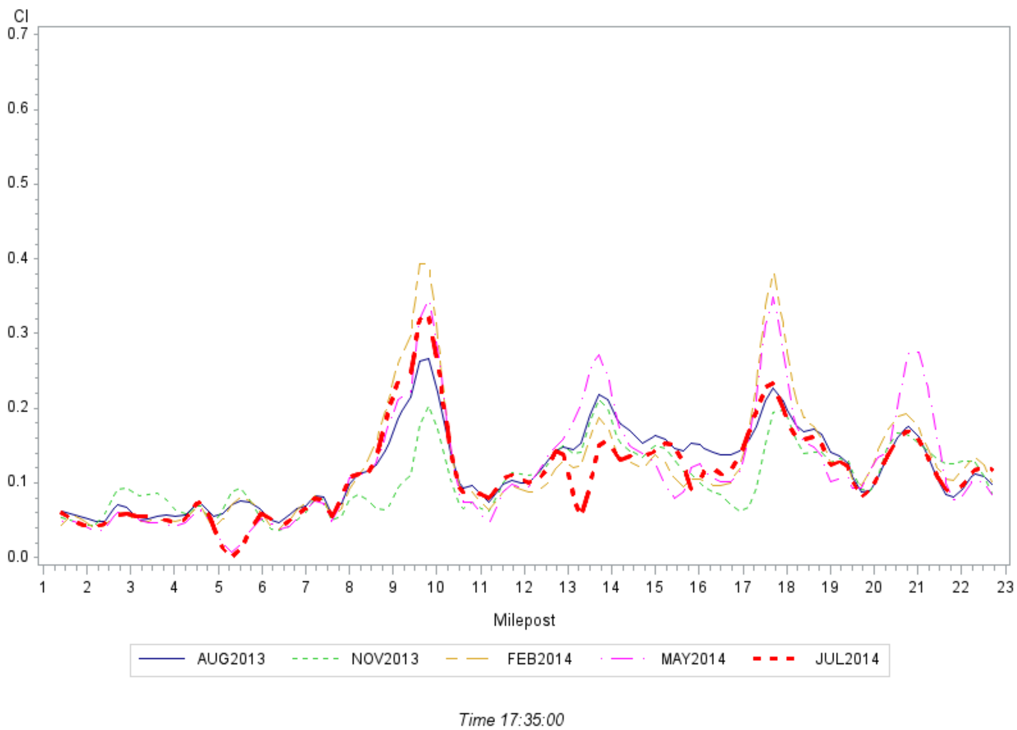


Figure 3-13 SR 408 Eastbound Peak Hour Congestion Index and Trend of Congestion

Based on the system congestion evaluation, the exact time when the system reaches the peak congestion intensity can be identified. Congestion conditions at each detection point at this peak time were extracted for SR 408, SR 417 and SR 528. SR 414 and SR 429 were excluded because for SR 414 only one detection point has congestion and for SR 429 there is no congestion detected. This effort provides some insights into the trend of congestion at different locations along the road.

For SR 408 Eastbound (Figure 3-11 and Figure 3-13), congestion intensity measured by occupancy and CI implies that the congested segments experience relatively less severe congestion compared with February and May 2014, but not necessarily better than 2013. For Westbound, the alleviation of congestion at congested segments is significant.

For SR 417, congestion intensity remains stable during the past one year according to occupancy. Based on CI, congestion increased near MP 31 for both Northbound and Southbound increased in a small amount. In conclusion, the congestion conditions on SR 417 did not change significantly.

For SR 528, congestion concentrated on the segment near MP 10 for both Eastbound and Westbound. Comparing the congestion at this segment in the five months during the past one year, it is suggested by both CI and occupancy that significant reduction of congestion intensity has been achieved.

As a result, the longitudinal analysis confirms operation improvement on SR 408, SR 414 and congested segments on SR 528. SR 417 and SR 429 remain stable during the past one year. Considering SR 408 and SR 528 are the expressways that experience most congestion, significant improvement on these two expressways indicate the successful management by the CFX.

3.3.2 Ramp Congestion

Ramps on the expressways lead the vehicles into the mainline and divert the vehicles out of the system. When congestion occurs on off-ramps, queues can build up on the mainline and affect the mainline congestion and safety. When congestion occurs on on-ramps, traveling speed on mainline and ramps are likely to differ significantly. The variation of speed near the merging area can greatly affect the mainline speed as well as probability of sideswipe crashes. Identifying ramps experiencing congestion will help improve both operation and safety on the expressways.

SR 408 has 37 ramps on Eastbound and 37 ramps on Westbound. SR 414 Eastbound has 8 ramps and SR 414 Westbound has 7 ramps. There are 31 ramps located on SR 417 Northbound and 32 ramps on SR 417 Southbound. SR 429 contains 17 ramps on Northbound and 16 ramps on Southbound. For SR 528, 19 ramps are on the Eastbound and 18 ramps on the Westbound. To identify the ramps that experience congestion, only the ramps having more than 10000 vehicles per day on weekdays were selected. If the ramps have less volume, they are unlikely to have congestion. Both occupancy and CI were used to evaluate the congestion conditions on the ramps.

As seen in Figure 3-14 and Figure 3-15 and figures in Appendix O and Appendix P, several ramps experience congestion during the peak hours. For SR 414, SR 417 and SR 528, the ramps on the three expressways were found to have no congestion on them. The on-ramp at MP 9.7 on SR 408 Eastbound has moderate congestion during the evening peak hours according to the profile of CI. This on-ramp has relative high occupancy for most time of the day. The location of this on ramp is at the interchange of SR408 and I-4 in downtown Orlando. On SR 408 Westbound, congestion occurs on two off-ramps in the morning peak hours, at MP 9.9 and MP 10.3 respectively. Off-ramp at MP 9.9 takes vehicles off the expressway to I-4 Westbound and off-ramp at MP 10.3 takes vehicles from SR 408 to I-4 Eastbound. The congestion on SR 408 ramps indicate that in the morning, more traffic is traveling from I-4 to SR 408 while in the evening more vehicles are traveling from SR 408 to I-4.Except the ramps on SR 408, only one ramp on SR 429 was found to have congestion. The off-ramp is at MP 19.8 of SR 429 Southbound. During the evening peak hours, both CI and occupancy increased significantly and indicate moderate congestion. This congested ramp is located next to Winter Garden Village, a big shopping center and residential area. The land use property of this region explains why congestion is found on this particular ramp.

Results of the ramp congestion evaluation identify four ramps on the expressways that experience congestion. Three of the ramps are on SR 408 and one on SR 429. In addition, three of the four ramps are off-ramps and one is on ramp. Future operation improvement should also take these ramps into consideration.

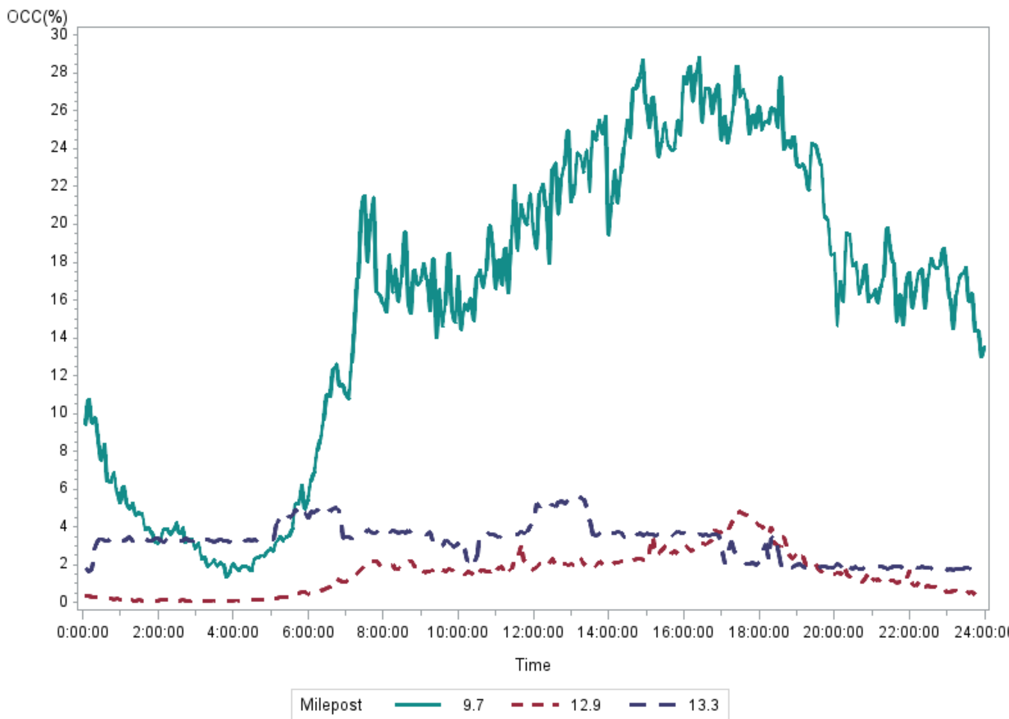


Figure 3-14 SR 408 Eastbound Ramp Occupancy Profile

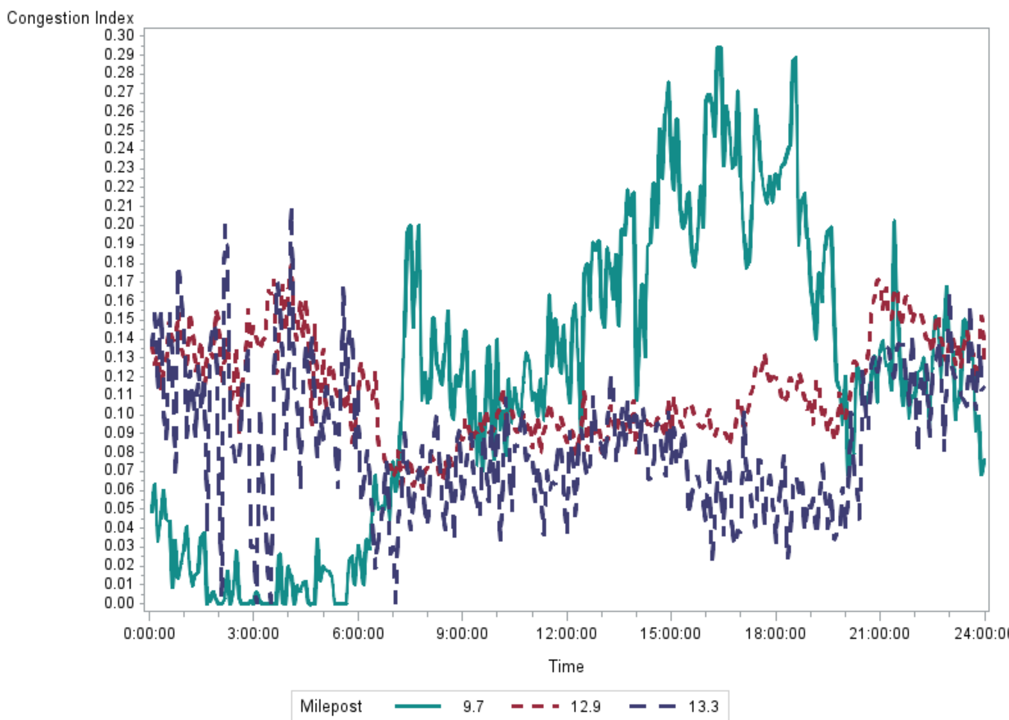


Figure 3-15 SR 408 Eastbound Ramp Congestion Index Profile

4 DMS APPLICATION IN CONGESTION MANAGEMENT

4.1 DMS Application in Queue Warning

Traffic congestion results in travel delay, excess fuel consumption and congestion costs. In 2010, Orlando ranked the 3rd in Florida in terms of the above three standards (38,260,000 hours delay, 11,883,000 gallons excess fuel, and 811 million dollars congestion costs) (*23*).

Traditionally, increasing road capacity has been a common countermeasure to alleviate congestion. Due to the limited land resources, public investment and increasing travel demand, only adding more capacity to the system is not a long-term solution. Public transportation, road pricing and other measures to reduce traffic are also encouraged or implemented to ease traffic congestion. However, these steps are not able to change the current supply and demand greatly and quickly enough. Consequently, traffic management is crucial in order to enhance the efficiency of the road and lessen the intensity of congestion.

Recent years saw the rise of active traffic management (ATM). It is a combination of congestion management techniques. The goal of the ATM strategies is to better the roadway system's performance on road segments experiencing frequent congestion, or susceptible to crashes, bottlenecks and adverse weather conditions.

4.1.1 Queue Warning

Queue warning is a strategy to warn drivers of upcoming congestion and allow drivers enough time in advance to make decisions whether to detour or stay on the route. From a safety perspective it also allows drivers enough decision and reaction time to slow down. Dynamic message signs (DMS) are the most common media to convey the traffic information to upstream drivers. Variable speed limits and lane control signals often work together with queue warning signs.

The potential benefits offered by the queue warning system include prevention of primary and secondary crashes (also the severity is expected to be reduced), delay of the onset of congestion, and travel time improvement. The basic principle behind queue warning is alerting the drivers to congestion conditions, drivers' caution will rise, and more smooth and uniform traffic flow be achieved.

4.1.2 Queue Warning Implementation

In Germany, the queue warning system involves displaying a congestion pictograph on each side of the speed harmonization gantry or DMS indicating congestion ahead. The gantries are generally spaced 1 km apart, and the system typically begins reducing speeds between three and four gantries before an incident. It was also noted that users are interested in knowing the location of the queue and what route they should take to avoid it (*24*).

The Netherlands alerts travelers to congestion and queues by flashing lights and speed signs on variable speed limit signs. The system, generally located every 500 m, provides queue tail warning and protection in known bottleneck locations. The Dutch have seen definite benefits from their congestion warning system. The throughput increased and incidents decreased (*24*).

Researchers from the Netherlands interviewed morning drivers about the queue warning signs. The drivers comments on the signs indicated some important issues such as that the first sign should be placed further in advance so that drivers could still take another road (*25*).

In Canada, Highway 402 installed the queue warning system. They remind the drivers of the location of congestion downstream using the system. They had demonstrated that the implementation of the system was a success in terms of rear end collision reduction on this road (*26*).

In Sweden, Belgium and France, the queue warning systems have all been successfully applied.

In United States, it is recommended that the queue warning message displays should be implemented at regular intervals based on dynamic traffic detection. It is also suggested that the queue warning system should work in conjunction with speed harmonization (*24*).

4.1.3 Placement of Queue Warning Signs

Exact guidelines about the placement of queue warning signs in the United States were not found. Only general principles have been discussed, which is presented in the previous section.

The Manual on Uniform Traffic Control Devices (MUTCD) 2009 edition addresses the placement of warning signs as in Table 4-1. The warning signs should leave the drivers with adequate Perception-Response Time (PRT) to make corresponding adjustment. However, it is stated that the distance between the sign and the warned location should not be too far, such that drivers might tend to forget the warnings, especially in urban areas.

Table 4-1 Guidelines for Placement of Warning Signs (adapted from MUTCD 2009)

Posted or 85th-Percentile Speed	Advance Placement Distance[1]								
	Condition A: Speed reduction and lane changing in heavy traffic[2]	Condition B: Deceleration to the listed advisory speed (mph) for the condition							
		0[3]	10[4]	20[4]	30[4]	40[4]	50[4]	60[4]	70[4]
20 mph	225 ft	100 ft[6]	N/A[5]	--	--	--	--	--	--
25 mph	325 ft	100 ft[6]	N/A[5]	N/A[5]	--	--	--	--	--
30 mph	460 ft	100 ft[6]	N/A[5]	N/A[5]	--	--	--	--	--
35 mph	565 ft	100 ft[6]	N/A[5]	N/A[5]	N/A[5]	--	--	--	--
40 mph	670 ft	125 ft	100 ft[6]	100 ft[6]	N/A[5]	--	--	--	--
45 mph	775 ft	175 ft	125 ft	100 ft[6]	100 ft[6]	N/A[5]	--	--	--
50 mph	885 ft	250 ft	200 ft	175 ft	125 ft	100 ft[6]	--	--	--
55 mph	990 ft	325 ft	275 ft	225 ft	200 ft	125 ft	N/A[5]	--	--
60 mph	1,100 ft	400 ft	350 ft	325 ft	275 ft	200 ft	100 ft[6]	--	--
65 mph	1,200 ft	475 ft	450 ft	400 ft	350 ft	275 ft	200 ft	100 ft[6]	--
70 mph	1,250 ft	550 ft	525 ft	500 ft	450 ft	375 ft	275 ft	150 ft	--
75 mph	1,350 ft	650 ft	625 ft	600 ft	550 ft	475 ft	375 ft	250 ft	100 ft[6]

[1] The distances are adjusted for a sign legibility distance of 180 feet for Condition A. The distances for Condition B have been adjusted for a sign legibility distance of 250 feet, which is appropriate for an alignment warning symbol sign. For Conditions A and B, warning signs with less than 6-inch legend or more than four words, a minimum of 100 feet should be added to the advance placement distance to provide adequate legibility of the warning sign.

[2] Typical conditions are locations where the road user must use extra time to adjust speed and change lanes in heavy traffic because of a complex driving situation. Typical signs are Merge and Right Lane Ends. The distances are determined by providing the driver a PRT of 14.0 to 14.5 seconds for vehicle maneuvers (2005 AASHTO Policy, Exhibit 3-3, Decision Sight Distance, Avoidance Maneuver E) minus the legibility distance of 180 feet for the appropriate sign.

[3] Typical condition is the warning of a potential stop situation. Typical signs are Stop Ahead, Yield Ahead, Signal Ahead, and Intersection Warning signs. The distances are based on the 2005 AASHTO Policy, Exhibit 3-1, Stopping Sight Distance, providing a PRT of 2.5 seconds, a deceleration rate of 11.2 feet/second^2, minus the sign legibility distance of 180 feet.

[4] Typical conditions are locations where the road user must decrease speed to maneuver through the warned condition. Typical signs are Turn, Curve, Reverse Turn, or Reverse Curve. The distance is determined by providing a 2.5 second PRT, a vehicle deceleration rate of 10 feet/second^2, minus the sign legibility distance of 250 feet.

[5] No suggested distances are provided for these speeds, as the placement location is dependent on site conditions and other signing. An alignment warning sign may be placed anywhere from the point of curvature up to 100 feet in advance of the curve. However, the alignment warning sign should be installed in advance of the curve and at least 100 feet from any other signs.

[6] The minimum advance placement distance is listed as 100 feet to provide adequate spacing between signs.

In California Department of Transportation's Traffic Manual Chapter 4 about signs, the placement of warning signs is also specified. They state that in rural areas, the warning signs should normally be placed about 150m (0.09mi) in advance of the conditions. On high-speed roads, particularly on freeways, the advance warning distance may have to be as great as 450m (0.28mi) or more (*27*). These standards are similar to those provided by MUTCD.

These guidelines are designed for general warning signs. However, the property of queue warning message signs is different. The MUTCD's criterion is based on PRT and adjusted for sign legibility distance. Following these guidelines, the drivers will be informed of upcoming congestion and slow down accordingly, which is adequate to avert hitting the back of the queue. Nevertheless, it might not be sufficient for detour, as a problem raised by the aforementioned Dutch study.

From the perspective of offering drivers alternative routes, it is critical that after the drivers see the queue warning message that there will still be an off-ramp upstream of the congested area. Only in this case would the driver be able to make a decision of route choice.

4.2 Expressway Congestion Area and Suggested DMS Locations

On the expressways, the congestion areas have been identified in previous chapter. Based on the identified congested segments or locations, the DMS upstream can be used for congestion warning. Furthermore, for the congested ramps, DMS can also be used to remind motorists about the traffic condition on downstream ramps. In case that no DMS exists upstream to the congested segments, future DMS can be considered at these places.

Table 4-2 shows the congested segment on SR 408 Eastbound is located around MP 18. It can be seen from the table that the length of the queue changes over time. In total the congestion lasts for about 40 minutes from 17:30 PM to 18:10 PM. The maximum length of the queue was extracted to represent the congestion condition. According to the end of the queue when it is most congested, the upstream DMS is located. Figure 4-1 visually displays the congested segments and nearest upstream DMS. The beginning of queue (MP 18.4) is near the interchange with Dean Road and the end of the queue (MP 17.7) is at the interchange with SR 417. The nearest upstream DMS is at MP 15.2. The distance between the DMS and end of queue is 2.5 miles, which can warn drivers when they approach the queue.

SR 408 Westbound as shown in Table 4-3, Figure 4-2 and Figure 4-3 has two queues in the morning peak hours. The first queue is near Orlando Executive Airport. The congestion exists from Conway Road Toll Plaza to the interchange with Semoran Blvd. One DMS is located at MP 15.2. The second queue is from the interchange with I-4 to interchange with Crystal Lake Drive, about 2.3 miles long. Although one DMS is found at MP 11.8 within the congested segment, no DMS upstream can be used for queue warning. Therefore, one DMS is suggested near MP 13.6 to MP 14.6 for potential implementation in the future for queue warning in Figure 4-3.

Table 4-2 SR 408 Eastbound Congestion Area

Hour	17						18	
Minute	30	35	40	45	50	55	0	5
Beginning of Queue	18.4	18.4	18.4	18.4	18.4	18	18	18
End of Queue	18	18	17.7	17.7	17.7	17.7	17.7	17.7

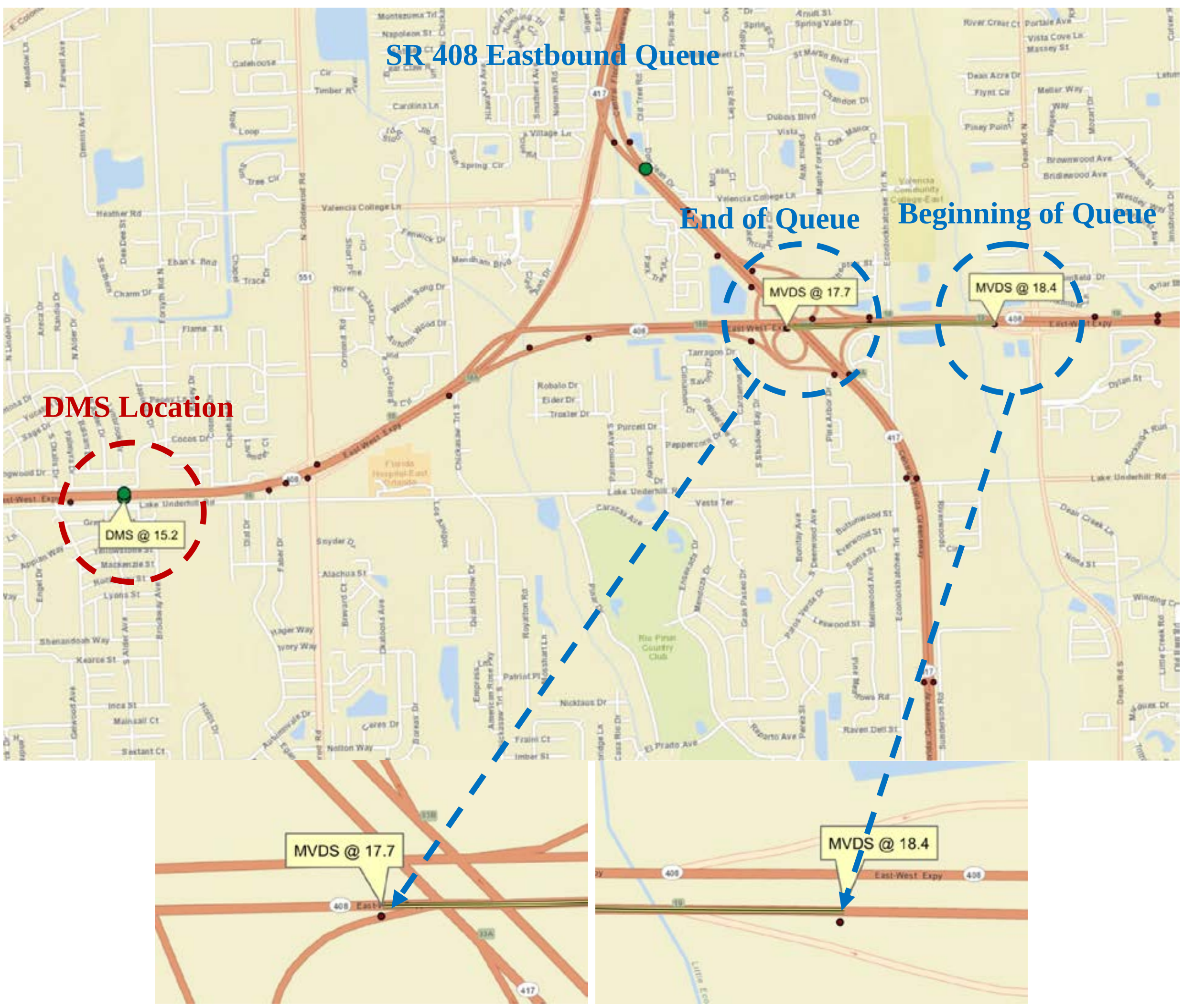


Figure 4-1 SR 408 Eastbound Congestion Segment and Upstream DMS Location

Table 4-3 SR 408 Westbound Congestion Area

Hour	7								8												9	
Minute	20	25	30	35	40	45	50	55	0	5	10	15	20	25	30	35	40	45	50	55	0	5
Beginning of Queue 1	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3		
End of Queue 1	13.6	13.6	13.6	13.6	13.6	14.4	14.4	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6		
Beginning of Queue 2	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
End of Queue 2	10.6	10.6	10.6	11.6	12.1	12.6	12.6	12.6	12.6	12.1	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	10.9	10.6	10.6

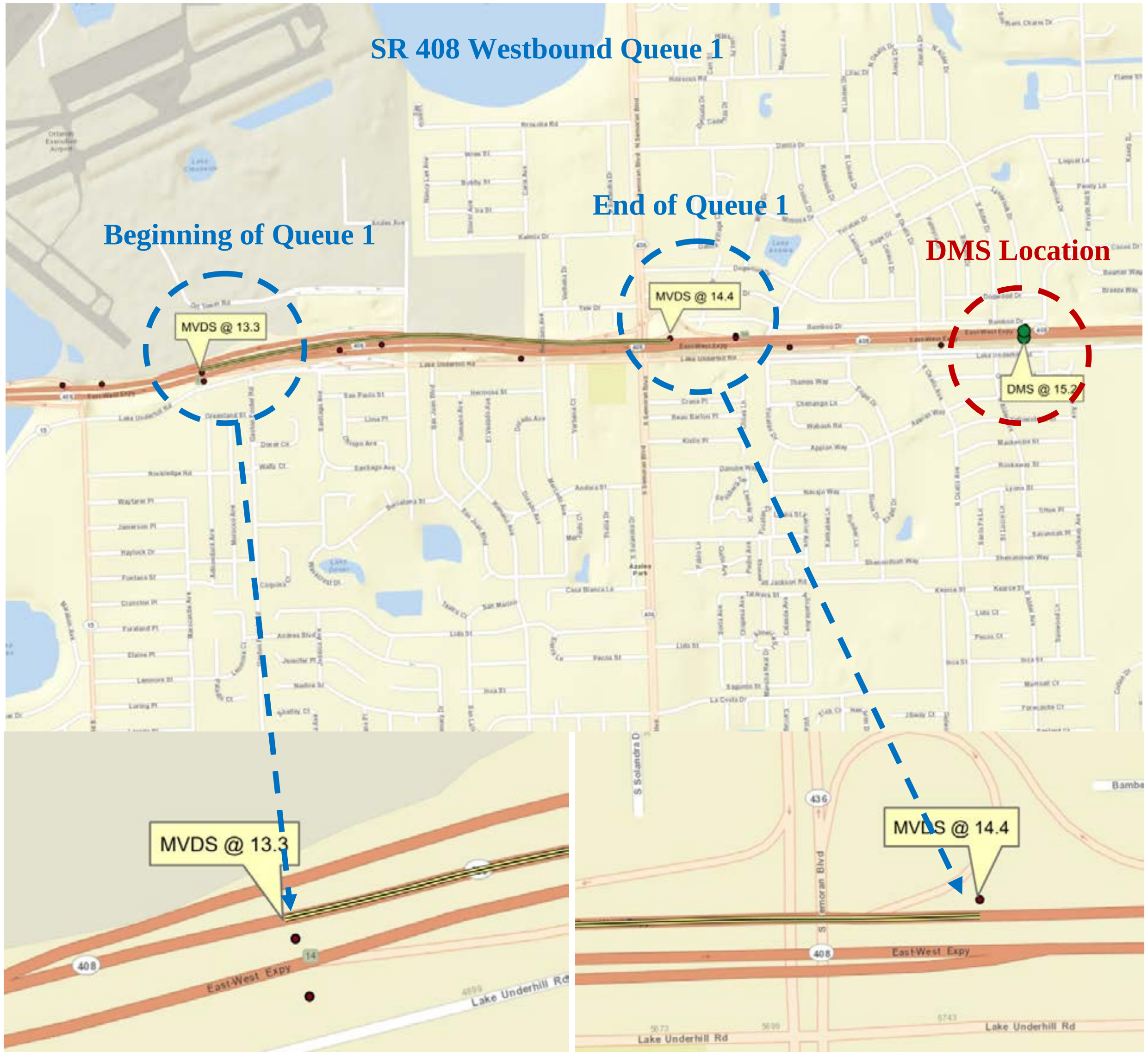


Figure 4-2 SR 408 Westbound Congestion Segment 1 and Upstream DMS Location

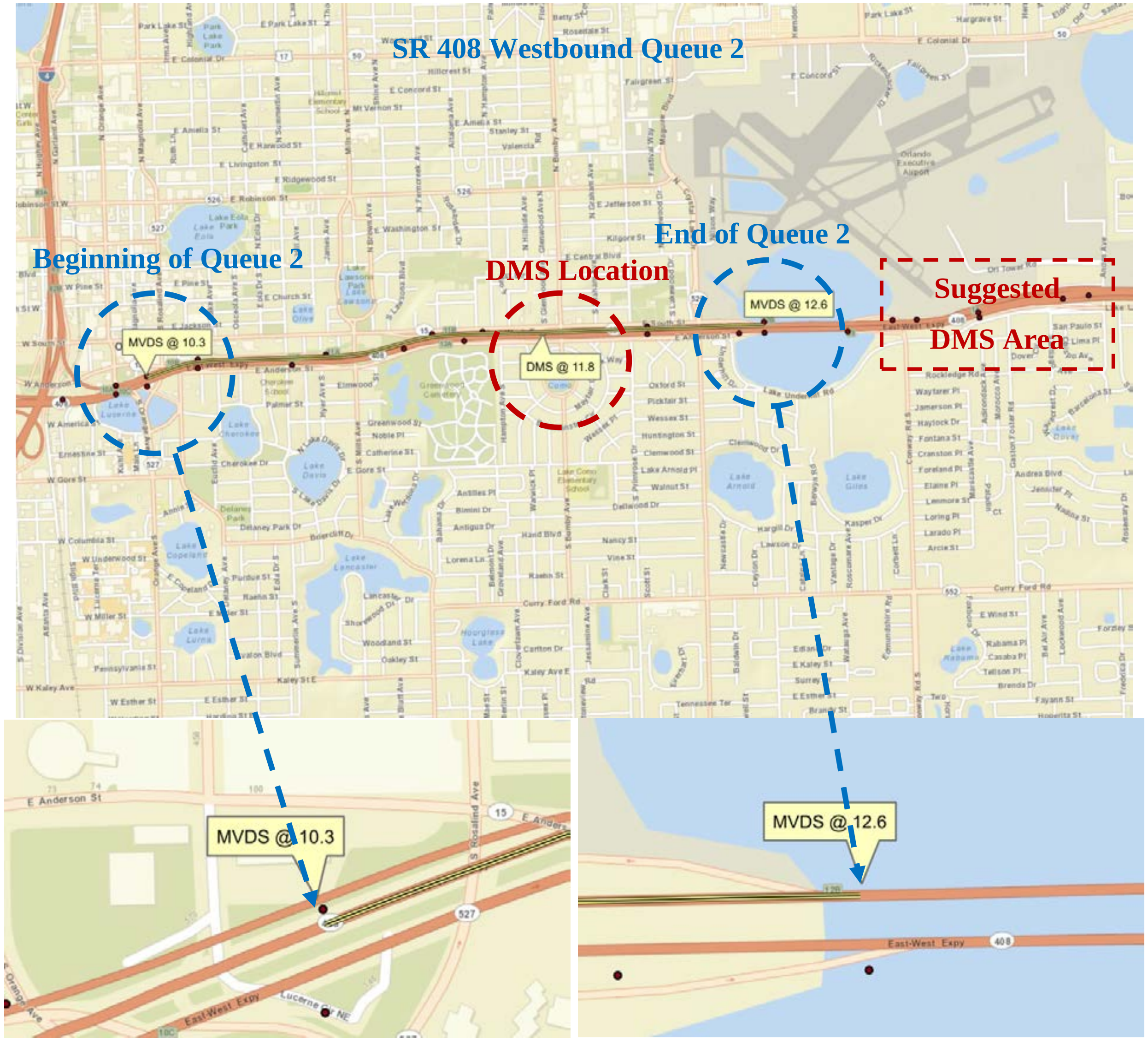


Figure 4-3 SR 408 Westbound Congestion Segment 2 and Suggested DMS Area

Congestion on SR 414, SR 417 and SR 528 and the existing or suggested DMS could be found in Appendix Q. On specific expressways, only one detector reports congestion. For these conditions, the place with congestion will be specified as congestion location. SR 414 Eastbound experiences congestion near the end of the roadway segment. Only one MVDS sensor at the interchange with Orange Blossom Trail detects congestion for around 15 minutes from 7:50 AM to 8:05 AM. However, there is currently no DMS upstream to this congestion location. Correspondingly, potential location for new DMS is suggested to be MP 7.3 to MP 8.3.

SR 417 Northbound experiences congestion on one segment and at one detection location. The congested segment is located between the interchange with East Colonial Dr and the interchange with University Blvd. The congested segment is relatively short and one upstream DMS is located at MP 33.4 which can be used for queue warning. The congested location at 37.7 on SR 417 Northbound is at the boarder of Orange and Seminole County with no upstream DMS nearby. It is suggested that a DMS at MP 35.7 to MP 36.7 might be considered in the future. The detection location at Southbound MP31.9 near interchange with SR 408 is also identified as a congested location. Congestion at this location might be due to the merging traffic from SR 417 Southbound and SR 408 Eastbound. Currently no DMS is located upstream to this congestion location, thus potential DMS can be installed in the segment from MP 32.9 to MP 33.9.

On SR 528 Eastbound has evening congesting lasting for about one hour. The congested segment is near interchange with Tradeport Dr and west to Beachline Airport Mainline Toll Plaza. When vehicles approach the toll plaza, there is only one express lane on the cross-section. And 35 mph speed limit is imposed on this lane. Therefore during the peak hours, queue can build up on this lane. One DMS is to this segment at MP 8.6, about 0.4 mile upstream to the end of the queue. On SR 528 Westbound at the interchange with SR 417, morning congestion is observed. The morning congestion exists during from 7:45 AM to 8:10 AM and from 8:45 AM to 8:55 AM. No existing DMS is located upstream to the SR 528 Westbound congestion area. As a response, to warn the motorists of oncoming congestion, a DMS at MP 12.0 to MP 13.0 can be considered.

Table 4-4 summarizes the congestion segment on each direction of the five expressways. The congested time period is also given. For the DMS application for queue warning, existing locations of DMS signs upstream to the identified congested area have been checked. In case a

DMS is found, its milepost is given. If no DMS is available at present, the suggested DMS area is listed for consideration. In total, there are four locations that already have DMS which could be used for queue warning and five locations where future implementation of DMS could be considered for the purpose of congestion management.

Table 4-4 Mainline Congestion Segment and Location Identification and DMS Application for Congestion Management

Expressway	Direction	Congested Segment / Location	Congested Time Period	Existing Upstream DMS	DMS Location / Suggested DMS Area
SR 408	EB	MP 18.4 (Interchange with Dean Rd) → MP 17.7 (Interchange with SR417)	17:30--18:10	Yes	15.2
	WB	MP 13.3 (Close to Conway Rd) → MP 14.4 (Interchange with Semoran Blvd)	07:20--09:00	Yes	15.2
	WB	MP 10.3 (Interchange with I4) → MP 12.6 (Interchange with Crystal Lake Dr)	07:20--09:10	No	13.6--14.6
SR 414	EB	MP 9.3 (Interchange with Orange Blossom Trail)	07:50--08:05	No	7.3--8.3
SR 417	NB	MP 35.5→ MP 35.2 (between East Colonial Dr and University Blvd)	17:20--18:00	Yes	33.4
	NB	MP 37.7 (near boarder between Orange and Seminole County)	17:20--18:00	No	35.7--36.7
	SB	MP 31.9 (south to Interchange with SR408)	17:20--18:00	No	32.9--33.9
SR 528	EB	MP 9.8 → MP 9.0(Interchange with Tradeport Dr, west to Beachline Airport Mainline Toll Plaza)	17:10--18:15	Yes	8.6
	WB	MP 10.3 → MP11.0 (Interchange with Semoran Blvd)	07:45--08:10 08:45--08:55	No	12.0--13.0

In addition to mainline congestion management using DMS, congestion conditions on ramps could also be informed to motorists via DMS. On the expressway system, four ramps are found to experience congestion during the morning or evening peak hours as illustrated in Figure 4-4 to Figure 4-7. Three ramps are located on SR 408, and the fourth on SR 429. Upstream DMS have been found for each of the ramp. Consequently, they can serve as queue warning signs. On SR 408 Eastbound, the congested ramp is from I-4 Westbound to SR 408 Eastbound located at MP 9.7. During 15:00 to 19:40, congestion exists on this ramp. The DMS at MP 7.7 can be used to warn motorists on the mainline of potential congestion at the merging area near the ramp. On SR 408 Westbound, two off-ramps, one connected with I-4 Eastbound and the other one connected with I-4 Westbound are identified to be congested during in the morning peak hours. When queues are building up on these ramps and affecting mainline traffic, the DMS at MP 11.8

can be considered for queue warning. The congested off-ramp on SR 429 Southbound is at the interchange with Daniels Road. The region nearby is large shopping center and residential area. Congestion is found from 17:00 PM to 18:20 PM. The nearest upstream DMS is located at MP 20.7, and can be used to warn the motorists about the congestion on this ramp in advance. Table 4-5 summarizes the information about ramp congestion and DMS application for queue warning on ramps.

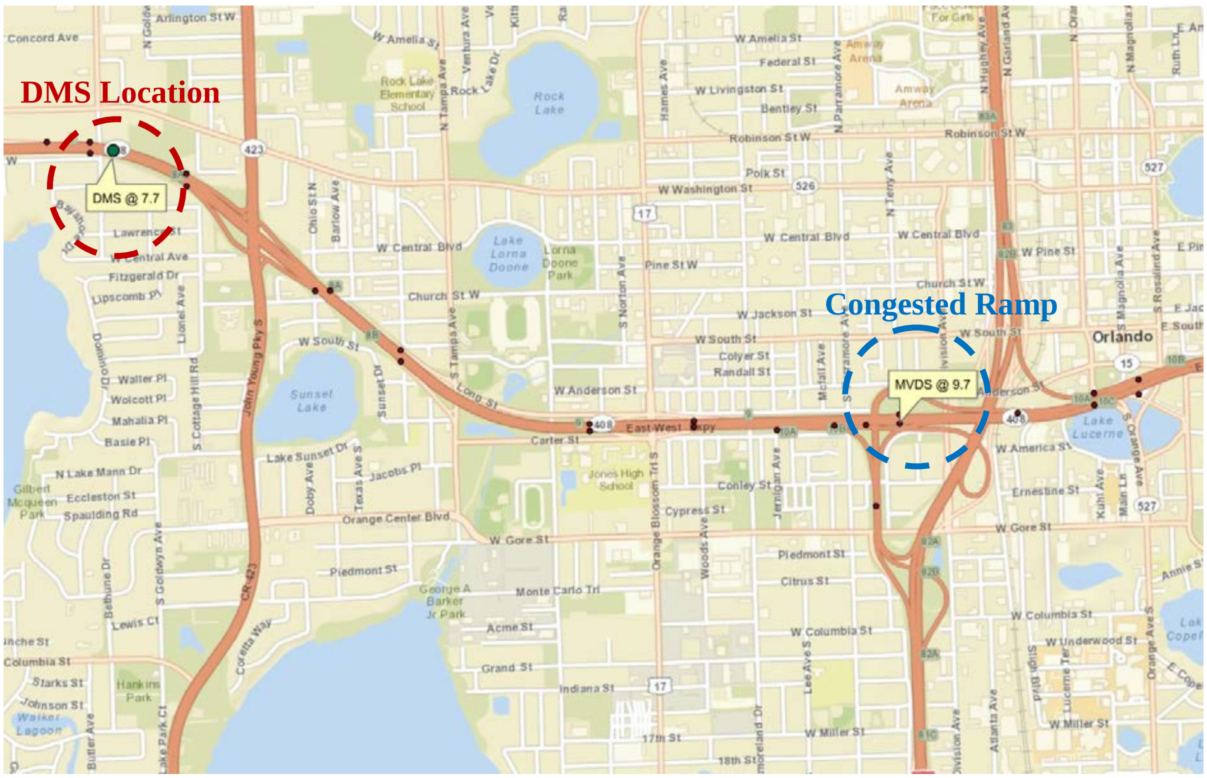


Figure 4-4 SR 408 Eastbound Congested Ramp and Upstream DMS Location

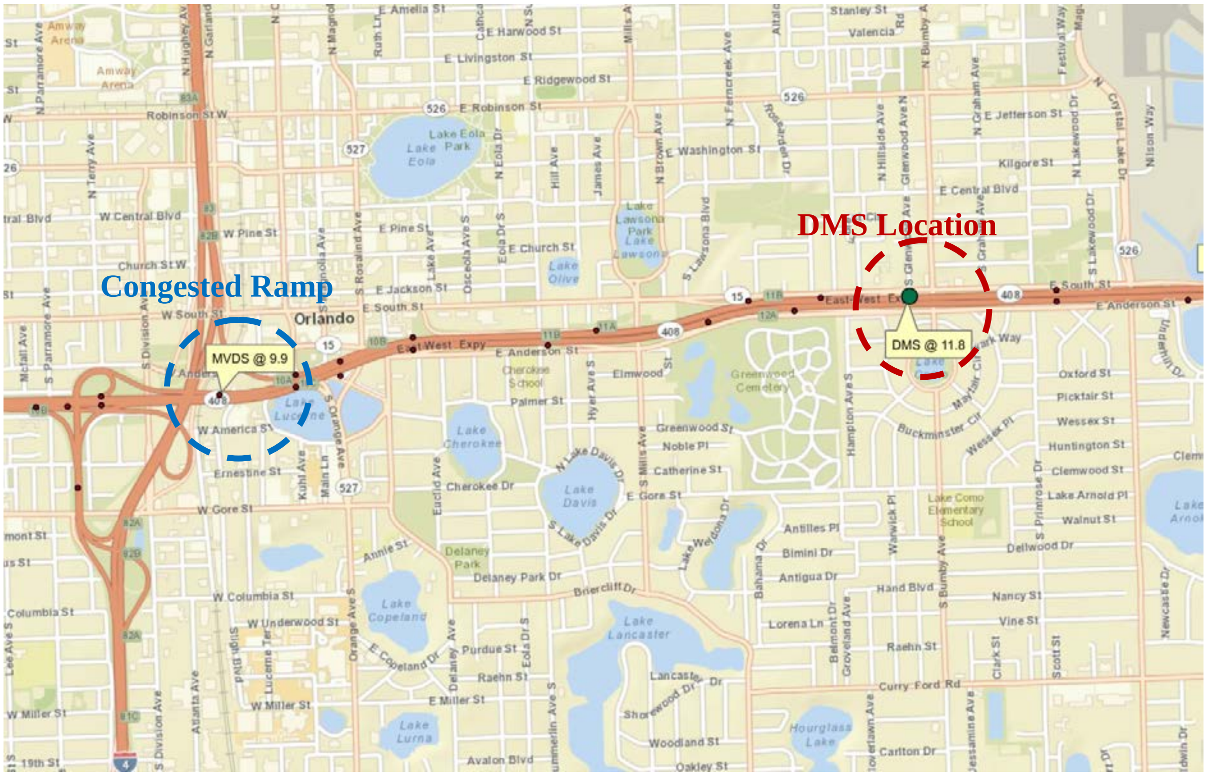


Figure 4-5 SR 408 Westbound Congested Ramp 1 and Upstream DMS Location

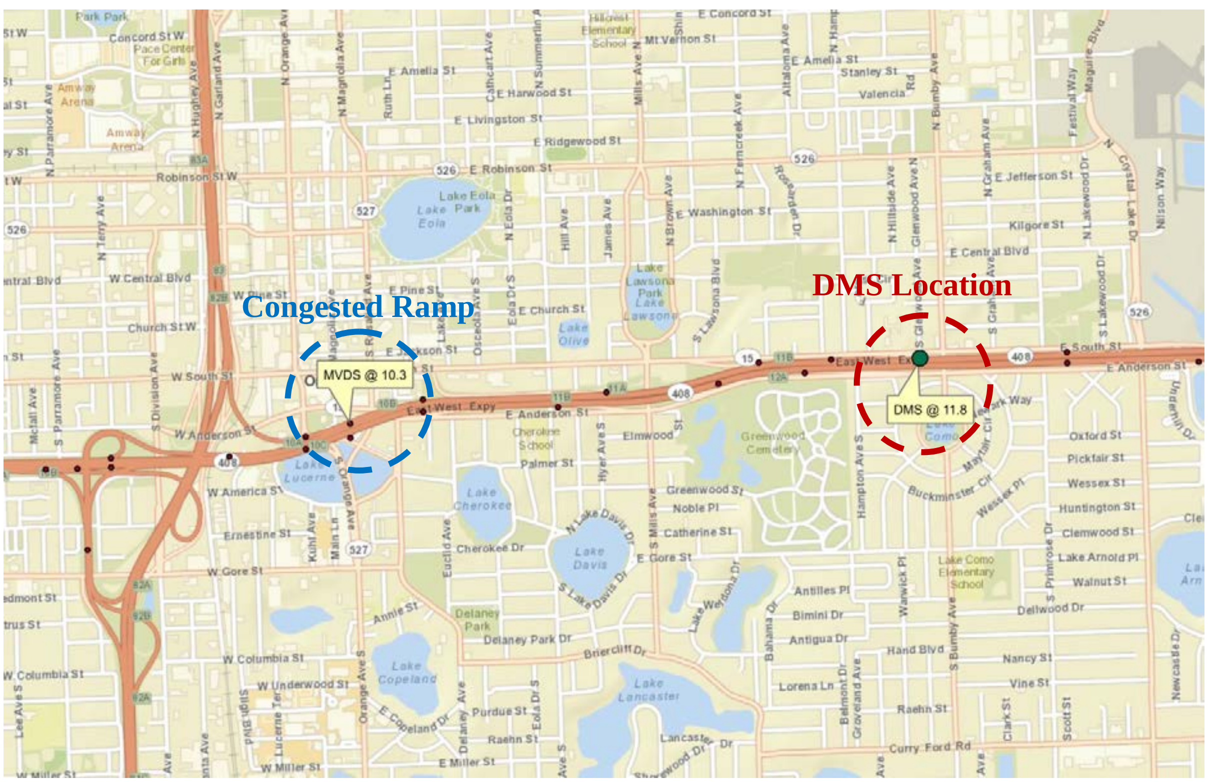


Figure 4-6 SR 408 Westbound Congested Ramp and Upstream DMS Location

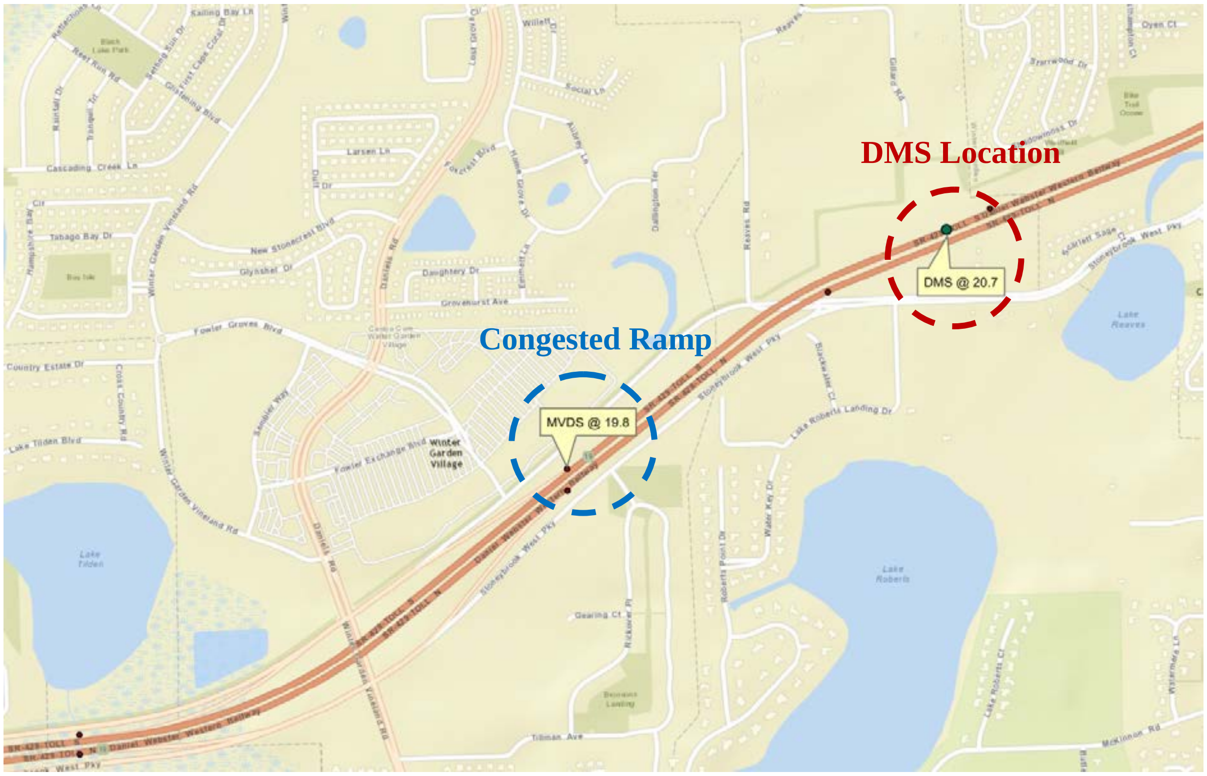


Figure 4-7 SR 429 Southbound Congested Ramp and Upstream DMS Location

Table 4-5 Ramp Congestion Identification and DMS Application for Congestion Management

Expressway	Direction	Ramp Location	Congested Time Period	Upstream DMS Location
SR 408	EB	MP 9.7 (I4 WB → SR 408 EB)	15:00 -- 19:40	7.7
SR 408	WB	MP 9.9 (SR 408 WB → I-4 WB)	07:25 -- 08:00	11.8
SR 408	WB	MP 10.3 (SR 408 WB → I-4 EB)	07:35 -- 09:05	11.8
SR 429	SB	MP 19.8 (Interchange with Daniels Rd)	17:00 -- 18:20	20.7

5 RAMP CLOSURE PRACTICE ON THE EXPRESSWAYS

Congestion alleviation on the mainline and ramps is expected to improve the performance of the expressways system and to provide motorists with efficient services. However, in case of total shut-down on the mainline, other strategies are in need to divert traffic from the mainline to local roads and prevent vehicles from entering the expressway and worsening the congestion. Ramp closure is a specific practice to alleviate mainline congestion in such cases. With the purpose of understanding the toll and turnpike authorities' procedures and practices for closing on-ramps in case of total shut-down of the mainline travel lanes, a questionnaire containing twelve short questions was designed. The survey was sent out to toll authorities in the United States and countries around the world to learn from other agencies' experience.

5.1 Introduction on Toll Authority Survey Response

Ten domestic responses from eight states in the US, and seven international responses have been received. Figure 5-1 presents the states from which we received responses. The domestic toll and turnpike authorities are Delaware Department of Transportation (DelDOT, Delaware), Florida's Turnpike Enterprise (Florida's Turnpike, Florida), Miami-Dade Expressway Authority (MDXWay, Florida), Maryland Transportation Authority (MDTA, Maryland), Minnesota Department of Transportation (MnDOT, Minnesota), New Hampshire Department of Transportation Bureau of Turnpikes (NH Turnpike Bureau, New Hampshire), New Jersey Turnpike Authority (New Jersey Turnpike, New Jersey), Richmond Metropolitan Authority (RMA, Virginia), Pocahontas 895 (Virginia), and West Virginia Parkways Authority (WV Parkways Authority, West Virginia).

Along with the survey response, DelDOT also provided us with the Toll Plaza Modified Operations Plan for Closures and Waivers. The manual is to provide guidelines for 1) temporarily suspending toll collection at the mainline toll plazas in the event of evacuation; 2) an activated detour which utilizes the tolled facility to route traffic past or around an incident which severely impacts another roadway. Although it's not directly for ramp closure and traffic detour, it offers valuable information about traffic management in case of emergency.

Seven international responding authorities as shown in Figure 5-2 are Attica Tollway Operations Authority (Greece), Moreas Tollway Concessionaire (Greece), Olympia Odos Operation S.A. (Greece), West Nippon Expressway Company, Ltd (Japan) and Korean

Expressway Corporation (KEC, South Korea). Two Belgian authorities responded: NV Tunnel Liefkenshoek currently is the only organization in Belgium that operates a tolling system at Liefkenshoek tunnel; PMO Duurzame Mobiliteit has plans to introduce a universal kilometer charging system in 2016. Since one response is based on the authority's experience of tunnel operation and the other system is still at planning stage, their responses are listed in a separate section.

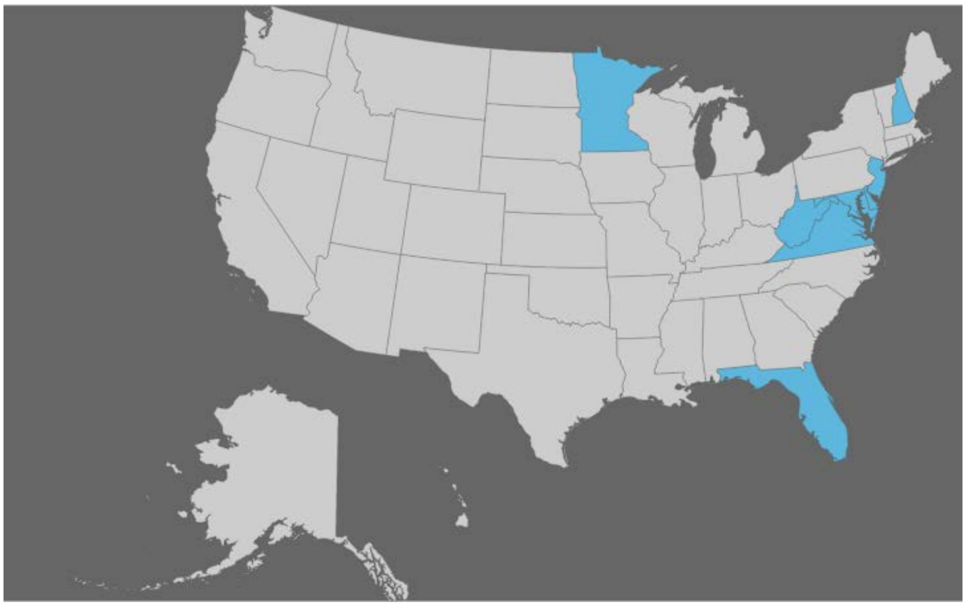


Figure 5-1 Domestic States with Responses

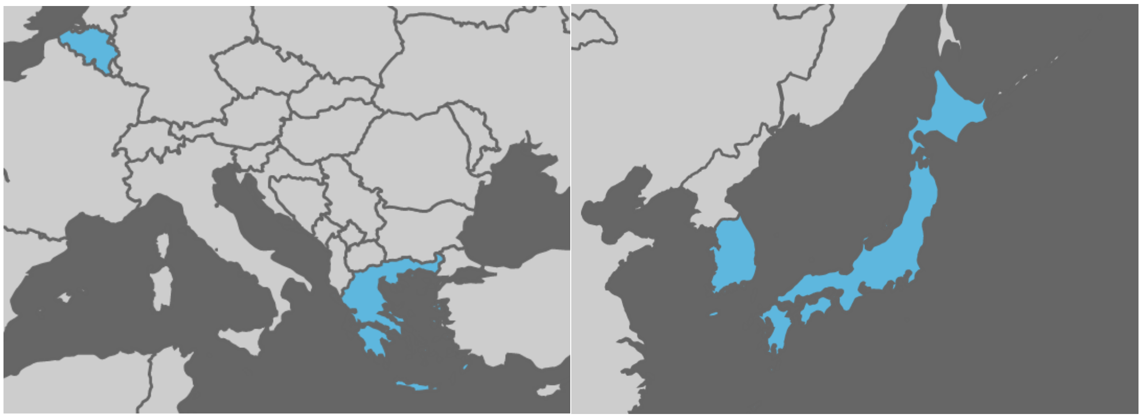


Figure 5-2 International Responses (Belgium, Greece, Japan & South Korea)

5.2 Summary of the Questionnaire

The responses from the toll authorities (domestic or international) are given below. The questionnaire is attached as Appendix R. Both the counts and percentages (in parentheses) are summarized. In the questionnaire, a toll authority might skip specific questions in the absence of concrete information. On the other hand, it is likely that multiple options of a question are appropriate to be chosen. Tables 5-1 to 5-15 show the results of the survey questions. Both count and percentage data are calculated and presented in the tables. Figures 5-3 to Figure 5-11 further illustrate the results of these questions for the total domestic and international responses.

5.2.1 Existing Toll Collection System

The existing toll collection systems on each authority's roadways have been investigated. From the responses (Table 5-1 and Figure 5-3) we have collected, open tolling systems possess obvious advantages over the traditional toll plazas. No domestic authorities in the survey reported the exclusive use of plazas. The combination of open tolling and plazas represents the majority of toll collection methods in the United States except in Minnesota which operates open tolling system only. The international responses indicated that the involved countries still have a higher portion of toll plazas. The Attica Tollway Operations Authority and West Nippon Expressway Company have both open tolling and plazas in their systems. The KEC also stated that they have plans to install open tolling systems.

The superiority of the open tolling systems over the traditional toll plazas lies in that they need less manpower, and enhance the road capacity by removing bottle-necks. They also improve travelers' driving comfort and reduce the travel time. The application of open tolling is advantageous for both toll authorities and the toll road users. In practice, the combination of these two toll collection systems is most common. Compared with either open tolling system only or toll plazas only, the combination of the two could accommodate the needs of both the frequent and infrequent toll road users depending on whether or not they have the Electronic Toll Collection (ETC) transponder.

Table 5-1 Question 1: Current Toll Collection System

Toll Collection	Domestic	International
(1) Open tolling only	1 (10%)	0 (0%)
(2) Combination of open tolling and plazas	9 (90%)	2 (40%)
(3) Plazas only	0 (0%)	3 (60%)

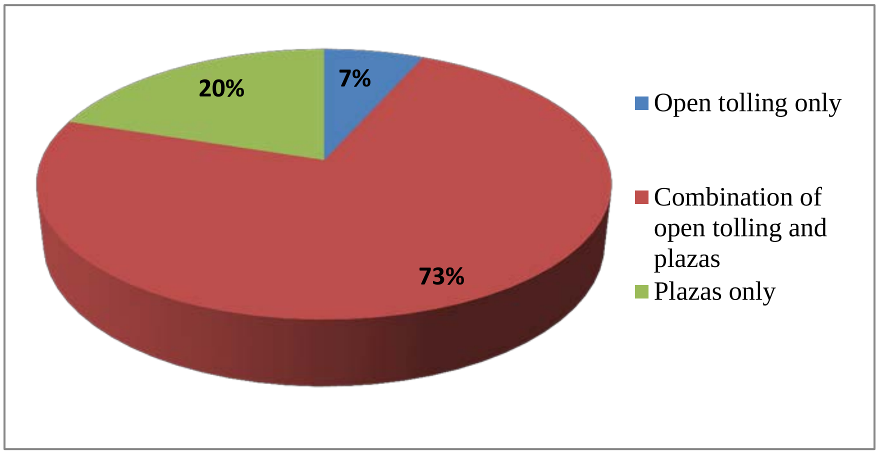


Figure 5-3 Current Toll Collection Systems

In Florida, according to the CFX 2012 Toll Facilities Reference Manual (*28*), the roadway segments operated by the CFX have open tolling system, self-service "Exact Coins" payment, and artificial service "Change Receipts" payment. The toll collection methods on the mainline or on ramps are combinations of open tolling and either one or both of the self-service and manual service.

5.2.2 Practice of Ramp Closure

When incidents or congestions occur on the toll facility, total shut-down of the mainline travel lanes can be the consequence. In this case, countermeasures have to be taken so that the queues can dissipate in a relatively short time. One way to address this problem is to limit the traffic entering the facility upstream of the shut-down area. More traffic entering the system would worsen the situation.

All but one of the toll road authorities (domestic and international) claimed that in the event of a major incident or congestion they implement the practice of closing the on-ramps and inform the drivers of a shut-down of the mainline travel lanes as shown in Table 5-2 and Figure 5-4. NH Turnpike Bureau explained that in lack of this practice, they still follow the guidelines of the Manual on Uniform Traffic Control Devices (MUTCD). MUTCD states that ramps may be closed by using signs and Type III barricades; early coordination with officials having jurisdiction over the affected cross streets is needed before ramp closings. It is suggested that portable DMS can be applied for ramp closure, and incident management in temporary traffic control zones.

Table 5-2 Question 2: Ramp Closing Practices in Case of Total Shut-down

Closing ramps	Domestic	International
(1) Yes	9 (90%)	5 (100%)
(2) No	1 (10%)	0 (0%)

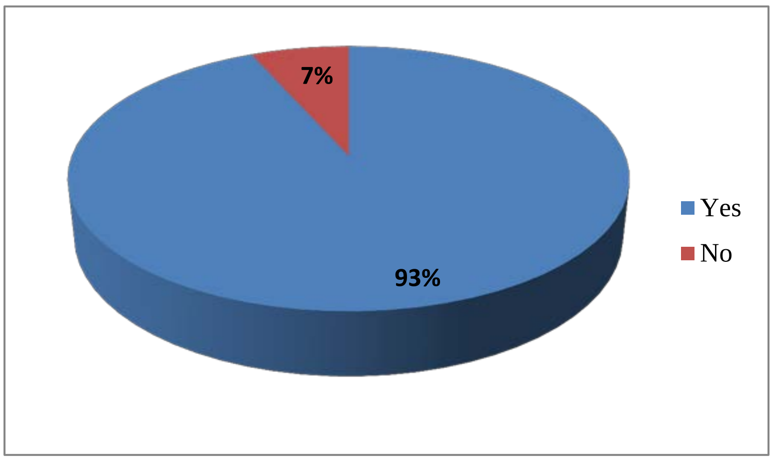


Figure 5-4 Ramp Closing Practices in Case of Total Shut-down

The practices that a toll authority would implement fall into two scenarios: 1) with frontage road available; 2) with no frontage road available. The results from the authorities' responses (in Table 5-3, Figure 5-5, Table 5-4 and Figure 5-6) show that regardless of the availability of frontage roads, the procedures are almost similar. For domestic toll authorities, DelDOT, Florida's Turnpike and MDXWay, Virginia's Pocahontas 895 and RMA, MnDOT, and New Jersey Turnpike do not differentiate their procedures based on frontage roads. MDTA reported that for most of their toll road segments, there are no parallel frontage roads adjacent to their facilities. WV Parkways Authority applies all of the procedures listed in the questionnaire but further explained the minor difference of the procedures they use according to the availability of frontage road. For international respondents, only KEC implements different strategies in the two situations. For the authorities who shared with us the detailed information as how the procedures are carried out or what they do according to the availability of frontage road, we outlined their responses in the following paragraph.

Table 5-3 Question 3: Procedures When Frontage Road is Available

Procedures when frontage road available	Domestic	International
(1) Re-route vehicles to downstream ramps	1 (10%)	1 (20%)
(2) Detour to other surface streets	2 (20%)	0 (0%)
(3) Treat on a case by case basis	5 (50%)	4 (80%)
(4) Other	4 (40%)	0 (0%)

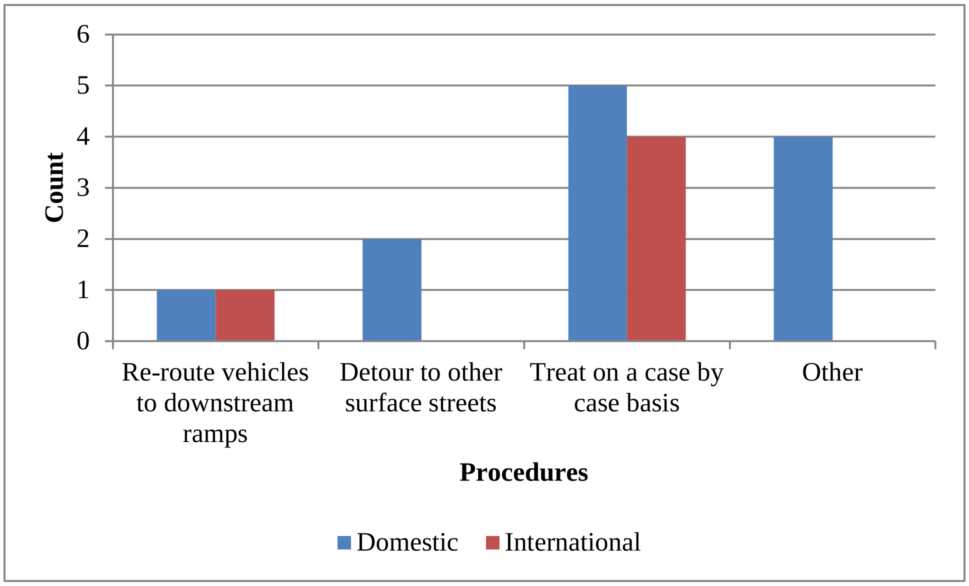


Figure 5-5 Procedures When Frontage Road is Available

Table 5-4 Question 4: Procedures When No Frontage Road is Available

Procedures when no frontage road available	Domestic	International
(1) Re-route vehicles to downstream ramps	1 (10%)	0 (0%)
(2) Detour to other surface streets	3 (30%)	1 (20%)
(3) Treat on a case by case basis	5 (50%)	4 (80%)
(4) Other	4 (40%)	0 (0%)

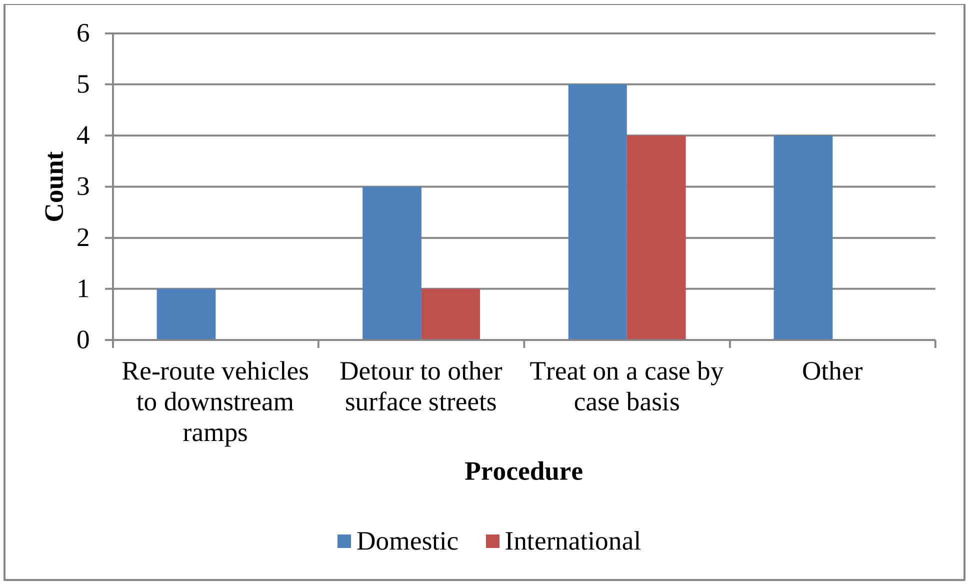


Figure 5-6 Procedures When No Frontage Road is Available

The detailed information regarding ramp closure procedures suggested by each authority include:

- Route traffic through the open road tolling (ORT) lanes at each plaza (DelDOT)
- SOP (Standard Operating Procedure) will make decision if diversion of the travel lanes and closures of on-ramps are needed for a long-term incident. Turnpike Roadway Maintenance and Traffic Operations will also provide recommendations to the Incident Command System (ICS). According to Federal Highway Administration (FHWA) "a systematic tool used for the command, control, and coordination of emergency response". The closure of mainline at diversion point as well as at the on-ramps is completed via available troopers, per local law enforcement, road rangers, and contracted MOT (Maintenance of Traffic) vendors. It is a case by case decision if the authority can route traffic directly to a downstream ramp or is only able to divert vehicles to other surface streets. (Florida’s Turnpike)
- Traffic is diverted from open lanes to toll lanes at the toll plaza, or to another ramp for exit. (Pocahontas 895)
- Freeway Incident Traffic Management (FITM) plans have been established for each segment (interchange to interchange) of the facilities. If the incident is of middle to long term duration, exit ramp detours are posted via dynamic message signs. Entrance ramp

detours are typically only established for planned (construction, maintenance) detours. For most of the continuous length facilities, there are signs installed on the cross streets to guide motorists to the parallel roadways and signs on the parallel facility to guide motorists back to the affected facility at the next cross street location. (MDTA)

- Emergency detours are designed with permanent signage when a frontage road is available. Emergency gates are in place to run traffic around when no frontage road is available. (WV Parkways Authority)

Even when no procedures/practices are prepared, the authorities confirmed that they do provide information to motorists as shown in Table 5-5. DelDOT, Florida's Turnpike, MDXWay left this question blank. The reason could be due to that when the shut-down of mainline travel lanes occurs, they always come up with the countermeasure procedures.

Table 5-5 Question 5: Providing Information to Motorists

Provide information to motorists	Domestic	International
(1) Yes	7 (70%)	5 (100%)
(2) No	0 (0%)	0 (0%)

5.2.3 Procedures of Ramp Closure

After the questionnaire was distributed, another question was added and sent to the toll authorities. This question emphasizes on the procedures of how the authorities close the ramps and the devices they use for the closure. From this further communication, seven domestic and four international toll authorities responded this question at detailed level shown as in Table 5-6 and Table 5-7.

Table 5-6 Ramp Closure Procedure by Domestic Toll Authority

Toll Authority	State	Ramp Closure Procedure
DelDOT	Delaware	The traffic management team prepared a "Toll Plaza Modified Operations Plan for closures and waivers" booklet that describes in detail the methods used in shutting down the Cash lanes and ancillary ramps. They have provided a trailer for each plaza that has a supply of cones and other necessary equipment to aid in shutting down the lanes. The authority is currently planning to install permanent variable message boards to assist in MOT.
Florida's Turnpike	Florida	Florida's Turnpike has no fixed gates. Only exception to this has been through specific construction projects where that contract's Incident Management Plan has included pre-staged MOT devices within the construction limits. The Turnpike indicated that these projects have typically been lengthy work zones where barrier wall has been placed limiting shoulder areas, etc. Ramp closure is typically done initially and immediately by Florida Highway Patrol or mutual aid request to a local law enforcement unit to block an entrance ramp to the mainline. Law enforcement will block the directional ramp only, but will also block the interchange entrance at the arterial roadway as well. Road rangers will also be part of an initial ramp blockage either with or without law enforcement. The experience is that "blue lights" from law enforcement on scene with a road ranger MOT set-up is the most effective. Florida's Turnpike stated that they have had occasions when a road ranger by themselves at this type of set-up does not deter motorists from going through or around cones and vehicle to enter the closed ramp. From the information offered by Florida's Turnpike, cone setup at rollover scene (lane blocking) is also illustrated (shown in appendix). The diagram may be of use if cones are also implemented in ramp closure.
Maryland Transportation Authority	Maryland	Maryland Transportation Authority responded that they do not stage cones or have permanently installed gates. However, they have their own police force and they help set up road block at the gore entrance.
New Jersey Turnpike	New Jersey	When the mainline needs to be closed due to unforeseen incident, a state police vehicle will block the ramp(s) until when maintenance trucks come to block the ramp(s). The turnpike stated that they have too many ramps to have cones at each location and would still need personnel there to put the cones out. The New Jersey Turnpike will also check with the state DOT to have them post messages on their DMS to alert motorists of the closure.
Pocahontas 895	Virginia	Pocahontas 895 in Virginia responded that they use cones and signage when they close the ramps.
Richmond Metropolitan Authority	Virginia	The RMA stated that they typically close their ramps with cones and barrels. And they usually put up DMS sign informing motorists the cause of the ramp closure and the expected duration. Police department may also close ramps on their system. In this case, a vehicle with lights will be parked at the entrance ramp.
WV Parkways	West Virginia	When frontage road is available, they close ramps and detour the traffic with permanent signage. When no frontage road is available, then emergency gates are in place to run traffic around.

Table 5-7 Ramp Closure Procedure by International Toll Authority

Toll Authority	Country	Ramp Closure Procedure
Attica Tollway	Greece	Attica tollway system has 39 toll stations, out of which 4 are mainline toll plazas and the remaining 35 are ramp toll plazas. In extreme cases, access to the motorway can be completely closed. When the need to close entrance ramps arises, Attica tollway uses simple pole and chain to deter vehicles from entering the ramp. The detailed ramp closure procedure is that a heavy-duty yellow/black chain is suspended between two hooks, one welded on a free-standing pole and one welded on a safety barrier. An "Entrance Closed" sign is placed in front of the chain and the entrance is hence closed. Closure of ramps is carried out by the patrol personnel of operating company, with the presence and the assistance of the traffic police. The traffic police remain present for the full duration of the ramp closure, providing assistance to the motorists and ensuring that no vehicles enter the motorway. Attica tollway also provides pictures illustrating the devices they use for ramp closure. The pictures are attached in appendix.
Olympia Odos	Greece	The entrance ramps are closed by police force or closed physically. As to how to close them physically, it is not mentioned.
Moreas Tollway	Greece	The authority does not have gates or any other automated equipment nor permanently staged cones or other similar material "waiting to be used". They stated that their closure practices rely on toll plazas (of which two toll plazas are on entrance ramps). Police assistance is required in case of shut-down.
West Nippon Expressway Company	Japan	Some of the system's ramps have fixed gates. The gates would be closed in case of unusual event such as traffic crashes and/or extreme weather conditions such as heavy rain. DMSs are located at all the toll gates to inform the passengers of the event.

Other authorities in their responses reported whether they will re-route the vehicles to downstream ramps, detour vehicles to other surface streets or treat the condition on case by case basis. And the media they implement to distribute the closure or detour information. Nevertheless, they do not provide detailed information as how they close the ramps.

Besides the responses collected from the toll road authorities via questionnaire and direct communication, researchers at UCF also conducted an online literature search for ramp closing procedures. It is found that on most DOT's or Turnpike authorities' website, only the ramp closure schedule will be posted. FHWA's Ramp Management and Control Handbook (*29*) provide guidelines and case studies for ramp closures.

According to the handbook, there are three types of ramp closures: permanent, temporary, and time-of-day. Temporary closures may be implemented due to construction activities, special events or weather-related events. Time-of-day closures are typically focused on the morning or afternoon peak periods. This type of closures facilitates mainline flow.

Some practical instances of these two types of closures include:

During the Tocoma Dome event in Washington State, Exit 133 was closed using barricades and DMS to warn motorists.

MnDOT has been using gates since 1996 to prohibit freeway access during unsafe driving conditions such as severe snowstorms and major crashes.

In Milwaukee, Wisconsin, I-43 southbound at State Street, the ramp was equipped with a gate that automatically closed daily from 2 to 6 pm and opens immediately after. This was a peak period closure. It was reported that the gate required extensive maintenance because it was often broken (and broken within weeks of repair).

The various ways and devices to provide ramp closure are provided in the handbook.

Hawaii DOT used traffic cones to temporarily close the Lunalilo Street on-ramp and the Vineyard Boulevard off-ramp along the westbound H-1 freeway.

Type III barricades are used in the Wisconsin example mentioned above. They are suitable where closures are infrequent. The advantage of this type of barricade is the low cost and high visibility to motorists.

Semi-permanent barriers (water-filled barrels or flexible pylons) can be used for full ramp closures on a temporary basis. Long Island Expressway in New York utilizes “drag net” devices (chain link fence with run-out cables) at on-ramps.

Automatic ramp gates can be used to prevent access to the facility. Washington State DOT, Colorado DOT and Caltrans have the automatic gates. They work for peak-period ramp closures, special events or closures due to poor visibility (e.g., fog). Tennessee DOT had an automated gate system at ramp entrance to I-75 in conjunction with fog warning system in 1992. However, the gates require frequent and timely maintenance.

Wisconsin DOT uses horizontal swing arms as traffic gates where closures are anticipated to be more frequent.

5.2.4 Ramp-closure Information and Information Media

When the decision of closing the on-ramps has been made, the shut-down information needs to be delivered to the drivers. Most toll road authorities indicated that they apply multiple measures to convey the ramp-closure information to drivers. Among them, Dynamic Message Signs (DMS) are the most widely-used media. As shown in Table 5-8 and Figure 5-7, all authorities implement DMS on their systems. Radio and fixed signs are also in use. As for other communication channels in service, different authorities have their own strategies.

Table 5-8 Question 6: Media for Ramp-closure Information

How to provide ramp-closure information	Domestic	International
(1) Dynamic Message Sign (DMS)	10 (100%)	5 (100%)
(2) Radio	5 (50%)	1 (20%)
(3) Fixed Signs	5 (50%)	3 (60%)
(4) Other	6 (60%)	3 (30%)

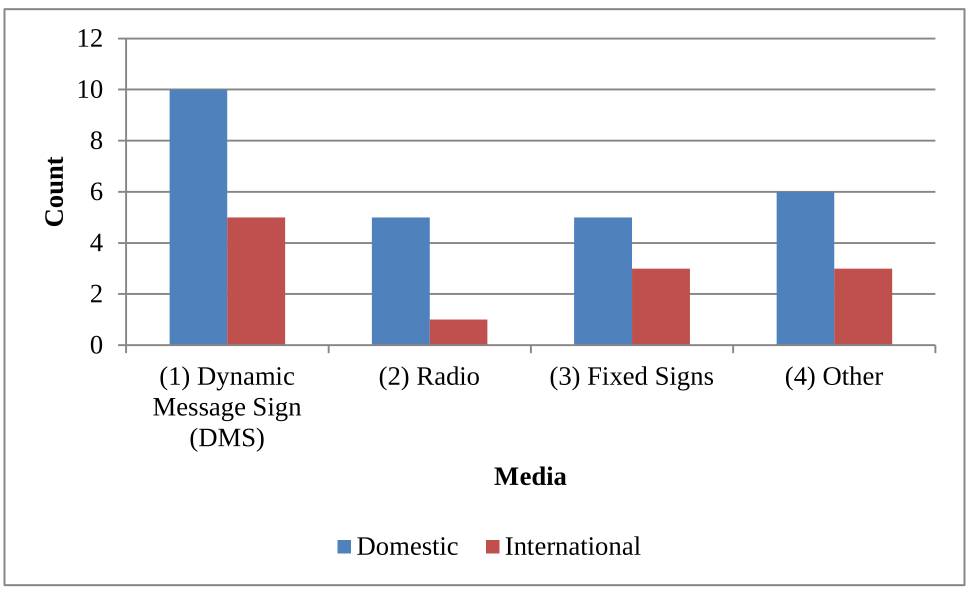


Figure 5-7 Media for Ramp-closure Information

DelDOT closes off cash lanes with MOT. Florida's Turnpike has maps and 511 services available for drivers. MDXWay posts their advisories on a website and also distributes the information via state 511 services. MDTA besides the above-mentioned methods also releases the traffic conditions through TV and social media like Twitter and Facebook, etc. WV Parkways

Authority lets their toll personnel inform drivers at toll booths as well as internet (www.WV511.org) and social networking. NH Turnpike Bureau also utilizes news media to transfer the information to drivers.

The Moreas Tollway Concessionaire in Greece sends messages from toll staff to motorists at plazas. Attica Tollway Operations Authority contacts the media to spread the information. Olympia Odos Operation S.A. provides the news by both toll collectors and media.

The total percentage of the authorities which provide advice based on specific closure is half of the authorities involved in the survey (Table 5-9 and Figure 5-8).

Table 5-9 Question 7: Whether Provide Advice Based on Specific Closure Condition

Whether provide advice based on specific closure condition	Domestic	International
(1) Yes	5 (50%)	2 (40%)
(2) No	4 (40%)	3 (60%)

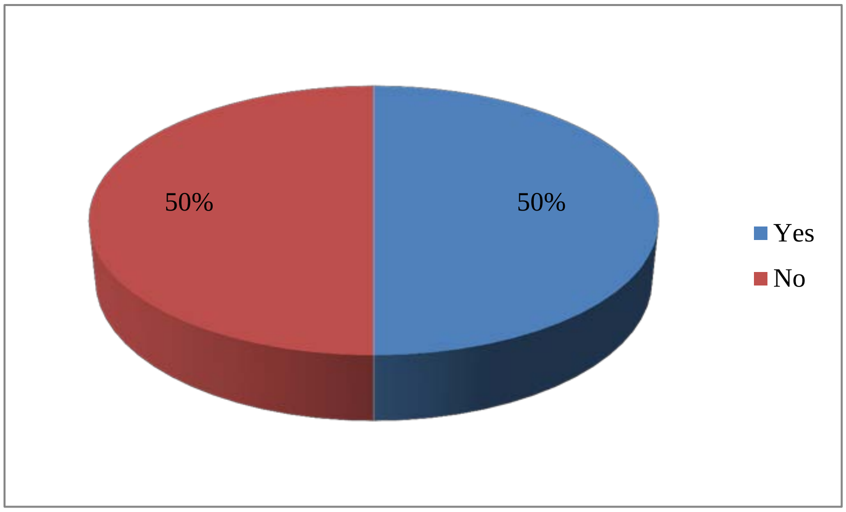


Figure 5-8 Whether Advice Provided Based on Specific Closure Condition

For those authorities who provide suggestions to drivers, the advices provided are listed below:

- DelDOT: Suggestions are based on declared state of emergency.
- Florida's Turnpike: Traveler information is provided. Unless a clear detour is provided, information may only include where the closure is, and that motorists need to seek alternate routes to avoid delays and congestion.

- Pocahontas 895: Alert the traveling public to the next available exit or travel lane
- MDTA: DMS notifies travelers of the general reason (crash, construction, etc.) and the specific location of the closure. If the incident is of a long term nature, media advisories will provide general information intended to assist motorists in making appropriate decisions.
- KEC: Traffic condition is provided by DMS, traffic advisory radio, Digital Multimedia Broadcasting (DMB) service.
- Moreas Tollway Concessionaire: Information regarding closure cause, forecast duration if known is given.

Except two domestic authorities, the others in the survey provided to us information about whether their procedures change depending on other traffic factors (Table 5-10 and Figure 5-9). From the results, the factors affecting carrying-out the procedures include:

- Peak hour traffic volumes;
- Estimated duration of incidents;
- Time of day;
- Type of roadway (speed limit, number of lanes, etc.) ;
- Case by case evaluation.

Table 5-10 Question 8: Whether Procedure Changes Depending on Other Factors

Whether procedure changes depending on factors such as speed limit, number of lanes, time of day	Domestic	International
(1) Yes	4 (40%)	3 (60%)
(2) No	4 (40%)	2 (40%)

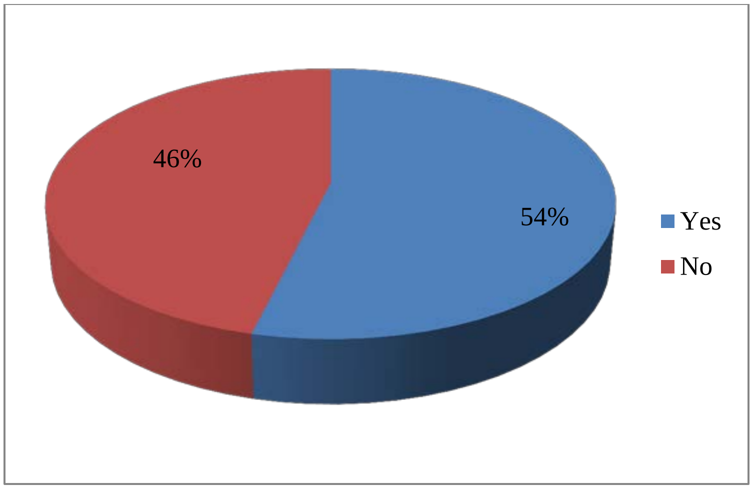


Figure 5-9 Whether Procedure Changes Depending on Other Factors

Examples were given by the authorities. For instance, if the authority has a closure and diversion at nearest arterial, however if it is approaching a peak hour and/or duration is estimated to be longer than an hour, the authority may advise motorists to use the nearest expressway to expressway interchange as a diversion instead of diverting to a signal controlled arterial. This is not always an option depending on the location of the incident. Another example is that the MDTA's FITM plans identify when a particular detour route is preferable over another due to time of day or vehicle restrictions, presence of large schools or churches, etc.

5.2.5 On-ramp Volume Control Strategy

The implementations of on-ramp volume control strategies are opposite for domestic and international authorities. Out of the ten domestic toll authorities, only MnDOT has affirmative response (Table 5-11 and Figure 5-10). It did not give further explanations about the strategies they employ. KEC controls the on-ramp volume based on the travel speed of the mainline. If the speed is less than 70km/h (43.5 mph), they operate traffic signal at 30 seconds interval. The Attica Tollway Operations Authority controls the volume by lifting bars of each toll station. The Olympia Odos Operation S.A.'s strategy is manually supported by the road patrollers and traffic police. West Nippon Expressway Company indicated they occasionally apply ramp metering.

Table 5-11 Question 9: On-ramp Control Strategy

Do you have on-ramp control strategy	Domestic	International
(1) Yes	1 (10%)	4 (80%)
(2) No	9 (90%)	1 (20%)

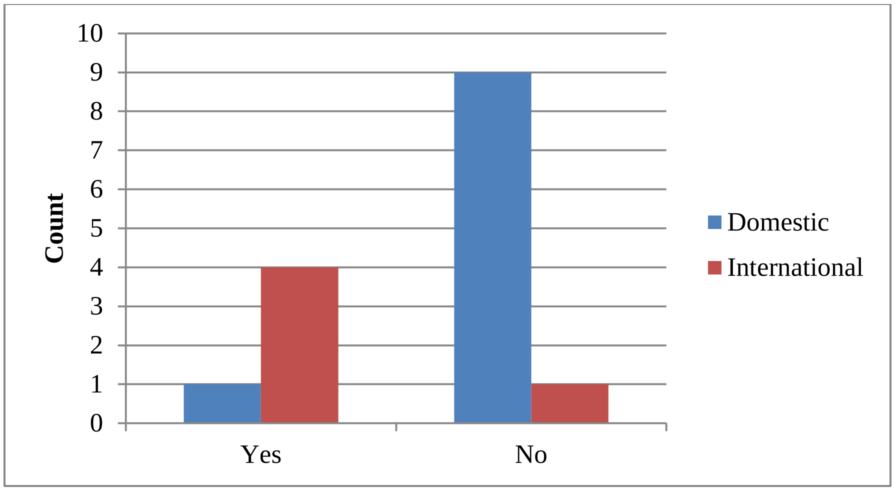


Figure 5-10 On-ramp Control Strategy

5.2.6 Existing ITS System

ITS systems utilize information and communication technologies in road infrastructure, vehicles and users, and traffic management and operation. The toll authorities were asked about the current ITS systems that they implement. The results are given in table 5-12 and Figure 5-11.

ETC ranks as number one. The DMS are also heavily used. DMS can be used for multipurpose. Estimated travel time, congestion, incident, and other warning messages can all be displayed on DMS. Remote Traffic Management Sensors (RTMS) are radars operating in the microwave band. They are installed on road-side poles and each one can replace multiple inductive loop detectors, thus making it very efficient. They can record traffic volume, lane occupancy, vehicle speed, and aggregate the information on lane basis. Automatic Vehicle Identification (AVI) systems have been around for a long time. They have proved their accuracy and reliability in ETC system, and they also play a critical role in traffic surveillance. Travel time estimation can be derived through the detection or measurement instruments installed along the roadway such AVI, RTMS, loop detectors, etc. Active traffic management incorporates variable speed limits, hard-shoulder running, queue warning and ramp-metering. These strategies aim at smoother traffic flow and lower congestion. Recently researchers at UCF showed substantial safety benefits of Active Traffic Management. Other systems reported by these agencies involve radio advisory system and advanced patrolling system.

Table 5-12 Question 10: Current ITS Systems on Roadways

What ITS system do you use on roadways	Domestic	International
(1) Automatic Vehicle Identification (AVI)	6 (60%)	1(20%)
(2) Dynamic (Changeable or Variable) message signs	9 (90%)	5 (100%)
(3) Remote Traffic Management Sensors	8 (80%)	3 (60%)
(4) Active Traffic Management	3 (30%)	3 (60%)
(5) Travel time estimation	6 (60%)	2 (40%)
(6) Electronic Toll Collection (ETC)	10 (100%)	5 (100%)
(7) Other	1 (10%)	1 (20%)

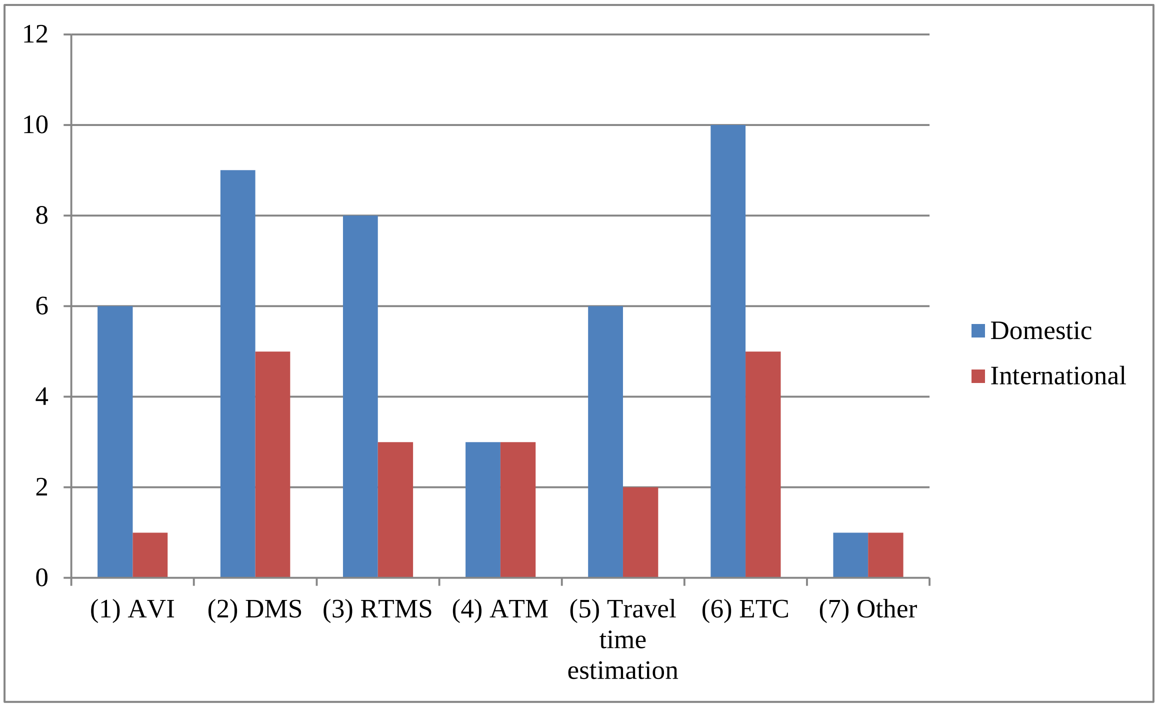


Figure 5-11 Current ITS System on Roadways

The following table (Table 5-13) summarizes the ITS systems used on each authority's roadway. The other ITS systems the authorities suggested include CB Radio Advisory System, which focuses on commercial traffic with the intent of allowing truck operators to prepare for the conditions ahead; Supervisory Control and Data Acquisition (SCADA) system for tunnel and other M&E (Monitoring and Evaluation) equipment control and monitoring.

Table 5-13 Existing ITS Systems Implemented by Toll Authorities

	Toll Authority	ITS systems
Domestic	Delaware Division of Motor Vehicles	2, 3, 6
	Florida's Turnpike Enterprise	1, 2, 3, 5, 6, 7
	Pocahontas 895	6
	Miami-Dade Expressway Authority	2, 3, 5, 6
	Maryland Transportation Authority	1, 2, 3, 4, 5, 6
	Richmond Metropolitan Authority	1, 2, 6
	West Virginia Parkway Authority	1, 2, 3, 6
	Minnesota Department of Transportation	2, 3, 4, 5, 6
	New Jersey Turnpike Authority	1, 2, 3, 5, 6
	New Hampshire Turnpike Bureau	1, 2, 3, 4, 5, 6
International	Korean Expressway Corporation	2, 3, 5, 6
	Moreas Tollway Concessionaire	2, 4, 6, 7
	Attica Tollway Operations Authority	2, 4, 6
	Olympia Odos Operation S.A.	1, 2, 3, 4, 6
	West Nippon Expressway Company, Ltd.	2, 3, 5, 6

* The number shown above corresponds to the ITS systems in the survey question No.10

5.2.7 Average Spacing between Ramps

The spacing between two adjacent ramps heavily relies on the area (rural/urban) where the road segment is located. Normally, a rural road section will have less access and the spacing between ramps will be much longer than that in urban areas. In the questionnaire results, DelDOT reported that the distance between their only two ramps is 12 miles. Florida's Turnpike has 136 interchanges and 460 centerline miles, this calculates to an average interchange spacing of 3.5 miles. Nevertheless, in the most rural section of the Turnpike, the average interchange spacing is 44 miles (Exit 152, Exit 193, and Exit 240 = 88 centerline miles with only 3 interchanges). Virginia's Pocahontas 895 system has an average ramp spacing of 3 miles. MDXWay operates their roadway with an average of 1 mile interval of ramps. MDTA indicated that on urban Interstate facilities they manage, the spacing is less than one mile in some locations. On rural portions, the spacing is closer to three miles or more. On RMA's system, the spacing between ramps ranges from 0.5 to 1 mile. WV Parkways Authority reported a 5 to 6 miles ramps interval. MnDOT has an average of 1 mile ramp interval on their road. NH Turnpike Bureau stated that the interval on their system depends on the location (rural/urban). The results from international responses show that the average distances between two ramps are: 5.43 miles (KEC, Korea), 6.2

(Moreas Tollway Concessionaire, Greece), 4 or 5 miles (Attica Tollway Operations Authority, Greece), 4.48 miles (Olympia Odos Operation S.A., Greece), 15 miles (West Nippon Expressway Company, Japan).

5.3 Experience and Ideas on Safety and Traffic Management

At the end of the questionnaire, we asked the toll authorities to share their experience and ideas about safety and/or traffic management on their systems. Table 5-14 lists the suggestions of domestic toll authorities and Table 5-15 of international authorities.

Table 5-14 Domestic Toll Authorities on Safety and/or Traffic Management

Toll Authority	Suggestions
Florida's Turnpike Enterprise	The Turnpike's Traffic Management Center (TMC) is very pro-active in incident management and utilizes tools such as the Road Ranger program, RISC (Rapid Incident Scene Clearance) program, STARR (Specialty Towing and Roadside Repair) program. In addition, the Turnpike TMC coordinates well with other agencies including the districts, toll authorities, media, etc. In terms of safety, the traffic engineering group reviews every fatal crash that occurs on the system and performs numerous safety analyses for projects and traffic safety initiatives on behalf of the Turnpike.
Pocahontas 895	Pocahontas 895 is a lightly traveled road, so little is needed in terms of traffic management. The authority does have roadway cameras to monitor for traffic issues. Safety is a top concern and they employ the DMS and fixed signage to convey safety information.
Miami Dade Expressway Authority	System wide DMS deployment about to commence. Road Rangers fleet contains DMS boards, system wide camera surveillance for incident management.
Maryland Transportation Authority	Technology and traffic conditions are changing rapidly and require constant partnership between operations, enforcement, engineering, maintenance and construction teams. For optimal results all parties must support common goals.
West Virginia Parkways Authority	The WV Parkways Authority has an emergency detour plan in place with permanent signage and a standard operating procedure in place, which can be applied to each section of the highway, in the case that an emergency closure of the highway is needed.
Minnesota Department of Transportation	MnDOT have a High Occupancy Lane (HOT, MnPASS lane) in Minnesota on two of our corridors, I-394 and I-35W, both have direct connects into downtown Minneapolis. Our tolling is passed on dynamic pricings so the system is totally automated. The price of the toll can range from .25$ to $8.00 with the average around $1.75. The tolling is from 6-10am and 2-7pm.
New Hampshire Turnpike Bureau	NH Turnpike utilizes the DOT Traffic Management Center to communicate construction activity, accidents, and other

Table 5-15 International Toll Authorities on Safety and/or Traffic Management

Toll Authority	Suggestions
Korean Expressway Corporation	To alleviate traffic congestion, the authority operates Lane Control System (LCS) in the metropolitan region. It uses right shoulder as driving way, if travel speed of main-line is less than 70km/h.
Moreas Tollway Concessionaire	ITS system is complemented by field personnel (patrol/intervention teams) in order to ensure coverage of incidents on segments (between interchanges) where CCTV and other ITS field equipment is not present.
Attica Tollway Operations Authority	Queue Warning, Junction Control, Dynamic Re-routing Information, Truck Restrictions, Ramp Metering
Olympia Odos Operation S.A.	On an interurban corridor under construction, close cooperation between all parties (constructor, operator, police, state administration) is needed. It is also quite vital to integrate the alternative routes to the relevant traffic management plans.

5.3.1 Response from Belgium

On Tunnel Liefkenshoek's system, open tolling only and combination of open tolling and plazas coexist. In case of total shut-down of the mainline travel lanes, the authority will re-route and detour the vehicles. Fixed signs are used to provide drivers with ramp-closure information. The authority confirmed that their advice to drivers depend on the specific closure condition and the closure procedure varies according to factors such as speed limit, number of lanes, time of day, etc. without further information. The ITS systems employed on their system include AVI and RTMS.

A universal kilometer charging system will be introduced in 2016 by PMO Duurzame Mobiliteit. The system is planned to be an "open tolling only" system where no physical obstacles (barriers, toll plazas) will be present. The ITS systems that are expected on the road system are AVI, DMS, RTMS, Active Traffic Management, ETC, and travel time estimation. Ramp closure practices and procedures are not available at this stage. The authority stated that safety/traffic management is foreseen within the normal road operations.

5.4 Toll Plaza Modified Operations Plan for Closures and Waivers

The ETC system of DelDOT can be temporarily turned off in the event an emergency response requires the use of the toll plaza for routing traffic around an incident in order to get through the area.

Suspended toll payment conditions include:

- Natural and man-made disasters
- Major traffic incidents
- HAZMAT spills (hazardous material spill)
- Special events

Under one of the above four conditions, incident responses are needed. Some of the response guidelines can serve as guidelines for ramp closures. In the response guidelines, DelDOT suggests the districts should pre-position resources to their appropriate staging areas according to the traffic control plan. The incident responder at the scene will shut down traffic through the area and activate the appropriate detour. DMS and portable DMS are recommended to display traveler messages in the area to alert motorists to the current conditions.

To carry out the procedures, traffic control point should be identified. The traffic control point location is staffed to ensure the continued movement of traffic inside or outside an area of risk during an emergency or disaster. The equipment for the traffic control includes: traffic cones, traffic barricades, arrow boards, DelDOT trucks, DMS, and exit signs.

5.5 Preliminary Statistical Tests Results

Preliminary statistical tests have been applied. Since the sample size is small, Fisher's exact test is applied. Test results on Question 1 reveal that the domestic and international choices of toll collection system differed greatly (p=0.022). For Questions 3 and 4, test also indicates that the procedures that the authorities implement do not vary significantly no matter frontage road is available or not (p=0.8785). Paired t-test shows no significant of difference between domestic and international selections of these procedures (t value = 0.64, p=0.544). The selections of media to distribute information to drivers are also similar in Question 6 (t value = 1.21, p=0.312) for domestic and international authorities. For Question 7 whether the authorities provide advice based on the specific closure condition and Question 8 if the procedure changes depending on factors such as speed limit, number of lanes, time, etc., Fisher's tests confirms that no significant distinctions have been found between the United States and other countries. In contrast, the international application of ramp control strategy is much higher than that of the United States (p value = 0.017). Finally, current ITS systems on each authority's roadway have been examined. It shows that the usage of the ITS systems listed in Question10 has similar pattern both at home and abroad.

5.6 Summary and Conclusions

To better understand how the toll and turnpike authorities deal with total shut-down of the mainline travel lanes, a questionnaire composed of twelve short questions was developed and distributed to domestic and international toll authorities. In total, ten domestic responses from eight states and seven international responses from three countries have been received.

The results of the survey are summarized. For the questions, some have only one appropriate option that a toll authority is able to choose while others might have multiple applicable options. Some authorities skipped certain questions in the absence of concrete information. In all, the toll authorities participating in the survey shared precious information as how they manage their system during a total shut-down of the mainline traffic lanes.

In the survey, it is reported that the combination of open tolling and plazas is the predominant toll collection method in the United States. The implementation of open tolling is also becoming more common overseas. When total shut-down of the mainline travel lanes occurs, almost all domestic and international authorities claimed they have practices for closing on-ramps. The practices are found not varying significantly with or without the presence of frontage road. In most cases, the practices are carried out on a case by case basis. Authorities reported that they would also re-route vehicles to downstream ramps or detour them to other surface streets. Other specific strategies adopted by these authorities are reported, such as Florida's Turnpike's SOP, Maryland Transportation Authority's FITM plans and WV Parkways Authority's emergency detours.

An additional question was designed and sent to the toll authorities to gain insight on how they close ramps in case of total shutdown. Six domestic and three international authorities responded us with detailed information as how they close the ramps and the equipment they implement closing the ramps.

Even when no procedures or practices are available for on-ramp closing, the authorities still gave confirmative responses that they provide information to motorists. The media to convey the information to drivers includes DMS, radio, fixed signs, and others like maps, TV, websites, telephone (511 systems), and toll personnel, etc. Furthermore, if available, the authorities send drivers detailed information about the cause of the shut-down, the location and expected duration of the closure, and where the alternative routes would be. As for potential factors affecting the procedures, the authorities pointed out that these factors can be the peak hour traffic volumes, time of day, types of roadway (speed limit, number of lanes), and estimated duration of incidents.

Despite the on-ramp closing procedures applied during shut-down of the mainline travel lanes, on-ramp volume control strategies are not common in the United States. For international countries, in contrast, certain forms of control practices have been reported by most of the authorities.

From the survey, each authority's system is equipped with multiple ITS systems. Electronic Toll Collection, Dynamic Message Signs, Remote Traffic Management Sensors, and Automatic Vehicle Identification systems are prevalent. Some other ITS systems like CB Radio Advisory System, and Supervisory Control and Data Acquisition systems are also in use.

At the end of the survey, the toll authorities shared their experience and ideas about safety and/or traffic management on their systems.

6 TRAFFIC SAFETY EVALUATION

Traffic safety is also an important indicator of expressway performance and significantly related with operation. On the one hand, turbulence in traffic flow will cause variation in traveling speed thus posing risks to motorists. On the other hand, traffic crashes can reduce the roadway capacity temporarily and lead to delay and congestion. Therefore, improvement in operation will have positive effects on traffic safety and the same effects on operation are expected by improving traffic safety. Traffic crash data from January 2011 to June 2014 were collected to evaluate the traffic safety conditions on the expressway system. Selection of this time period is partly because the issue of data completeness with 2010 crashes. In the data preparation section, it has been explained that from July 2012 the crash records in S4A data is complete for whole Florida. As for Orange County, by checking the number of crashes as shown in Table 6-1, the research team also included data from 2011 since the total crash numbers of these years are comparable. All the data used in the safety analysis is from S4A database.

6.1 Crash Data Preparation

The crashes contained in S4A are geocoded data with longitude and latitude information. Nevertheless, crash direction, and roadway milepost are not available. To locate these crashes and assign the direction and milepost information to these crashes, a Geographic Information System (GIS) network specifically for the expressways is created using ArcGIS. The original GIS data is downloaded from FDOT website. The research team made adjustment to keep only the expressways as shown in Figure 6-1.

Table 6-1 Crash Data Preparation for CFX Expressway System

Year	Orange County Crashes	Expressway Mapped Crashes	Expressway Unmapped Crashes	SR 408 Crashes	SR 414 Crashes	SR 417 Crashes	SR 429 Crashes	SR 528 Crashes
2011	32026	1379	52	666	30	337	83	263
2012	35847	1375	88	626	25	369	78	277
2013	40476	1484	79	700	40	355	76	313
2014 (Jan -- Jun)	21322	859	35	361	35	218	67	178

As seen in Table 6-1, a small portion of crashes during each year were unmapped and could not be located. The research team referred to the original crash report for indications of crash location and found several issues that might cause this issues. First of all, these unmapped crashes lacked the coordinate information and were assigned with the location (0, 0). Second, the description of these crashes was unclear therefore the location could not be identified. For instance, one crash was described as “near Holland Toll Plaza” for which the toll plaza could not be found on SR 408. Third, some crashes have conflicting descriptions about the crash site such as that the crash street is recorded as SR 408. However, in the narrative part the police officer described that the crash was on SR 414. In conclusion, these crashes were not used for the safety analysis.

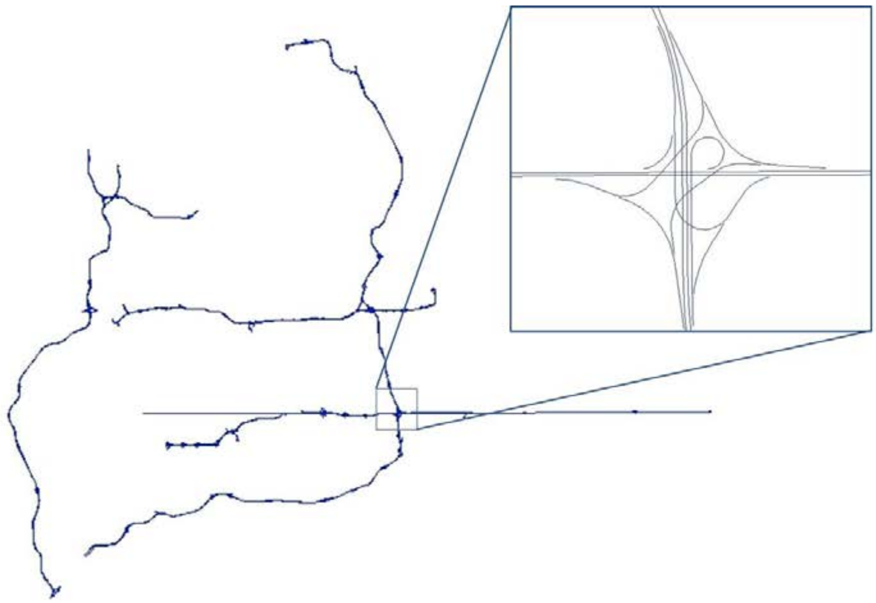


Figure 6-1 Expressway Network in GIS

To locate the crashes on the expressways, the crashes occurring within Orange County during one year period were selected in the first place as shown in Figure 6-2. Then an initial selection of crashes on the expressways was conducted. In the crash report, there is one column indicating the crash street based on which crashes on expressways could be collected. However, the naming of the expressways is not consistent. As a solution, several key words that can be used for the same expressway were extracted using the Structured Query Language (SQL) technique as shown in Table 6-2. The “%” means any string of zero or more characters and “_” means any single character within the string in SQL. Using these criteria, the initial selection was made as displayed in Figure 6-3.

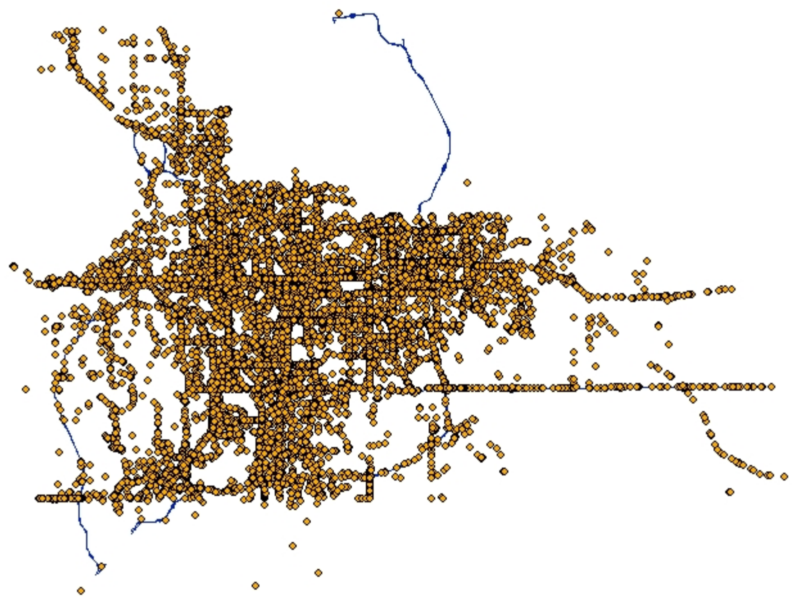


Figure 6-2 Total Crashes of Orange County in 2011

Table 6-2 Key Words Used for Expressway Crash Selection

Expressway	Key Words
SR 408	“%408%”, “%E-W%”, “%E/W%”, “%EAST_WEST%”, “EW %”, “%EASTWEST%”
SR 414	“%414%”, “%APOPKA EXPY%”, “%JOHN LAND%”, “%MAITLAND BLVD%”
SR 417	“%417%”, “%CENTRAL_FL%”, “GREENEWAY”
SR 429	“%429%”, “%BELTWAY%”, “%WEBSTER%”
SR 528	“%528%”, “%BEELINE%”, “BEACHLINE”

As can be seen in Figure 6-3, the majority of the crashes after the initial selection are located on the expressways. A few of the crashes that are not related to the expressways were also included because they share the same key words that are used to filter the expressway crashes. In addition, some crashes on the expressways occurred on the segments that are not operated by CFX. These crashes would also not be included in further analysis. Therefore a final selection based on the roadway segments that are operated by CFX was executed. The roadway information for each expressway was archived in FDOT Interchange Report (*30*). It should be noted that this report is last updated in 2012 therefore a few sections that underwent changes might not be reflected in Table 6-3. For northern segment used to be part of SR 429 is now SR 451. And currently SR 414 and SR 429 share one segment together. Therefore SR 414 now extends for 9.62 miles. The interchange of SR 408 and SR 417 was changed during these time period, thus the segment from MP 16.649 to MP 17.090 no longer exists. For the other parts of the system, most segments remain the same.

Figure 6-3 Initial Selection of Expressway Crashes in 2011

Table 6-3 Expressway Segment and Operation Authority

Route	County	Roadway ID	Local Milepost	Cumulative Milepost	Authority
SR 528	Orange	75471000	00.000 – 08.421	00.000 – 08.421	Florida's Turnpike
		75002000	07.944 – 30.341	08.421 – 30.818	CFX
		75005000	00.000 – 04.957	30.818 – 35.775	Florida's Turnpike
	Brevard	70007000	00.000 – 09.956	35.775 – 45.731	Florida's Turnpike
		70070000	05.200 – 12.968	45.731 – 53.499	Florida's Turnpike
SR 408	Orange	75474000	00.000 – 00.759	00.000 – 00.759	Florida's Turnpike
		75008170	01.417 – 05.132	00.759 – 04.474	CFX
		75008000	00.382 – 11.852	04.474 – 15.944	CFX
		75008160	00.000 – 06.260	15.944 – 22.204	CFX
SR 414	Orange	75340000	00.000 – 09.620	00.000 – 09.620	CFX
SR 417	Osceola	92472000	00.000 – 02.906	00.000 – 02.906	Florida's Turnpike
	Orange	75472000	00.000 – 02.192	02.906 – 05.098	Florida's Turnpike
		75301000	00.000 – 20.017	05.098 – 25.115	CFX
		75300000	00.000 – 11.501	25.115 – 36.616	CFX
		77470000	00.000 – 17.445	36.616 – 54.061	Florida's Turnpike
SR 429	Osceola	92473000	00.000 – 04.528	00.000 – 04.528	Florida's Turnpike
	Orange	75473000	00.000 – 05.325	04.528 – 09.853	Florida's Turnpike
		75320000	18.000 – 40.000	09.853 – 31.853	CFX

The results of the final selection are illustrated in Figure 6-4. In this figure, the crashes not related to expressways and those crashes not occurring on segments operated by CFX have been excluded. In the final crash data, crashes on the mainline, ramps and toll plaza cash lanes on the segments managed by CFX are selected. Figure 6-5 shows the detail about how these crashes are assigned. Both crash direction and mileposts are assigned to the crashes using ArcGIS. For each year, the same process was repeated to extract the expressway crash data from 2011 to June, 2014. The crash count for each expressway in each year is shown in Table 6-1. SR 408 has the most crashes and SR 414 has the lowest crash count during each year. SR 417 has slight more crashes than SR 528. Several factors can contribute to the crash pattern on the expressway system. SR 408 is the spine of the system and carries the most traffic. SR 417 and SR 528 have relatively long segment length. However, the eastern part of SR 528 is located in suburban area, thus lighter traffic on this segment lead to fewer crashes compared with SR 417. SR 414 is the shortest of the five expressways and most crashes on SR 414concentrate near the eastern end of the roadway segment.

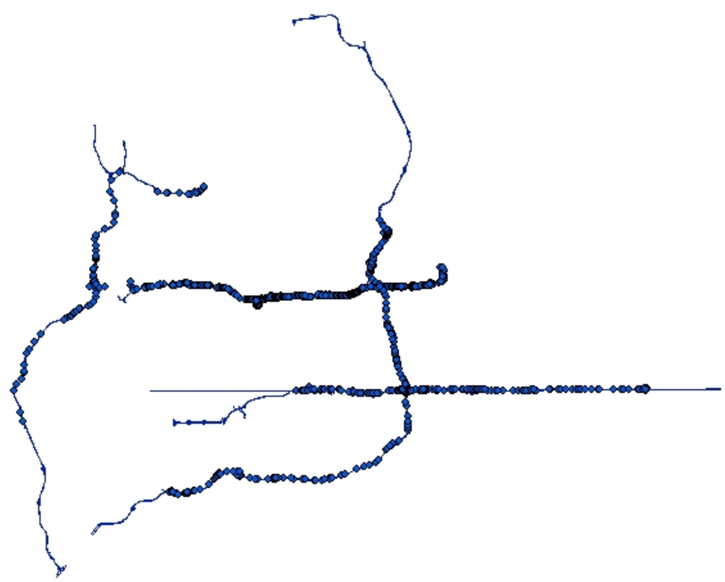


Figure 6-4 Final Selection of Expressway Crashes in 2011

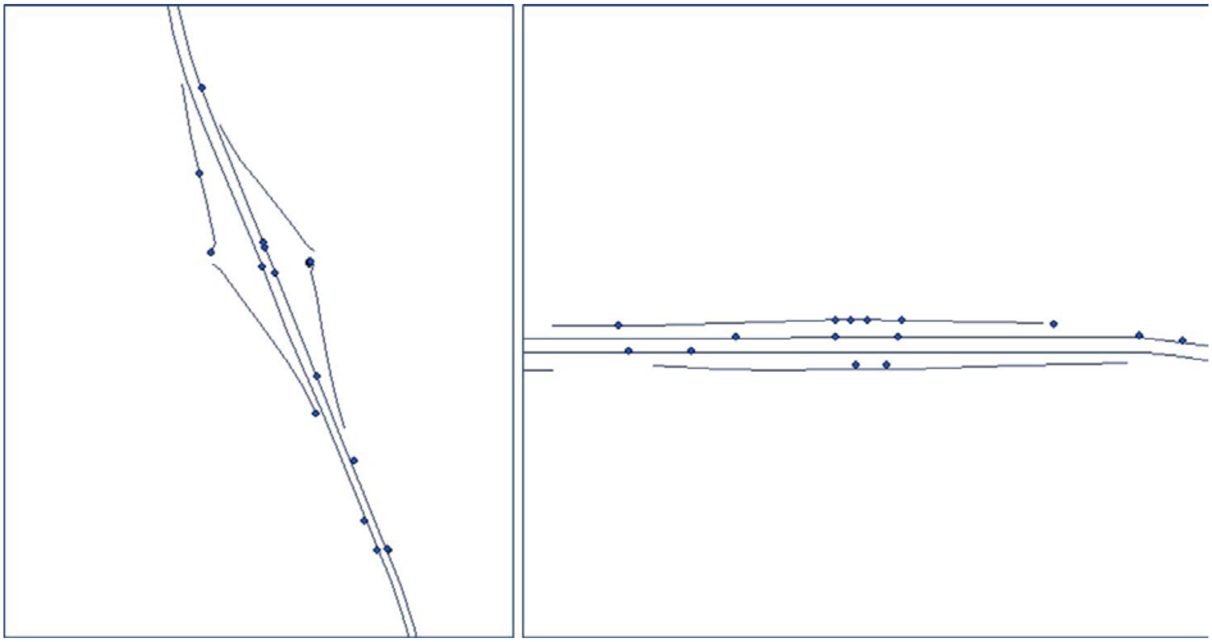


Figure 6-5 Crash Match on Mainline, Ramp and Toll Plaza Cash Lanes

6.2 Expressway Safety Overview

Traffic safety can be viewed by the type of lanes on which the crashes occurred since the crash mechanism on these types of lanes can be distinct. On the expressways, there are three types of lanes, namely the mainline including toll plaza express lanes, toll plaza cash lanes, and ramps. Table 6-4 displays the crashes by the types of lane for each expressway in 2011. Table S-1 to Table S-3 show the same information for other years.

For SR 408, most of the crashes occurred on the mainline. For SR 414, ramps have more crashes than the mainline. On SR 417, in 2011 and 2012, mainline has the most crashes. In 2013 and the first half of 2014, crash count on ramps exceed the crashes on the mainline on SR 417. SR 429 has slightly more crashes on the mainline. On SR 528, the majority of crashes occurred on the mainline.

Table 6-4 Expressway Crash by Type of Lane in 2011

Expressway	Total Crash	Mainline	Toll Plaza Cash Lane	Ramp
SR 408	666	476	20	170
SR 414	30	10	0	20
SR 417	337	204	15	118
SR 429	83	56	3	24
SR 528	263	208	13	42

Figure 6-6 and Table 6-5 show the crash count on SR 408 by the type of lanes in the three and half years. The trend is relatively stable without significant changes. For each type of crashes, there is a small increasing in the number of crashes at mainline toll plaza cash lanes on SR 408. For SR 414, ramp crashes are the major crash type on the expressway as shown in Table T-1 and Figure T-1. There is also an increasing trend in the total number of crashes on SR 414. This might be because that in 2012, the construction of SR 414 had not yet been completed. As a result, in 2013 and 2014, more crashes are expected on the whole segment of SR 414 when the construction is finished. On SR 417, there is a decreasing trend of mainline and toll plaza crashes during the past years (shown in Table T-2 and Figure T-2). However, the crashes on ramps are increasing. Crashes on SR 429 decreased trend from 2011 to 2013. However, in the first half year of 2014, the crash count is close to the number of crashes for the whole year of 2013 on SR 429 (Table T-3 and Figure T-3). On SR 528, there is also steady increase in crashes, with a reduction of toll plaza crashes (Table T-4 and Figure T-4). Since complete 2014 crash data are not available at this moment, only the first six months are used.

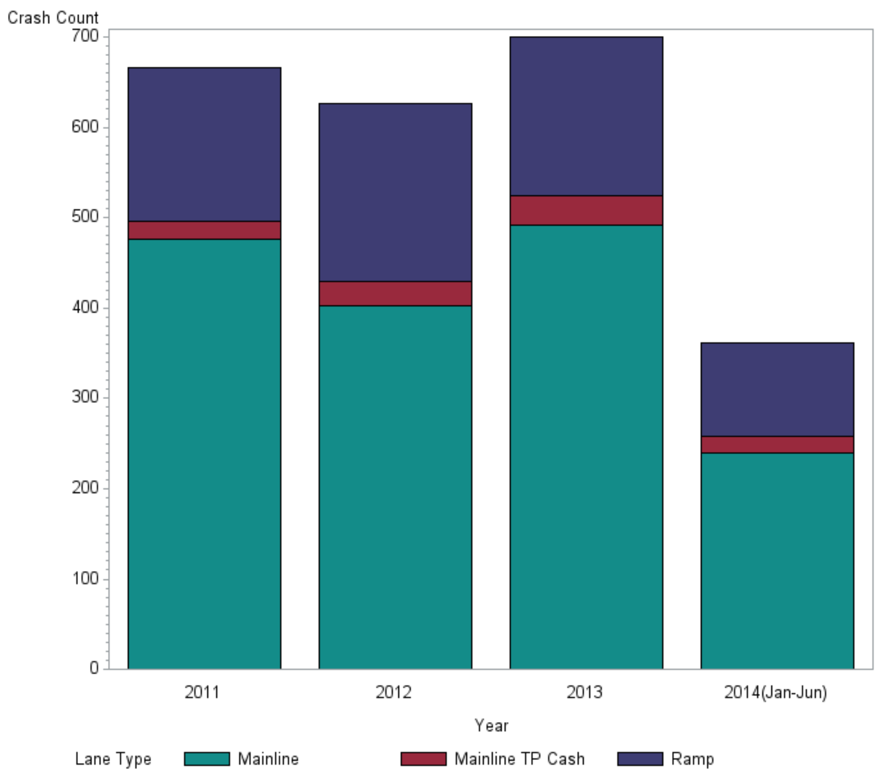


Figure 6-6 SR 408 Crash Count by Year

Table 6-5 SR 408 Annual Crash Count by Type of Lane

Lane Type	Year			
	2011	2012	2013	2014 (Jan -- Jun)
Total Crash	666	626	700	361
Mainline	476	402	492	239
Toll Plaza Cash Lane	20	27	32	19
Ramp	170	197	176	103

Generally speaking, the crash trend is stable over the time period for SR 408 and SR 417. SR 414 and SR 528 have small increase while crashes on SR 429 decreased. Since the complete crash data for 2014 are unavailable currently, only the data of the first half year are used. However, according to the six-month data, it is expected that in 2014 the crashes would increase. This potential increase is probably due to the recovered economy or other reasons that are not significant at this moment.

In addition to the general safety performance of CFX expressways in the recent three and half years, the CFX system performance against other turnpike authorities was compared using the 2012 mainline crashes data. In the safety performance comparison, the total crash counts are useful indicators of the safety condition (and sometime even the operation condition) of a particular location. However, due to the variation in roadway lengths, the traffic conditions, etc., comparing traffic safety levels between different routes based on crash frequency can be misleading. Crash rates for each expressway during one year combine crash frequency and vehicle exposure in evaluating the roadway safety:

$$R = \frac{C \times 100{,}000{,}000}{V \times 365 \times \sum L_i} \quad (4)$$

The variables in equation (4) are defined as:

R = Roadway Departure crash rate for the road segment expressed as crashes per 100 million vehicle-miles of travel (MVMT),

C = Total number of roadway departure crashes in the study period

V = Traffic volumes using Average Annual Daily Traffic (AADT) volumes

N = Number of years of data

L = Length of the roadway segment in miles

In the above equation, $AADT$ is used as traffic volume indicator. $AADT$ for the expressway is derived according to the segment AADT and segment length.

$$AADT = \frac{\sum(AADT_i \times L_i)}{\sum L_i}$$

Where $AADT_i$ is the $AADT$ for segment i, L_i is the length of the ith segment. Crash rates in 2012 for major toll expressways across Florida were compared as shown in Table 6-6.

Table 6-6 Crash Rates in 2012 on Toll Expressways in Florida

Rank	ROUTE	Local Name	Crash Count	Length	AADT	Crash Rate (100MVMT)
1	SR 836	DOLPHIN EXPRESSWAY	1536	10.596	147706.71	268.87856
2	SR 821	HEFT	1779	47.572	88975.07	115.14984
3	SR 589	VETERANS EXPY	213	11.458	54591.91	93.293123
4	SR 408 (CFX)	SR-408	402	22.591	66346	73.482342
5	SR 568	VETERANS EXPY	8	3.036	10418.18	69.295255
6	SR 91	TURNPIKE	3035	262.678	46607.47	67.918268
7	SR 408 (TURNPIKE)	SR-408	7	0.759	38100	66.319069
8	SR 869	SAWGRASS EXPY	302	20.809	64114.71	62.016205
9	SR 528 (CFX)	BEACHLINE	202	22.376	44547.5	55.520416
10	SR 417 (CFX)	SR-417	193	31.518	37650.68	44.558747
11	SR 528 (TURNPIKE)	BEACHLINE	171	24.242	44011.34	43.910685
12	SR 618	SELMON EXPY	83	14.132	37194.42	43.261723
13	SR 589	SUNCOAST PKWY	108	41.449	17611.24	40.534694
14	SR 417 (TURNPIKE)	SR-417	103	22.543	32962.68	37.97608
15	SR 93	ALLIGATOR ALY	118	49.2	18017.2	36.470082
16	SR 429 (TURNPIKE)	SR-429	12	9.853	10765.07	30.995814
17	SR 570	POLK PKWY	37	24.38	16166.23	25.71973
18	SR 429 (CFX)	SR-429	43	20.404	21621.89	26.703404
19	SR 93	I-75	42	25.783	21753	20.516526
20	SR 414 (CFX)	SR-414	6	5.662	15100	19.227002

According to the table above, among the toll and turnpike authorities' system across Florida, CFX's expressway system has relatively good safety performance in terms of crash rate. Compared with SR 836, SR 821, both of which travel through downtown Miami, and SR 589 in Tampa metropolitan area, SR 408 extends through downtown Orlando, but has a lower crash rate. Segments of SR 417 and SR 528 operated by CFX have the crash rates at median level. Crash rate for SR 429 segment on CFX's system is among the lowest.

6.3 Categorical Analysis of Expressway Mainline Crashes

More insights of the traffic safety conditions on expressways can be viewed through detailed categorical analysis of crashes. Crash type is one of the most important factors to understand the characteristics of crashes. On the mainline of the expressways, multiple types of crashes are recorded. The most common types include rear end crashes, off -road crashes, sideswipe crashes, rollover crashes and animal crashes. For some crashes that cannot be classified into these common crash types, they are recorded as “Other”. Some other crashes that miss the crash type information are recorded as “Unknown”. Table 6-7 shows the crash count in each year on the five expressways by types of crashes. On SR 408, rear end crashes are the most common type of crashes followed by off-road and sideswipe crashes. Off-road crashes are the majority crash type on SR 414, SR 417 and SR 429. On SR 528, the number of rear-end crashes are similar to the number of off-road crashes from 2011 to 2013. Furthermore, SR 417 and SR 528 have relatively more animal related crashes compared to other expressways. This might be because part of both SR 417 and SR 528 travel in the suburban areas around Orlando. By identifying the major crashes on each expressway, corresponding safety countermeasures can be proposed.

By investigating into the number of vehicles involved in a crash, it is found that on SR408, SR 417 and SR 528 most of the crashes are multi-vehicle crashes as shown in Table 6-8. SR 414 and SR 429 have single-vehicle crashes. Of the multi-vehicle crashes, most of the crashes involve two vehicles. On SR 408, the number of crashes involving more than two vehicles is significantly higher than other expressways. This can be partly explained by the heavy traffic load on SR 408. From the results of congestion evaluation, it is known that SR 408 has the higher congestion intensity compared with other expressways. In congested traffic flow, the turbulence of speed is more likely to cause multi-vehicle crashes.

Table 6-7 Crash Types by Expressway and Year

Expressway	Year	Crash Type							Total
		Rear End	Off-Road	Sideswipe	Rollover	Animal	Other	Unknown	
SR 408	2011	191	125	74	11	5	38	32	476
	2012	185	72	63	8	1	36	37	402
	2013	245	93	79	5	1	44	25	492
	2014 (Jan -- Jun)	130	34	49	1	0	16	9	239
SR 414	2011	1	6	1	0	0	2	0	10
	2012	0	3	2	0	0	1	0	6
	2013	2	7	2	0	0	3	0	14
	2014 (Jan -- Jun)	4	6	2	0	0	2	0	14
SR 417	2011	46	63	33	9	4	29	20	204
	2012	43	63	34	12	5	31	5	193
	2013	42	41	25	8	2	27	7	152
	2014 (Jan -- Jun)	25	33	13	2	1	23	6	103
SR 429	2011	11	18	4	7	2	12	2	56
	2012	5	16	5	3	1	11	2	43
	2013	12	19	7	2	0	6	1	47
	2014 (Jan -- Jun)	12	14	6	3	0	12	2	49
SR 528	2011	74	72	22	3	5	19	13	208
	2012	79	50	23	7	3	24	16	202
	2013	88	71	30	14	11	16	12	242
	2014 (Jan -- Jun)	60	30	28	4	1	18	2	143

Table 6-8 Number of Vehicles Involved in Crashes by Expressway and Year

Expressway	Year	Number of Vehicles Involved				Total
		1	2	3	≥ 4	
SR 408	2011	136	292	38	10	476
	2012	75	266	47	14	402
	2013	91	337	45	19	492
	2014 (Jan -- Jun)	32	162	40	5	239
SR 414	2011	7	2	0	1	10
	2012	4	2	0	0	6
	2013	7	6	1	0	14
	2014 (Jan -- Jun)	8	6	0	0	14
SR 417	2011	77	111	15	1	204
	2012	83	96	10	4	193
	2013	59	82	9	2	152
	2014 (Jan -- Jun)	37	60	4	2	103
SR 429	2011	34	21	0	1	56
	2012	25	16	2	0	43
	2013	21	20	5	1	47
	2014 (Jan -- Jun)	25	20	4	0	49
SR 528	2011	84	98	20	6	208
	2012	64	113	21	4	202
	2013	95	126	13	8	242
	2014 (Jan -- Jun)	39	84	17	3	143

Crash severities on the expressways in Table 6-9 indicate that the expressways have few fatal crashes in the past three and half years. This result implies relatively good safety performance of the expressways from the perspective of social and economic losses. Most of crashes on the expressway are property damage only crashes. Since SR 408 has the most crashes in total, the number of injury related crashes on SR 408 is also the highest. Nevertheless, the percentages of injury crashes in the total crashes on each expressway are similar.

Considering the weather effects on traffic safety, Table 6-10 shows that crashes under clear weather condition are still the majority of the crashes. Crashes in rainy weather are the second largest group of all. However, compared the probability of clear and rainy weather, it should be interpreted as that rainy weather could increase the likelihood of crash occurrences. Under rainy condition, both road friction and drivers' visibility will be affected by precipitation. Fog/smoke related crashes also exist during the studied time period but take only very small portion.

Table 6-9 Crash Injury Severity by Expressway and Year

Expressway	Year	Crash Severity			Total
		Property Damage Only	Injury	Fatality	
SR 408	2011	346	128	2	476
	2012	287	114	1	402
	2013	323	166	3	492
	2014 (Jan -- Jun)	172	67	0	239
SR 414	2011	3	7	0	10
	2012	5	1	0	6
	2013	9	5	0	14
	2014 (Jan -- Jun)	10	4	0	14
SR 417	2011	146	57	1	204
	2012	142	51	0	193
	2013	99	53	0	152
	2014 (Jan -- Jun)	80	23	0	103
SR 429	2011	33	23	0	56
	2012	28	15	0	43
	2013	32	15	0	47
	2014 (Jan -- Jun)	34	14	1	49
SR 528	2011	136	71	1	208
	2012	137	63	2	202
	2013	173	67	2	242
	2014 (Jan -- Jun)	88	55	0	143

Table 6-10 Weather Condition of Crashes by Expressway and Year

Expressway	Year	Weather Condition					Total
		Clear	Cloudy	Rain	Fog/Smoke	Missing	
SR 408	2011	304	67	93	5	3	472
	2012	268	63	62	3	6	402
	2013	332	78	77	1	4	492
	2014 (Jan -- Jun)	170	31	37	1	0	239
SR 414	2011	3	1	6	0	0	10
	2012	4	0	2	0	0	6
	2013	3	4	6	0	1	14
	2014 (Jan -- Jun)	6	2	6	0	0	14
SR 417	2011	131	36	33	4	0	204
	2012	138	27	26	2	0	193
	2013	92	35	24	1	0	152
	2014	57	24	21	1	0	103
SR 429	2011	40	5	11	0	0	56
	2012	24	11	7	1	0	43
	2013	26	12	9	0	0	47
	2014 (Jan -- Jun)	31	11	6	1	0	49
SR 528	2011	134	31	40	1	2	208
	2012	124	28	45	1	4	202
	2013	130	53	54	2	3	242
	2014 (Jan -- Jun)	91	29	20	3	0	143

Lighting conditions can also affect traffic safety on the expressways. In the crash reports, five categories about the lighting conditions are available. The five categories are dawn, daylight, dusk, dark lighted and dark not lighted. A few records of crashes have missing lighting condition. In the dark condition, most crashes on SR 408 and SR 414 are recorded as "dark lighted" condition (Table 6-11). On SR 417, SR 429 and SR 528 have significant more crashes with "dark not lighted". The results are related to the location of the expressways. On the segments located in the urban area, light poles are commonly installed. However, on the less traveled segments in the suburban area, there might not be adequate light poles.

Road surface conditions have impact on the friction between pavement surface and the tires thus affecting crash likelihood. After evaluating the recorded road surface conditions when crashes occur, the research team found high percentage of wet pavement related crashes as displayed in Table 6-12. For SR 408 and SR 417, there is small trend of decrease in wet pavement related crashes. While for SR 429 and SR 528, the increase trend can be seen. This pattern poses a challenge to bring down the wet surface related crashes on the two expressways. The future safety measurement should not overlook this issue.

Table 6-11 Lighting Conditions of Crashes by Expressway and Year

Expressway	Year	Lighting Condition						Total
		Dawn	Daylight	Dusk	Dark Lighted	Dark Not Lighted	Unknown	
SR 408	2011	3	321	11	130	4	3	472
	2012	3	291	10	84	8	6	402
	2013	11	368	10	98	0	4	491
	2014 (Jan -- Jun)	3	191	4	40	1	0	239
SR 414	2011	0	5	1	4	0	0	10
	2012	0	5	0	1	0	0	6
	2013	0	11	1	2	0	0	14
	2014 (Jan -- Jun)	0	10	0	4	0	0	14
SR 417	2011	6	143	7	36	12	0	204
	2012	1	122	8	43	19	0	193
	2013	2	98	2	42	8	0	152
	2014 (Jan -- Jun)	1	78	1	13	10	0	103
SR 429	2011	0	35	3	14	4	0	56
	2012	2	24	3	10	4	0	43
	2013	0	30	0	11	6	0	47
	2014 (Jan -- Jun)	3	33	1	8	4	0	49
SR 528	2011	3	129	12	28	34	2	208
	2012	6	137	6	26	21	4	200
	2013	7	143	6	48	35	3	242
	2014 (Jan -- Jun)	4	93	4	24	18	0	143

Table 6-12 Road Surface Conditions of Crashes by Expressway and Year

Expressway	Year	Road Surface Condition			Total
		Dry	Wet	Missing	
SR 408	2011	334	135	3	472
	2012	306	90	6	402
	2013	372	115	4	491
	2014 (Jan -- Jun)	184	55	0	239
SR 414	2011	3	7	0	10
	2012	4	2	0	6
	2013	4	10	0	14
	2014 (Jan -- Jun)	8	6	0	14
SR 417	2011	156	48	0	204
	2012	150	43	0	193
	2013	113	39	0	152
	2014 (Jan -- Jun)	70	33	0	103
SR 429	2011	45	11	0	56
	2012	31	12	0	43
	2013	33	14	0	47
	2014 (Jan -- Jun)	40	9	0	49
SR 528	2011	146	60	2	208
	2012	133	65	2	200
	2013	158	81	3	242
	2014 (Jan -- Jun)	100	43	0	143

6.4 Spatial Analysis of Expressway Crash

With the preliminary categorical analysis of expressway crashes, the more urgent task is to identify where each of these types of crashes are likely to occur. By identifying the distribution of these crashes, appropriate treatment could be applied to locations that are impacted by these specific issues.

For the total crashes on expressway system, the spatial pattern of crashes is examined through crash density. The spatial distribution of crashes on the mainline, mainline toll plaza cash lanes and ramps can be found in Figure 6-7 and Figure U-1 to Figure U-3 in Appendix U. From the figures, the concentration of each type of crashes and the changes in the past three and half years can be clearly identified. For the mainline crashes, the segment on SR 408 between the interchange with Semoran Blvd and SR 417 is the most concentrated area of mainline crashes in 2011. After 2011, the mainline crashes began to shift to the interchange of SR 408 and I-4. In the first six months of 2014, the segment that has the most mainline crashes is near the interchange of SR 408 and I-4 while the interchange with SR 417 is no longer identified as the hot spot. This reduction of crashes at the segment near SR 417 might be caused by the interchange improvement project on this specific interchange. Also, in 2013 and 2014, the segment on SR 528 near the interchange with Semoran Blvd has become a crash hot post. This area is the same segment that experiences congestion on SR 528. Fewer express lanes and lower speed limit on the lanes might contribute to the crash occurrence.

The number of crashes on mainline toll plaza cash lanes is relatively small compared with mainline and ramp crashes. As a result, the crash hot spots were not fixed in these years. Nevertheless, Pine Hills Mainline Toll Plaza, Conway Road Mainline Toll Plaza on SR 408, John Young Parkway Mainline Toll Plaza, University Mainline Toll Plaza on SR 417 and Beachline Mainline Toll Plaza on SR 528 are found to be the toll plazas on the mainline that can have more crashes on their cash lanes.

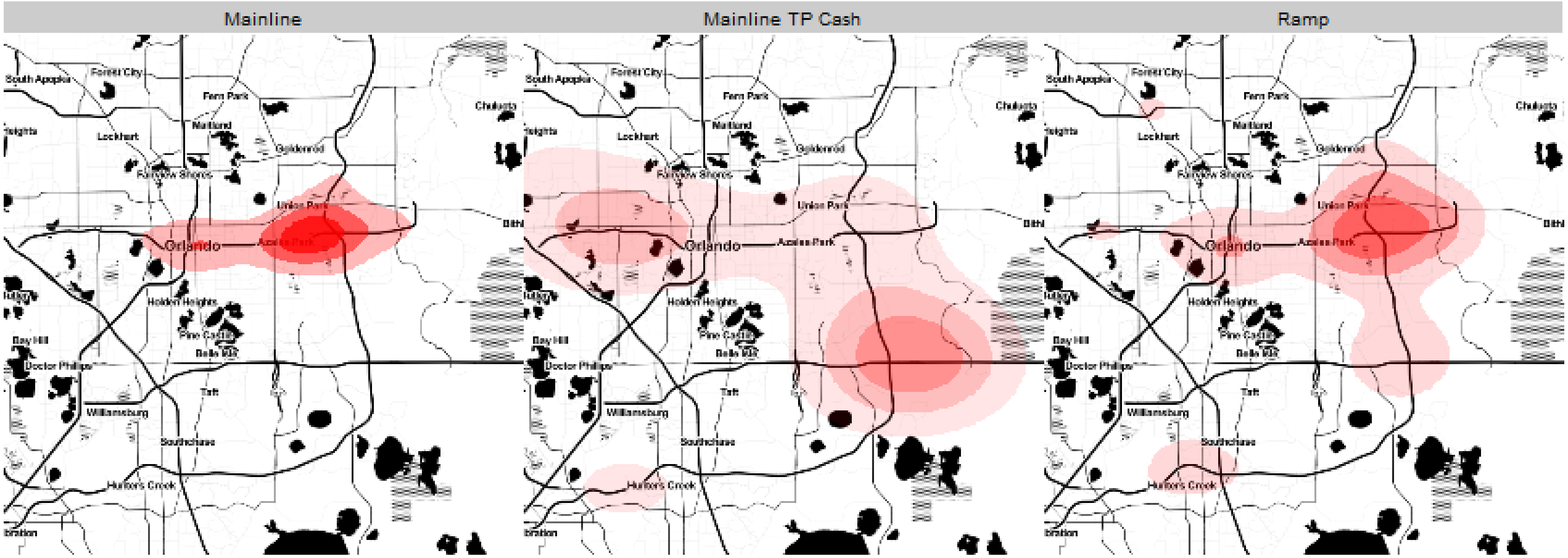


Figure 6-7 Spatial Pattern of Traffic Crashes by Types of Lane in 2011

For the ramp crashes, the similar pattern as mainline crashes on SR 408 can also be detected. From 2011 to 2013, ramps at the interchange between SR 408 and SR 417 have the highest crash density. However, this pattern changes in 2014 as that the interchange between SR 408 and I-4 becomes the concentration area of ramp crashes on SR 408. The interchange between SR 417 and SR 528 is also a major area for ramp crashes. Also, the ramps on SR 417 at John Young Parkway and Orange Blossom Trail are found to be more likely to have ramp crashes.

The findings of mainline crashes, mainline toll plaza cash lane crashes and ramp crashes shows the concentrated locations of each type of these crashes. Also the changes in crash density on the expressway system are found. The results can be used for potential safety improvement projects in the future.

Crash density by crash characteristics is also studied as shown in Figure 6-8 and Figure U-4 to Figure U-6. The patterns found in the four figures are basically the same. The most important finding is about the distribution of rear end crashes. In the congestion analysis, the most congested segments of the expressways are located on SR 408 and SR 528. In the safety analysis, the rear end crashes are found to most likely to occur on these congested segments. This result confirms the relationship between congestion and rear end crashes, which also highlight the importance of queue warning using DMS on the expressways.

The spatial distribution of crashes by the number of vehicles involved is similar to the results found above. Off-road and rollover crashes are more likely to be single-vehicle crashes while rear end and sideswipe crashes are the crashes involving at least two vehicles. One interesting trend about the multi-vehicle crashes can be found in Figure 6-9 and Figure U-7 to Figure U-9. In 2011, the multi-vehicle crashes are more concentrated near the interchange between SR 408 and SR 417. In the following two and half years, the concentration shifted to the interchange between SR 408 and I-4. This shows the significant effects of the interchange improvement project, but also points out the current problematic site for future improvement.

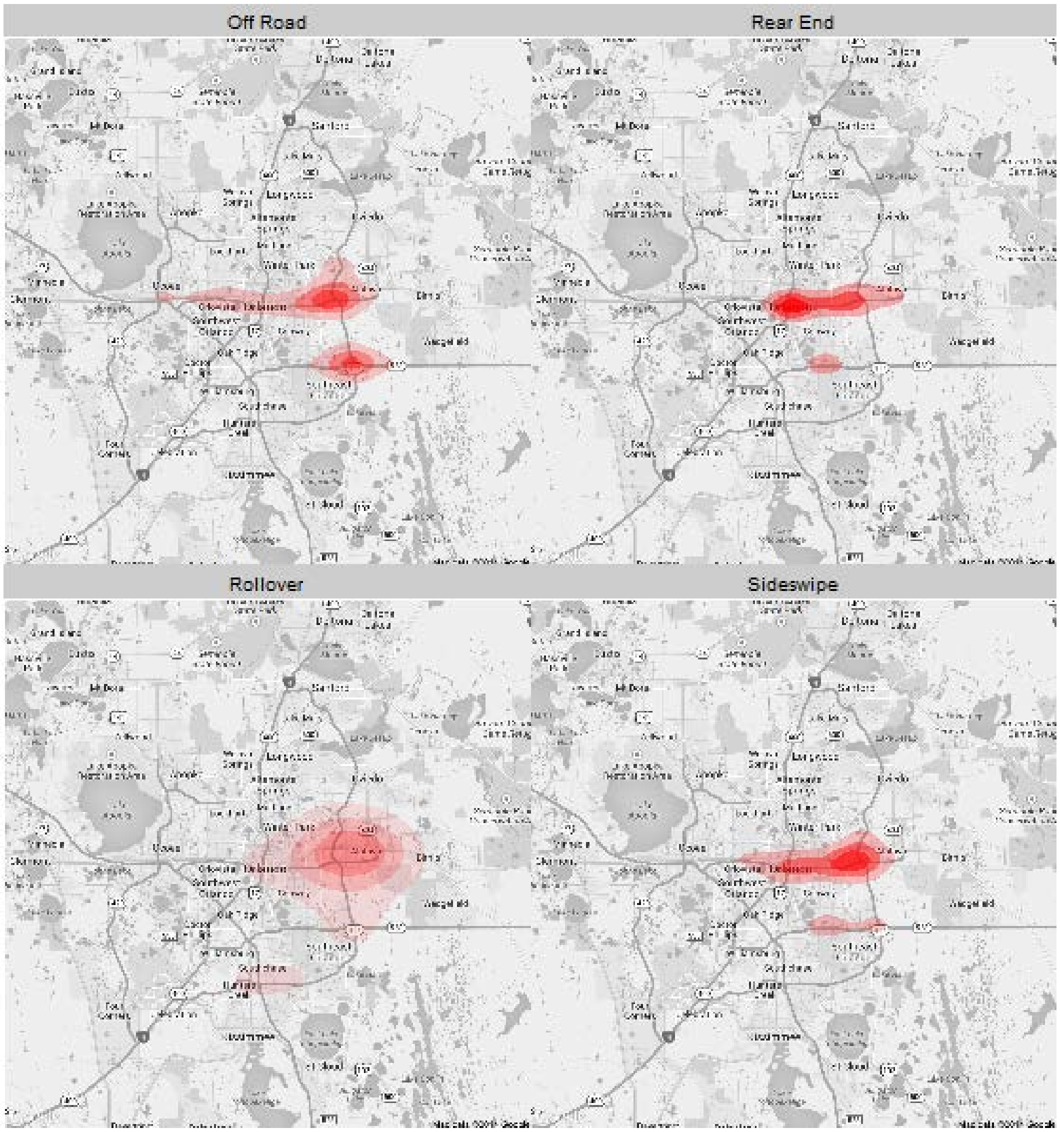


Figure 6-8 Spatial Pattern of Traffic Crashes by Crash Type in 2011

By examining the crash severity on the five expressways, it is found that since the fatal crashes are few, the spatial pattern of fatal crashes can be random as shown in Figure 6-10 and Figure U-10 to Figure U-12. The characteristics of injury and PDO crashes are relatively easy to be identified. The distributions of injury and PDO crashes are comparable. SR 408 contains the most concentrated area for injury crashes which is the congested segment. On SR 528, on the segment from Beachline Mainline Airport Mainline Toll Plaza to the interchange with SR 417 is the major area of these two types of crashes.

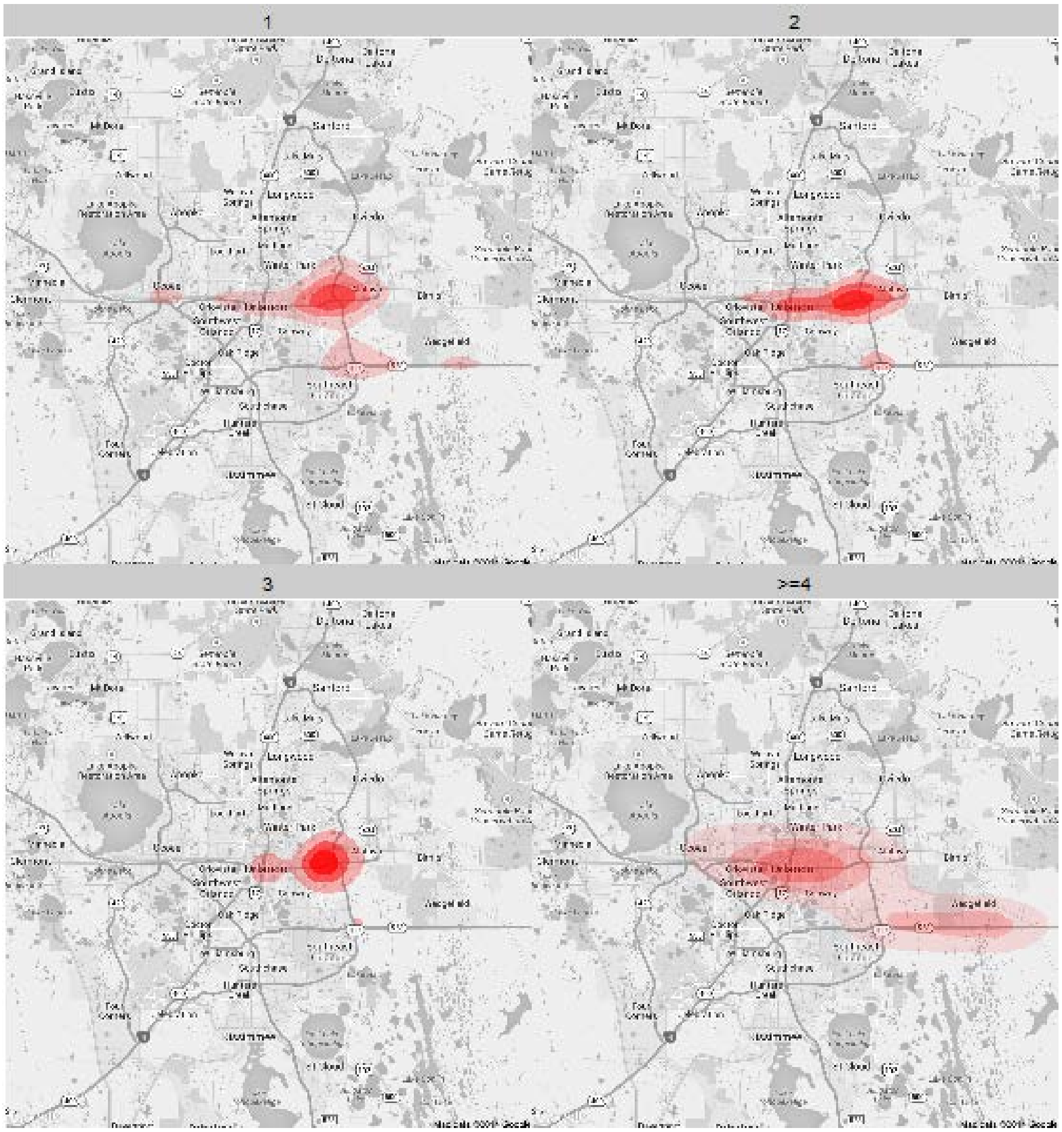


Figure 6-9 Spatial Pattern of Traffic Crashes by Number of Vehicles in 2011

Crashes based on the lighting conditions reveal the significant pattern of the crashes under dark conditions without lighting. Figure 6-11 and Figure U-13 to Figure U-15 all indicate that the segment on SR 528 east to the interchange with SR 417 is the major segment that the "dark - not lighted" crashes were observed. The segment of problem travels on the less populated suburban area to the coast area. Light poles are not commonly installed on along the road in this area. As a result, during the night time crashes might be caused by reduced visibility condition. The spatial analysis is proved to be particularly useful in identifying the segment on the expressways with specific safety problem. In the future, if light poles are installed on this segment, it is expected to bring down the crashes.

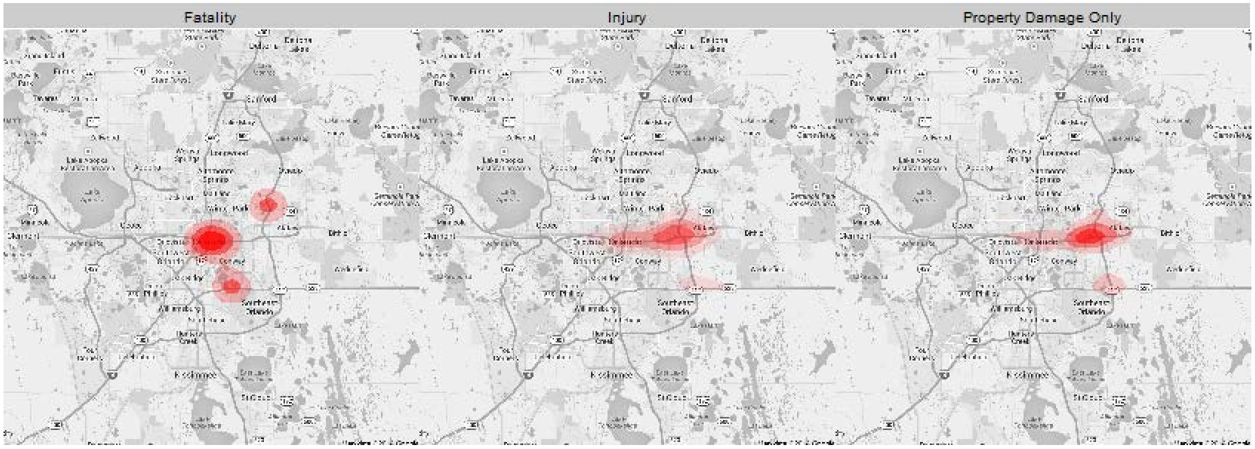


Figure 6-10 Spatial Pattern of Traffic Crashes by Crash Severity in 2011

Figure 6-11 Spatial Pattern of Traffic Crashes by Lighting Condition in 2011

Weather and road surface conditions are also considered to significantly affect the crash occurrence. In Figure 6-12 and Figure 6-13, the spatial distributions by weather and road surface conditions in 2011 are illustrated. It can be shown that under the rainy or wet pavement conditions, the interchanges are the most affected area. In 2011 and 2012, the interchange between SR 408 and SR 417 and the interchange between SR 528 and SR 417 have the highest crash density under rainy and wet pavement condition. In 2013 and 2014, the area on SR 408 moves to the interchange with I-4. The issue with SR 417 -- SR 528 interchange remains the same. Consequently, improving ramp safety should specifically focus on these two interchanges.

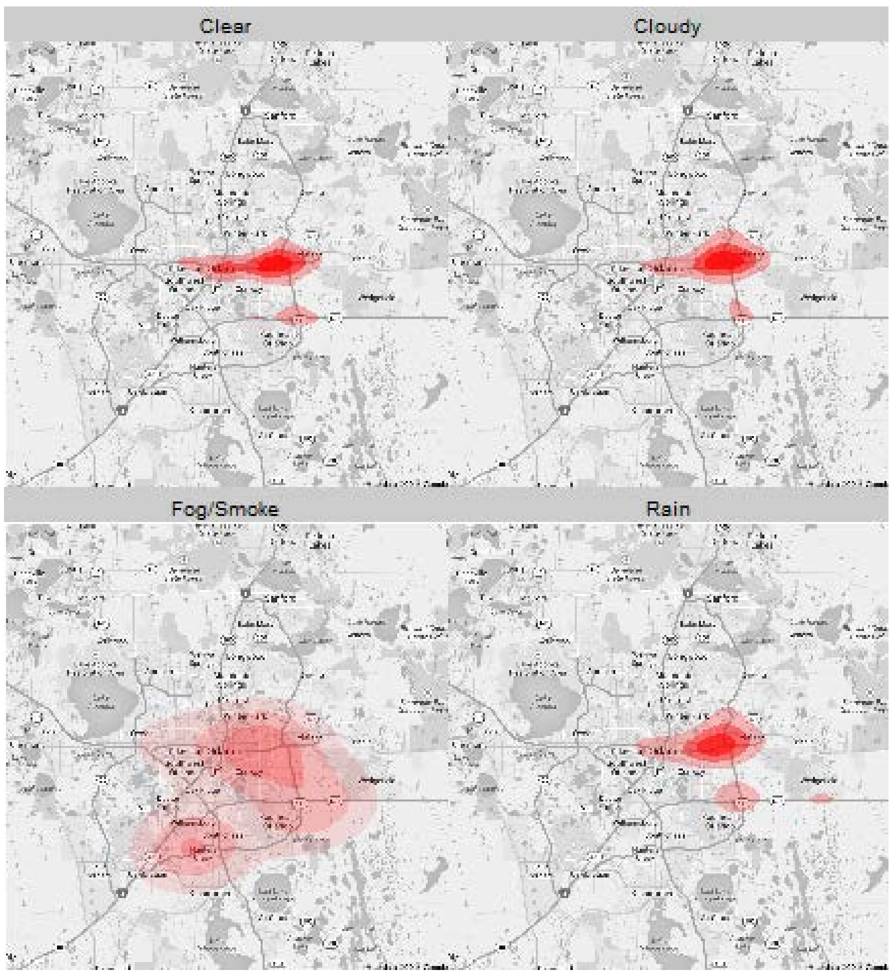


Figure 6-12 Spatial Pattern of Traffic Crashes by Weather Condition in 2011

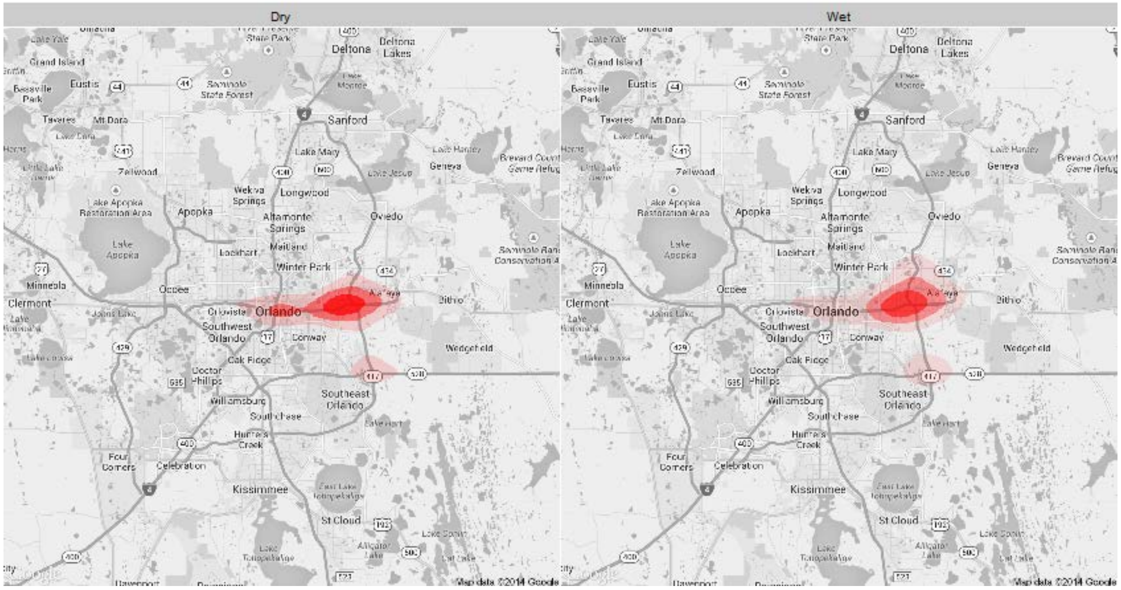


Figure 6-13 Spatial Pattern of Traffic Crashes by Road Surface Condition in 2011

6.5 Temporal Analysis of Expressway Crashes

Besides spatial characteristics of the crashes, the temporal properties of the crash distribution are also evaluated. For each expressway, the total number of crashes is aggregated into each hour of the day using three and half-year's crash data. All of the five expressways show the drastic increase of crash frequencies during the peak hours on weekdays. Figure 6-14 indicates that for SR 408, the morning and evening peak hours have the most crashes during the whole day on weekdays. Compared with evening peak hours, significantly more crashes occurred during the morning peak hours. ON SR 414, SR 417 and SR 528 as listed in Appendix W, both morning and evening have high numbers of crashes. On SR 429, only crashes only increased in the evening peak hours.

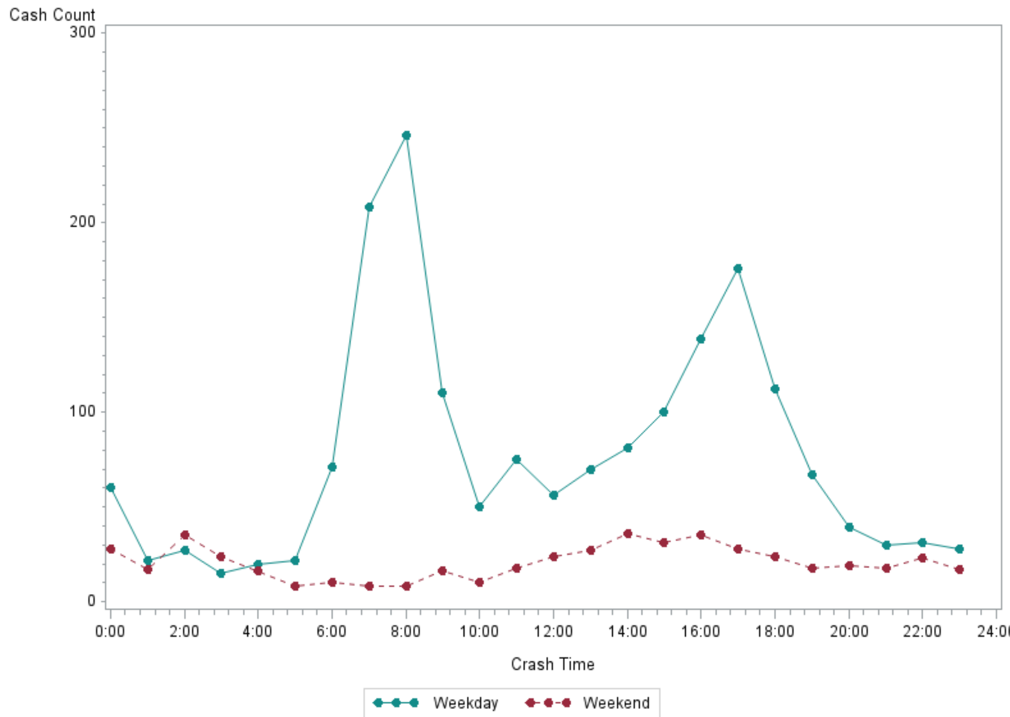


Figure 6-14 Temporal Distribution of Traffic Safety on SR 408

With the temporal distribution of the crashes known, the spatial-temporal distributions of crashes are given to show how the crashes are distributed during different time periods of a day. Each day is broken into four time periods, the morning peak hours (6:00 AM to 9:00 AM), non-peak day (9:00 AM to 16:00 PM), evening peak hours (16:00 PM to 19:00 PM) and non-peak night (19:00 PM to 6:00 AM).

During the morning peak hours, it is found that in 2011 the crashes mainly concentrated on the interchange between SR 408 and SR 417 as shown in Figure 6-15. Later in 2013 and 2014, the crash hotspot of morning peak hours is on the interchange between SR 408 and I-4. The same pattern has been confirmed in several spatial patterns of different crash types in previous section. Thus it can be stated that the interchange improvement project is significant to bring down crashes. However, the spatial pattern for evening peak hour crashes remains the same during the past three and half years. The interchange between SR 417 and SR 528 is the hot spot of evening peak hour crashes. The reason might be the traffic demand during evening hours on this area leading to more crashes. In the meantime, the congested segment on SR 528 is a segment where crashes are more likely to occur as well. The findings prove the close relationship between congestion and safety. In the future, it is best to have improvement projects considering both of these two aspects together.

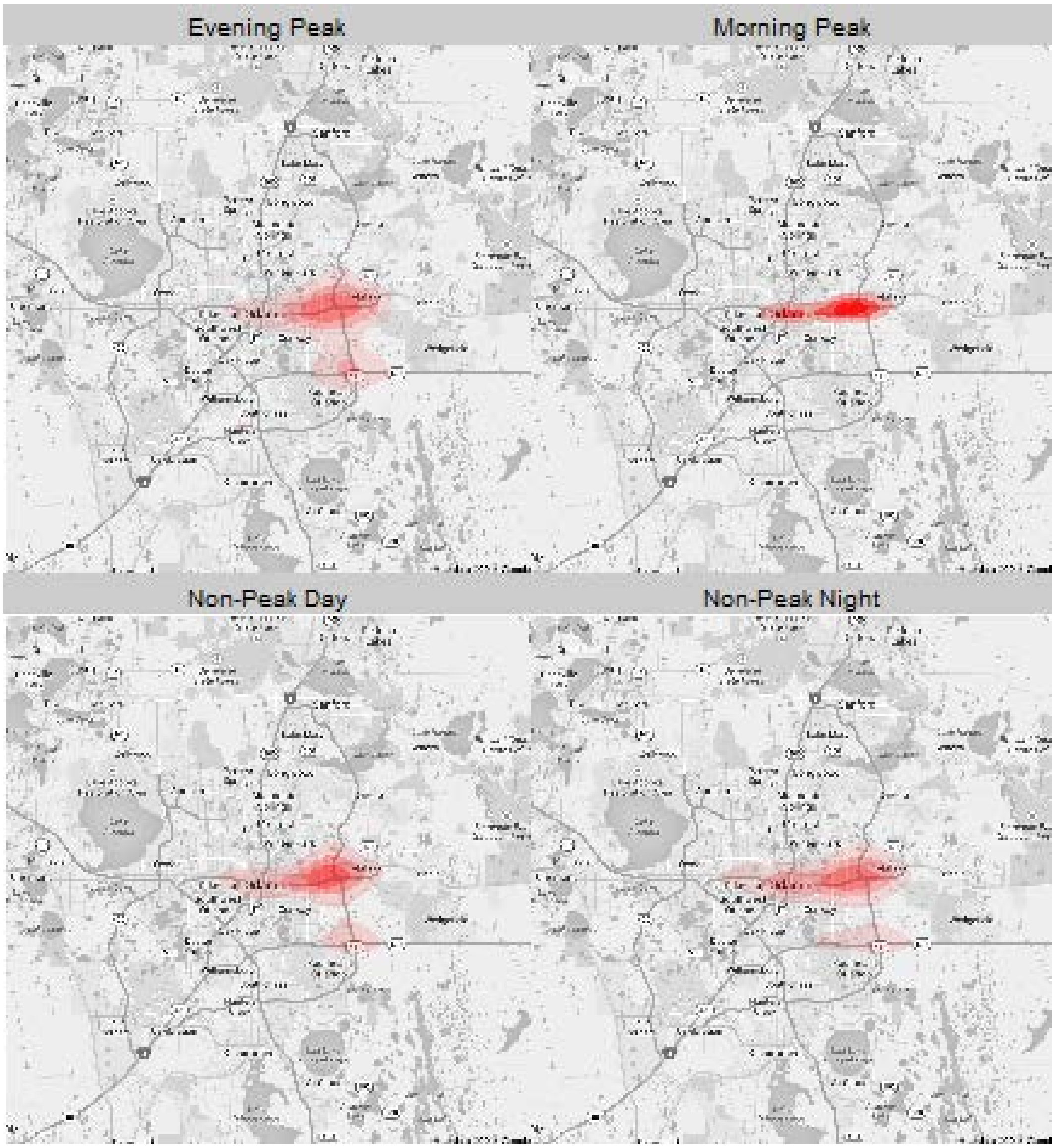


Figure 6-15 Spatial-Temporal Distribution of Traffic Crashes in 2011

7 CASE STUDY OF INTERCHANGE TRAFFIC SAFETY

The above chapter identifies the interchanges as crash concentration areas, especially for the interchange between SR 408 and SR 417 and interchange between SR 528 and SR 417. At the interchange, ramps connect the mainline and lead vehicles from one expressway to the other. Vehicles traveling on ramps often experience significant change of speed and sharp curves, which could result in traffic safety issues. This report is a case study of ramp traffic safety for the SR 417 – SR 528 interchange by the request of CFX. The objective of this work is to reveal crash mechanisms on ramps and identify corresponding safety countermeasures.

7.1 Crash Data

Crashes within the SR528-SR417 interchange from August, 2012 to September, 2013 were collected from the Signal 4 Analytics data base. Figure 7-1 below shows the range of selection. The range is selected to incorporate all the merging points between on-ramps and mainline and all the diverging points between off-ramps and mainline. In this way, it is guaranteed that all the crashes on ramps would be selected. In total, 106 crashes during this time period were geo-coded. The 106 crashes within the selection range include both ramp crashes and mainline crashes. The light blue dots stand for property damage only crashes; the blue dots represent injury crashes; the purple dots are where more than one crashes overlaid.

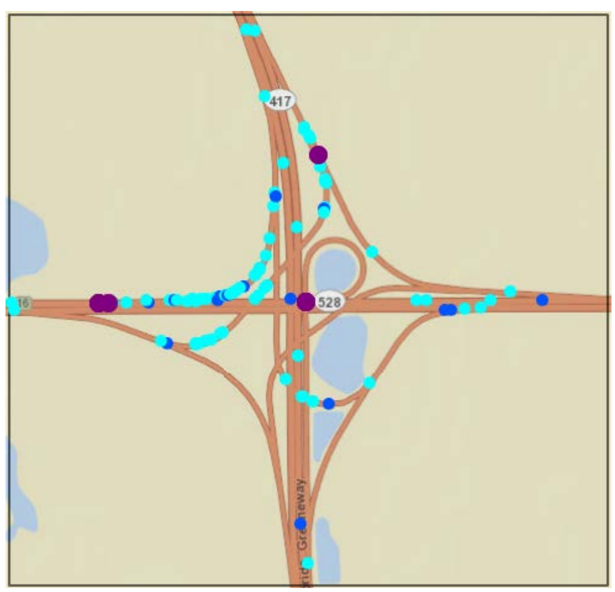


Figure 7-1 Total Crashes Within the Region of SR 417 -- SR 528 Interchange

In order to uncover the crash mechanisms on ramps, the crashes occurred on mainlines of SR 417 and SR 429 need to be excluded from the 106 total crashes within the interchange. After selection, 80 crashes occurring on ramps were identified. Figure 7-2 to Figure 7-6 present the locations of the 80 crashes. The dots in the five figures below indicate the locations of ramp crashes, of which the lighted ones represent the crashes on a specific ramp. Among the 80 crashes, 37 were on the off-ramp from SR 417 Southbound to SR 528 Westbound (Figure 7-2); 22 crashes were on the ramp from SR 528 Eastbound to SR 417 Northbound (Figure 7-3); 11 crashes on the ramp from SR 417 Southbound to SR 528 Eastbound (Figure 7-4); 7 from SR 528 Westbound to SR 417 Northbound (Figure 7-5). Three crashes were on the ramp from SR 417 Northbound to SR 528 Westbound (Figure 7-6).

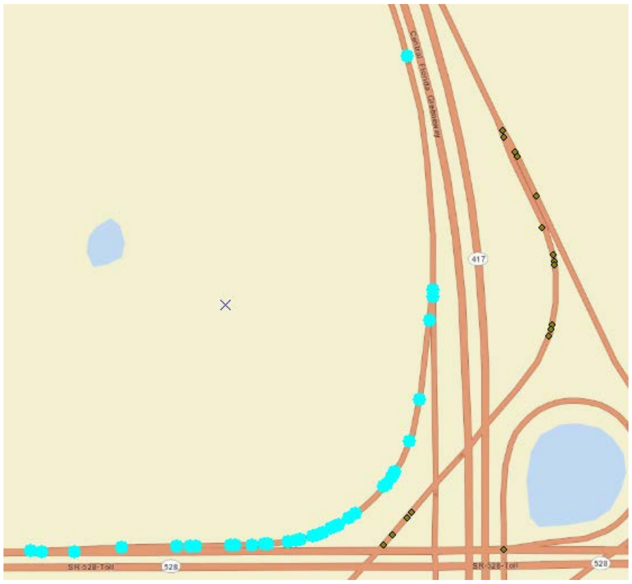


Figure 7-2 Ramp SR 417 SB -- SR 528 WB

Figure 7-3 Ramp SR 528 EB -- SR 417 NB

Figure 7-4 Ramp SR 417 SB -- SR 528 EB

Figure 7-5 Ramp SR 528 WB -- SR 417 NB

Figure 7-6 Ramp SR 417 NB -- SR 528 WB

7.2 Ramp Traffic Safety Overview

The distribution of crash time as shown in Figure 7-7 showed that on the ramps at SR 417 – SR 528 interchange, it is more likely to observe a crash from 9:00 AM – 10:00 AM in the morning, 14:00 AM – 16:00 AM in the afternoon, and 17:00 PM – 19:00 PM in the evening. The majority of the crashes were single vehicle crashes, accounting for 79% of all crashes. Seventeen crashes involved more than one vehicle (Figure 7-8). No fatalities resulted from these crashes, 11 injuries were found. Fourteen crashes were distraction related; however, only one of them led to injury.

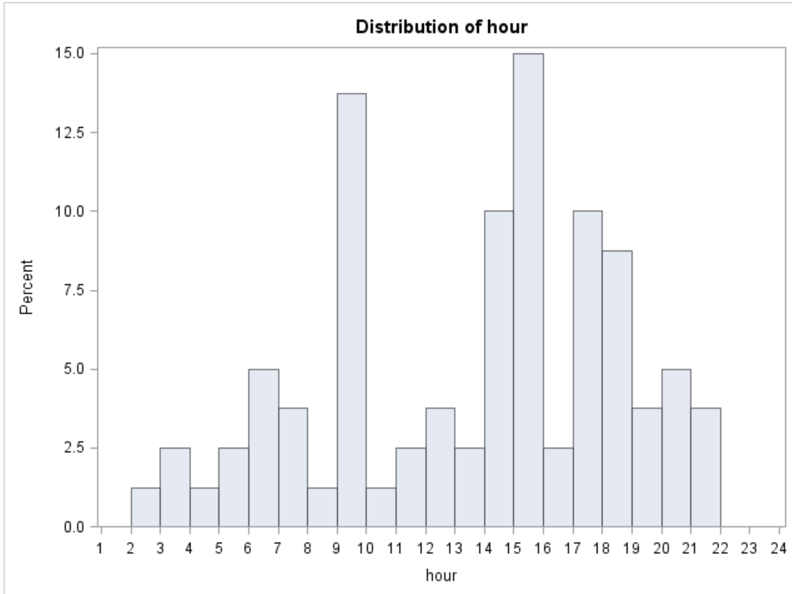


Figure 7-7 Crash Time Distribution

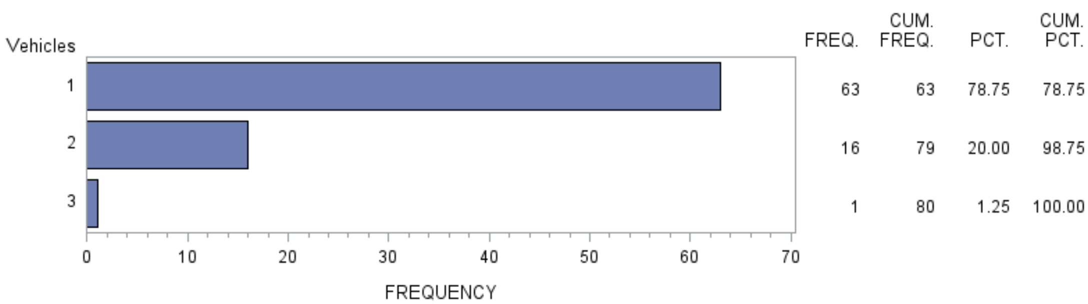


Figure 7-8 Number of Vehicles Involved in Crashes

Out of the 80 crashes, 44 crashes (more than 50% percent) were under the rainy condition compared with 27 crashes under cloudy and 9 clear condition. This is an unusual high rate for rain-related crashes, indicating precipitation could drastically increase the crash likelihood. Further investigation showed that for 25 crashes weather conditions were defined as contributing factors. What is worth mentioning is that although 44 crashes were recorded as under rainy weather, the information about road surface condition at the time of crash revealed 71 cases (89%) had wet surface at the crash time. This pattern indicated that the effect of rain could last longer. Regarding the light condition, thirteen crashes occurred when it was dark (8 with light, and 5 without light). Around three quarters of crashes (61 crashes) were recorded to occur during day light. The collision are recorded as "Angle" (angle crashes), "Front to Rear" (rear-end crashes), “Sideswipe, Same Direction” (sideswipe crashes), “Other” (crashes of other types) and “Unknown” (crash types unknown). The description about the manner of collision does not give detailed information about the crashes as 52 and 16 crashes were recorded as “Other” and “Unknown” respectively. By looking at the crash reports, it was found that among the total 68 crashes coded as “Other” or “Unknown”, most of them were related to hitting the guardrail face (52 crashes); and others related to concrete traffic barrier, guardrail end, ditch, and fence. The average estimated property damage amount was about $1,200 with average vehicle damage amount $4,500 for each crash. Table 7-1 is a summary of potential factors for crashes on ramps.

Table 7-1 Distribution of Environmental, Roadway Factors on Ramps

Variable	Levels	Ramp Crashes (N=80)	
		Freq	%
Road Surface Condition			
Dry		9	11%
Wet		71	89%
Weather Condition			
Clear		9	11%
Cloudy		27	34%
Rain		44	55%
Light Condition			
Dark - Lighted		8	10%
Dark - Not Lighted		5	6%
Dawn		2	3%
Daylight		61	76%
Dusk		4	5%
Crash Type/Manner			
Angle		4	5%
Front to Rear		4	5%
Guardrail Face		52	65%
Sideswipe, Same Direction		4	5%
Concrete Traffic Barrier		4	5%
Guardrail End		2	3%
Other/Unknown		10	13%
Contributing Circumstances: Environment			
None		54	68%
Other		1	1%
Weather Conditions		25	31%

7.3 Detailed Analysis

7.3.1 SR 417 Southbound – SR 528 Westbound

Of the 37 crashes on SR 417 Southbound to SR 528 Westbound, 5 crashes involved vehicles or drivers out of the state of Florida. The percentage of male drivers is 64.86% (24 cases), which significantly higher than the percentage of female drivers. The distribution of weather and roadway surface conditions for the crashes is that 5 crashes were under the clear weather and dry pavement, 7 cases for cloudy weather and wet pavement and 24 cases for rainy weather and wet pavement condition. The narrative part recorded by the officer at the scene in the crash report is not recorded in the crash data base. Nevertheless, this part contains information that provides further insights into the crash mechanisms, that's why we did inspect each report. Under the clear weather and dry pavement condition, the crashes more likely resulted from inappropriate driver maneuvers, such as lane-changing or unable to stopped to hit a vehicle already been involved in crashes. For the other situations both having wet pavements, the most common explanation is that when drivers negotiated the curve, they lost control of vehicle on the wet roadway and hydroplaned, and the collision manner is running into the guardrail. Thus, how to lower drivers speed on the curves so that they have control over their vehicle is critical to solve the safety problems with wet surface on ramps. Warning flashing lights or advisory speeds that is triggered by rain sensors could be a suitable countermeasure. In addition, when a crash occurs, moving the vehicle out of the roadway would certainly reduce the likelihood of secondary crashes.

7.3.2 SR 528 Eastbound – SR 417 Northbound

On the ramp from SR 528 Eastbound to SR 417 Northbound, it is found that only one crash out of the total 22 crashes was related to driver out of Florida. Ten female and 12 male drivers were deemed as drivers at fault. The ratio between the two genders is close to 1. Still, the road surface conditions for these crash cases were dominated by wet pavement. Twenty crashes were related to wet road surface. The crash mechanisms on this ramp are very similar to that on the ramp from SR 417 Southbound to SR 528 Westbound. Secondary crashes were also observed. One issue should be pointed out is that for several multi-vehicle crash cases, the crash report shows that some vehicles didn't stop after collision and left the scene without leaving or exchanging any information. In cases of hit-and-run crashes, countermeasures might be needed in the future to facilitate the investigation of crashes, e.g., cameras.

7.3.3 Other Ramps

The other three ramps, namely SR 417S – SR 528E, SR 528W – SR 417N and SR 417N – SR 528W, account for 21 crashes. No crashes related to out-of-state drivers or vehicles were found. Male drivers were at fault in 13 crashes and female drivers in the other 8 cases. The rain soaked pavement remains the most significant contributing factor of crashes. The ramps at the interchange are curves. When the pavement is wet, if the drivers do not slow down their speed in advance, they might fail to slow and slide on the rain soaked surfaces. For crashes involving single vehicle, the vehicles were eventually stopped by guardrails and rested on the shoulder. The forms of multi-vehicle crashes can be grouped into sideswipe or rear-end. Sideswipe crashes could be related to failure to negotiate the curve and slide into the adjacent lanes or inappropriate lane-changing behavior. Rear-end crashes are often secondary crashes when the vehicles on the ramps were unable to avoid hitting a stopped vehicle on roadway.

7.4 Potential Treatments

The analysis revealed that the wet pavement due to precipitation is the leading factor to the crashes on the studied ramps at the specific interchange. Rainy weather condition could greatly increase the chance that a vehicle would hydroplane on the curved roadway. The effect of rain could last even after the rain stops.

Potential treatments should include warning drivers during inclement weather condition (rain) and when the roadway surface is wet. Monitoring the pavement conditions might be considered since wet pavement is the most direct factor related to crash occurrence on this interchange. The warning information could be about the weather/pavement condition and the suggested speed during this time period.

In addition to alerting drivers about the roadway surface conditions, the more fundamental treatment is to maintain appropriate amount of pavement friction on ramps. High friction surface treatment (HFST) is an emerging technology that could reduce crashes on wet pavements. According to Federal Highway Administration (FHWA), at least 39 states have applied HFST on at least one project site to date. American Traffic Safety Services Association (ATSSA) listed HFST case studies describing the safety issues, locations and treatments.

In Florida, the Florida Department of Transportation (FDOT) District 4 Traffic Operations Office in consultation with the FDOT Central office and the FHWA has installed

Tyregrip high friction surfacing system. The system consists of a highly modified exothermic epoxy resin two-part binder usually top dressed with a calcined bauxite with a PSV (Polished Stone Value) of 70%+. The system is intended to provide road surface with durability and skid resistance on both dry and wet pavement conditions. These systems are implemented at the northbound interchange on-ramp at Royal Palm Boulevard and I-75 (Broward County), the I-595 interchange ramp to the Ft. Lauderdale airport. Figure 7-9 shows the location and details of HFST at the I-75 ramp from Evaluation of Innovative Safety Treatments. Figure 7-10 describes HFST installed at the I-595 ramp (Image: Florida Department of Transportation).

Figure 7-9 Tyregrip HFST System at I-75 Ramp

Figure 7-10 Tyregrip HFST System at I-595 Ramp

These two locations involved sharply curved ramps and the restrictive geometries and wet weather friction crashes. HFST was installed in 2006 and 2011 respectively. The Tyregrip high friction surfacing system at the I-75 ramp is also included in the FDOT's Report on Evaluation of Innovative Safety Treatments. This particular ramp had a crash history of 12 run-off-road crashes during 2002 to 2004. Among the 12 crashes, 83% were under wet road surface conditions. According to the report, before-after friction test was conducted and it was found that the friction number was much higher after the installation of Tyregrip surface system. Whether the treatment significantly reduced crashes could not be statistically determined due to the data limitations at the time when the report was composed. However, both vehicle speed and proportion of vehicles encroaching either the outer or inner shoulder before and after the application of the Tyregrip confirmed that vehicles slowed down on the ramps and the proportion of encroaching vehicles were reduced especially in wet pavement conditions.

Since these two cases also involved interchange ramps and the locations are also in Florida, their experience could be useful for potential treatment for the SR 417-SR528 interchange. The websites for High Friction Surface Treatment from FHWA and relevant case studies from ATSSA are attached in the Appendix for more detailed information.

As for the road geometry, the guardrails prevent the vehicle running off the roadway and the shoulders on both sides of the ramp provide vehicles temporary stopping spots. Several secondary crashes have indicated that removing the vehicle quickly off the traveling lane could help reduce the occurrence of this type of crash. Secondary crashes could be prevented by installing detectors (camera or otherwise) that post warning messages on an upstream DMS once a crash is detected.

When the pavement is dry, treatments for sideswipe crashes should be considered. Sideswipe crashes are more likely due to improper lane-changing behavior of the drivers. This maneuver should be taken with extra caution on ramps.

7.5 Conclusion

This case study presented a detailed investigation into crash information at the individual-crash level to shed light on the contributing factors leading to crashes on ramps at the interchange of SR 417 and SR 528. In total 80 crashes from August, 2012 to September, 2013 were located on the ramps during this time period.

Safety issues on ramps were examined from several points of view, including the drivers, the weather, the roadway condition and the collision manner.

Weather and roadway conditions have significant impact on the safety performance of the ramps at interchange. Since the ramps consist of curves, when the pavement is wet due to precipitation, vehicles could hydroplane on the road surface. The crash reports confirmed the issue. The majority (89%) of the total crashes occurred when the road surface was wet.

Crash types and collision manners show that single-vehicle crashes are the most common crash type. Multi-vehicle crashes could be due to various reasons; sliding of the vehicles, inappropriate lane-changing behavior, and hitting the rear of other vehicles, including secondary crashes.

To alleviate crashes on the ramps, several countermeasures have been discussed. Warning messages about the weather and roadway are the most direct method to raise the drivers caution during their trip. When it is raining or when the pavement is wet, drivers should be advised to travel at a safe speed. High Friction Surface Treatments have been widely used to provide road users appropriate frictions on ramps and curves. Two implementations of the Tyregrip systems are found in Florida. The installation of the system has been proved to successfully increase frictions between road surface and tires. Speed and proportion of vehicles encroaching the shoulders were both reduced. Guardrails and shoulders are useful to reduce the crash severity and the chance of secondary crashes. When a crash occurs, the vehicles involved should be removed from the traveling lane in time, and thus we suggest a detection system linked to an upstream DMS. Warning flashing lights and advisory speed could be triggered in wet conditions.

This report is aimed to benefit our understanding of crashes on ramps through detailed examination of each crash. In future when more ramps on CFX's system are considered, more prevalent conclusions and hidden information could be revealed.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 General

With the rapid development of traffic detection technology, more proactive traffic management can be achieved using the precise and rich information generated by these systems. The real-time nature of these data enables traffic managers to evaluate their system at more microscopic level and pinpoint the specific issue that may exist for efficient treatment. The Central Florida Expressway Authority (CFX) manages the expressway system in Orlando area and provides motorists with fast connections for both commuting and leisure trips. On CFX's expressway network, five expressways are currently under management. On these expressways, multiple ITS technologies are deployed. To minimize the inconvenience for drivers, Electronic Toll Collection (ETC) technology is implemented so drivers with E-PASS or SunPass do not need to slow down when they pass the toll plazas on the mainline. Automatic Vehicle Identification (AVI) system is installed to detect the vehicles both for toll calculation and travel time estimation. Since 2012, the authority has introduced Microwave Vehicle Detection System (MVDS) for better traffic monitoring. Compared with the existing AVI system that is mainly used for tolling, MVDS is specifically designed to keep records of traffic parameters on the traveling lanes of the expressways. With the traffic information extracted from these detection systems, CFX informs the road users about most up-to-date traveling information including estimated travel time, congestion warning and incident warning, etc. through the Dynamic Message Signs (DMS) installed at different locations on their expressways.

To take advantage of these systems and come up with more proactive traffic management strategies, this project aims at fully exploration the potential use of these traffic data to evaluate the performance of the expressway system. The current performance of expressway is evaluated from two perspectives: operation and safety. Traffic operation efficiency is measured by the congestion conditions on the expressways. The congestion intensity, congested segment and time duration are carefully reviewed. Based on the results of congestion evaluation, countermeasures especially by using DMS are proposed. The existing DMS that could be used for queue warning and places in need of potential DMS will be provided. In addition of regular congestion management, ramp closure procedures in case of emergency or total shutdown of mainline traffic are also investigated. A survey is designed and conducted to learn from other expressway authorities' experience in ramp closure. Traffic safety is assessed based on the historical crash data on the expressways. The crashes are analyzed by the crash types, severities and other characteristics. Based on the results, spatial analysis is conducted to find out the segments that have specific safety issues. Also, the crashes are also viewed from a temporal perspective to show the distribution of crashes along time. Besides the safety evaluation for the whole system, a case study focusing on ramp crashes at interchanges is provided to gain detailed insights about ramp safety. Recommendations are also attached in hope to improve the traffic safety performance on the expressways.

8.2 Congestion Evaluation

Both the AVI and MVDS traffic data are utilized to evaluate the congestion conditions on the expressways. Three different congestion measures are introduced based on the traffic parameters available in the two detection systems. Travel Time Index (TTI) is a time-based congestion indicator that uses the AVI data. Occupancy and Congestion Index (CI) are density-based and speed-based congestion measures that employ MVDS traffic data.

Congestion evaluation is conducted both using the most current data to reflect up-to-date congestion conditions and the longitudinal data over the past year to show the changes in congestion. Mainline congestion is evaluated for weekdays using the 5-minute interval data. The results show that because of recent upgrades in AVI system, the TTI measure suffers issues of missing data at several segments. The MVDS system is more stable and due to the dense deployment of MVDS sensors on the expressways. Complete spatial-temporal congestion profile could be generated. In addition, a preliminary comparison between TTI and CI shows that CI gives more detailed and perhaps more accurate estimation of congestion intensity on the expressways. On the other hand, the performances of CI and occupancy are comparable since they are both developed from the MVDS system.

The congested area for SR 408 is approximately from MP 17 to MP 19 on Eastbound in the morning peak and from MP 10 to MP 13 on Westbound in the evening peak hours. For SR 414, only the Eastbound experiences moderate congestion during morning peak hours, the congested segment is near MP 9.3. For SR 417, both directions experience moderate congestion during evening peak hours. The congested segment is near the interchanges with University Blvd which leads to University of Central Florida. No congestion was detected on SR 429. On SR 528, congestion is detected on Eastbound in the evening and on Westbound in the morning near the interchange between SR 417 and SR 528.

The longitudinal analysis confirms operation improvement on SR 408, SR 414 and congested segments on SR 528. SR 417 and SR 429 remain stable during the past one year. Considering SR 408 and SR 528 are the expressways that experience most congestion, significant improvement on these two expressways indicate the successful management by the CFX.

Since MVDS data can also monitor traffic on ramps, the ramp congestion is also examined. Based on the results, three ramps on SR 408 and one ramp on SR 429 experience congestion, among which three are off-ramps and one is on-ramp. The on-ramp at MP 9.7 on SR 408 Eastbound at the interchange of SR 408 and I-4 in downtown Orlando, the two off-ramps on SR 408 Westbound at MP 9.9 and MP 10.3 both connected to I-4 are found congested on SR 408. The off-ramp experiencing evening congestion is at MP 19.8 of SR 429 Southbound.

8.3 DMS Application in Congestion Management

To inform the drivers of congestion at downstream, the DMS can be used for queue warning. The benefit of providing queue warning information is mainly to prevent primary or secondary crashes, and to delay the onset of congestion and improve travel time. Queue warning has been implemented in several other countries including the United States. However, currently there are no exact guidelines about the placement of queue warning signs. General principles of warning signs, though, can be found from Manual on Uniform Traffic Control Devices (MUTCD).

To use the DMS on CFX's expressways for queue warning, the accurate congested segments are identified first. Based on the location of end of queue on the mainline, upstream DMS that are within 1 to 2 miles of the queue end are located. These DMS can be used for queue warning. If no DMS is found, then potential DMS can be considered in the future. For the congested ramps, same procedures are implemented. For the mainline congestion, four existing DMS are identified that can display queue warning messages. Five locations are also proposed for future consideration in case of additional DMS is needed. For the ramp congestion warning, all the four ramps have existing DMS upstream that can inform motorists of the ramp congestion.

8.4 Ramp Closure Practice

The survey about ramp closure practice is composed of twelve short questions. In total, ten domestic responses from eight states and five international responses from three countries have been received. The toll authorities participating in the survey shared precious information as how they manage their system during a total shut-down of the mainline traffic lanes.

The combination of open tolling and plazas is the predominant toll collection method in the United States as found in the survey. The implementation of open tolling is also becoming more common overseas. Almost all domestic and international authorities claimed they have practices for closing on-ramps in case of total shut-down on the mainline. In most cases, the practices are carried out on a case by case basis. Specific strategies such as Florida's Turnpike's SOP, Maryland Transportation Authority's FITM plans and WV Parkways Authority's emergency detours are reported. An additional question was designed and sent to the toll authorities to gain insight on how they close ramps in case of total shut-down. Six domestic and three international authorities responded us with detailed information as how they close the ramps and the equipment they implement closing the ramps.

Even when no procedures or practices are available for on-ramp closing, the authorities still gave confirmative responses that they provide information to motorists. The media to convey the information to drivers includes DMS, radio, fixed signs, and others like maps, TV, websites, telephone (511 systems), and toll personnel, etc. If available, the authorities send drivers detailed information about the cause of the shut-down, the location and expected duration of the closure, and where the alternative routes would be.

From the survey, each authority's system is equipped with multiple ITS systems. Electronic Toll Collection, Dynamic Message Signs, Remote Traffic Management Sensors, and Automatic Vehicle Identification systems are prevalent. Some other ITS systems like CB Radio Advisory System, and Supervisory Control and Data Acquisition systems are also in use.

CFX's system is also equipped with these ITS systems. By learning from other authorities' experience, CFX can make the most of their system and provide motorists with valuable information in extreme cases to enhance customer satisfaction.

8.5 Expressway Traffic Safety Performance

Traffic safety as an important indicator of expressway performance is also evaluated. The other motivation for safety evaluation is that it is widely believed that traffic safety is significantly related with operation. Improving either of them will have beneficial effects on the other. Traffic crash data from January 2011 to June 2014 were collected from S4A database to fulfill this task.

Much effort has been made in the data preparation process to ensure the accurate selection of crashes on the expressways. Data contain the crashes on the mainline, mainline toll plaza cash lanes and ramps. The data for the past three and half years indicate stable trend of safety performance on SR 408 and SR 417. For these two expressways, the crash counts for each year do not vary significantly. For the other three expressways, SR 414 and SR 528 have small increase while crashes on SR 429 decrease. Compared with other toll and turnpike authorities, the mainline safety conditions on CFX's expressway network perform relatively well. Compared with SR 836, SR 821, both of which travel through downtown Miami, and SR 589 in Tampa metropolitan area, SR 408 extends through downtown Orlando, but has a lower crash rate. Segments of SR 417 and SR 528 operated by CFX have the crash rates at median level. Crash rate for SR 429 segment on CFX's system is among the lowest.

Further analysis of safety by crash characteristics and the spatial patterns reveal significant features of the crashes on the expressway network. The rear end crashes are found to most likely to occur on these congested segments. This result confirms the relationship between congestion and rear end crashes, which also highlight the importance of queue warning using DMS on the expressways. Crashes based on the lighting conditions reveal that the segment on SR 528 east to the interchange with SR 417 is the major segment for the crashes occurring under dark without lighting condition. In the future, if light poles are installed on this segment, it is expected to bring down the crashes. Under the rainy or wet pavement conditions, the interchanges are the most affected area. . The issue with SR 408 – I-4 interchange and SR 417 -- SR 528 interchange are most significant. Consequently, improving ramp safety should specifically focus on these two interchanges. The temporal distribution of crashes indicates that most of the expressway crashes occur during morning and evening peak hours. And the crashes during peak hours are found to concentrate on the congested segments. This proves the close relationship between congestion and safety. Consequently, in the future it is best to have improvement projects considering both of these two aspects together.

8.6 Case Study of Interchange Traffic Safety

The results of traffic safety analysis suggest that crashes on the interchanges should be reviewed carefully. By the request of CFX, a case study focusing on the ramp traffic safety at the interchange between SR 528 and SR 417 is conducted.

To have comprehensive understanding about ramp crashes, information regarding the drivers, the weather, the roadway condition and the collision manner were extracted from original crash reports.

It is found that weather and roadway conditions have significant impact on the safety performance of the ramps at interchange. Ramps are normally constructed using curves. Therefore when the pavement is wet, vehicles could hydroplane on the road surface. Narratives by the drivers involved in the ramp crashes reports confirmed the issue. The majority (89%) of the total crashes occurred when the road surface was wet. Single-vehicle crashes are the most common crash type on the ramps due to hydroplane. Multi-vehicle crashes could be due to various reasons; sliding of the vehicles, inappropriate lane-changing behavior, and hitting the rear of other vehicles, including secondary crashes.

Several countermeasures have been discussed to reduce crashes on the ramps. Warning messages about the weather and roadway are the most direct method to raise the drivers' caution especially when it is raining or when the pavement is wet. High Friction Surface Treatments have been widely used to provide road users appropriate frictions on ramps and curves. The installation of the system has been proved to successfully increase frictions between road surface and tires in two application cases in Florida. Guardrails and shoulders are useful to reduce the crash severity and the chance of secondary crashes. When a crash occurs, the vehicles involved should be removed from the traveling lane in time, and thus we suggest a detection system linked to an upstream DMS. Warning flashing lights and advisory speed could be triggered in wet conditions.

9 POTENTIAL ITS IMPLEMENTATION ON THE EXPRESSWAYS

Besides the utilization of current ITS data reported in this project, further implementation of these data can be envisioned. The rich information recorded in real-time is not limited to the congestion evaluation elaborated in this report. Potential extensions of the usage of the data include travel time estimation and micro-simulation network construction.

9.1 Travel Time Estimation

Providing reliable estimated travel time to motorists not only improves the customer experience on the expressways but also help smooth the traffic flow by adjusting the motorists traveling speed on the expressways.

Travel time estimation relies heavily on the proper functioning of the traffic detection system. The accuracy and reliability of estimated travel time might also be challenged. CFX has the advantage of having both AVI and MVDS detection system. Using both of them for travel time estimation is expected to generate more accurate and reliable prediction. Appropriate data fusion techniques might be necessary for developing travel time calculation algorithm. Real-time estimation is an important field given the power of ITS technology. The AVI and MVDS data can be used to test the candidate algorithms for travel time estimation and validate the prediction accuracy and reliability.

9.2 Micro-Simulation using ITS Data

The data collected from MVDS and AVI systems can also provide adequate traffic information to build simulation network for expressways. MVDS sensors collect traffic volume on each on-ramp and off-ramp, which serve an essential input for simulation. Also, MVDS record the traffic volume by vehicle types. Thus, truck percentage, an important factor for traffic performance, can be obtained. Moreover, MVDS data provide speed information at one minute interval and AVI can be used to calculate travel time. Hence, the process of simulation validation can be successfully completed based on the speed or travel time.

VISSIM is one of the most widely used and indispensable tool to simulate the field traffic performance. It’s a microscopic, behavior-based, multi-purpose traffic simulation program which has already been used for various purposes such as evaluating geometric changes or the benefit estimation of new ITS instrument. The aggregated traffic data at 15-minute interval can reflect traffic fluctuates especially during the peak hours. After the calibration and validation of

VISSIM network, engineers can implement it to Active Traffic Management (ATM) system, e.g., the optimal Dynamic Message Signs (DMS) location, and the efficiency of traffic management strategies before actual field implementations.

APPENDIX A. AVI SENSOR DEPLOYMENT

Table A-1 SR 408 Eastbound AVI Sensor Deployment

Sensor ID	2012				2013											2014						
	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12	01	02	03	05	06	07
AVI-0408E-AlafayaTr																						
AVI-0408E-BumbyAve																						
AVI-0408E-ChickasawExi	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
AVI-0408E-ChickasawTr																						
AVI-0408E-ConwayRd																				●	●	●
AVI-0408E-DeanRd																						
AVI-0408E-EColonialDr																						
AVI-0408E-EconTr																					●	
AVI-0408E-GoldenrodRd																						●
AVI-0408E-Goldnrd_DMS																						
AVI-0408E-GoodHomesRd																				●	●	
AVI-0408E-HiawasseeRd																				●		●
AVI-0408E-I4																						
AVI-0408E-I4_Ramp																						
AVI-0408E-JYP																						
AVI-0408E-KirkmanRd																						
AVI-0408E-MillsAve																						
AVI-0408E-MillsAve_DMS																						
AVI-0408E-OBT																						
AVI-0408E-Orange_Ramp																						
AVI-0408E-PineHillsRd																						
AVI-0408E-RouseRd																				●		
AVI-0408E-SR417	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
AVI-0408E-SemoranBlvd																						
AVI-0408E-TampaAve																						
AVI-0408E-WBoundary																				●	●	●
AVI-0408E-WColonl_DMS																						

● AVI data not available in this month

Table A-2 SR 408 Westbound AVI Sensor Deployment

Sensor ID	2012				2013												2014					
	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	5	6	7
AVI-0408W-AlafayaTr																						
AVI-0408W-BumbyAve																						
AVI-0408W-CrystalLkDr																				●	●	●
AVI-0408W-DeanRd																				●	●	●
AVI-0408W-EColonialDr																						
AVI-0408W-FergusonRd																						
AVI-0408W-GoldenrodRd																						
AVI-0408W-GoodHomesRd																						
AVI-0408W-HiawasseeRd																				●	●	●
AVI-0408W-I4																						
AVI-0408W-I4_Ramp																						
AVI-0408W-JYP																						
AVI-0408W-KirkmanRd																						
AVI-0408W-Kirkman_DMS																						
AVI-0408W-MillsAve																						
AVI-0408W-OBT																						
AVI-0408W-OxalisAv_DMS																						
AVI-0408W-PineHillsRd																						
AVI-0408W-RouseRd																						
AVI-0408W-SR417																						
AVI-0408W-SemoranBlvd																						●
AVI-0408W-SummerlinAve																						
AVI-0408W-WBoundary																						●
AVI-0408W-WColonl_Ramp																				●	●	●

● AVI data not available in this month

Table A-3 SR 414 Eastbound AVI Sensor Deployment

Sensor ID	2012				2013												2014					
	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	5	6	7
AVI-0414E-HiawasseeDMS	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
AVI-0414E-HiawasseeRd																						
AVI-0414E-KeeneRd																						
AVI-0414E-MardenRd	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
AVI-0414E-OBT																						
AVI-0414E-SR429																				●	●	●
AVI-0414E-SR451	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			

● AVI data not available in this month

Table A-4 SR 414 Westbound AVI Sensor Deployment

Sensor ID	2012				2013												2014					
	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	5	6	7
AVI-0414W-HiawasseeRd																						
AVI-0414W-KeeneDMS	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
AVI-0414W-KeeneRd																						
AVI-0414W-OBT																						
AVI-0414W-SR429																				●	●	●
AVI-0414W-SR451	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			

● AVI data not available in this month

Table A-5 SR 417 Northbound AVI Sensor Deployment

Sensor ID	2012				2013												2014					
	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	5	6	7
AVI-0417N-BoggyCreek																					●	●
AVI-0417N-BoggyCrk_DMS																						
AVI-0417N-CurryFordRd																						
AVI-0417N-EColonialDr	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			●
AVI-0417N-IDrive_DMS																						
AVI-0417N-InnovationWy																				●	●	●
AVI-0417N-JYP																						
AVI-0417N-LakeNona																						
AVI-0417N-LandstarBlvd																						
AVI-0417N-LeeVistaBlvd																					●	●
AVI-0417N-MossParkRd																						
AVI-0417N-Narcooss_DMS																				●	●	●
AVI-0417N-Narcoossee																						
AVI-0417N-OBT																						
AVI-0417N-SR408																				●	●	●
AVI-0417N-SR528																						
AVI-0417N-Seminole_DMS																						
AVI-0417N-University																						
AVI-0417N-Valencia	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	

● AVI data not available in this month

Table A-6 SR 417 Southbound AVI Sensor Deployment

Sensor ID	2012				2013												2014					
	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	5	6	7
AVI-0417S-BoggyCreek																				●	●	●
AVI-0417S-BoggyCrk_DMS																				●	●	
AVI-0417S-CurryFordRd																						
AVI-0417S-CuryFord_DMS																						
AVI-0417S-EColonial																						
AVI-0417S-EColonl_DMS																				●	●	●
AVI-0417S-IDrive_DMS																						
AVI-0417S-InnovationWy																						
AVI-0417S-JYP																				●	●	
AVI-0417S-JYP_DMS																						
AVI-0417S-LakeNona																						
AVI-0417S-LandstarBlvd																						
AVI-0417S-Landstar_DMS																				●	●	
AVI-0417S-LeeVistaBlvd																						
AVI-0417S-MossParkRd																						
AVI-0417S-NarcoosseeRd																				●		
AVI-0417S-OBT																						●
AVI-0417S-SR408_E																						
AVI-0417S-SR408_W	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
AVI-0417S-SR528																					●	●
AVI-0417S-Seminole_DMS																						
AVI-0417S-SofEColonial	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			●
AVI-0417S-University																				●	●	●

● AVI data not available in this month

Table A-7 SR 429 Northbound AVI Sensor Deployment

Sensor ID	2012				2013												2014					
	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	5	6	7
AVI-0429N-CR535																						
AVI-0429N-CR535_DMS																						
AVI-0429N-Independence																				●	●	●
AVI-0429N-McCormickRd	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
AVI-0429N-OBT																				●	●	●
AVI-0429N-OBTa																				●	●	●
AVI-0429N-PlantSt_DMS																						
AVI-0429N-SR414	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
AVI-0429N-SR437A	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
AVI-0429N-SR438																				●	●	●
AVI-0429N-SeidelRd_DMS																						
AVI-0429N-Trnpike_Ramp																				●	●	
AVI-0429N-Turnpike_N																				●	●	●
AVI-0429N-Turnpike_S																						
AVI-0429N-US441	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
AVI-0429N-WestRd																				●	●	●

● AVI data not available in this month

Table A-8 SR 429 Southbound AVI Sensor Deployment

Sensor ID	2012				2013												2014					
	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	5	6	7
AVI-0429S-CR437A	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
AVI-0429S-CR535																						
AVI-0429S-CR535_DMS																						
AVI-0429S-Independence																					●	
AVI-0429S-LustRd_DMS	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
AVI-0429S-OBT																				●	●	●
AVI-0429S-OBTa																				●	●	●
AVI-0429S-SR414	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
AVI-0429S-SR438																				●	●	●
AVI-0429S-SeidelRd																						
AVI-0429S-Turnpike_N																						
AVI-0429S-Turnpike_S																						
AVI-0429S-US441	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
AVI-0429S-WColonialDr																						
AVI-0429S-WestRd																				●	●	●

● AVI data not available in this month

Table A-9 SR 528 Eastbound AVI Sensor Deployment

Sensor ID	2012				2013												2014					
	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	5	6	7
AVI-0528E-DallasBlvd																						
AVI-0528E-GoldenrodRd																						
AVI-0528E-ICP																						
AVI-0528E-NarcoosseeRd																						
AVI-0528E-SR417																				●	●	●
AVI-0528E-SR436																				●	●	●
AVI-0528E-SR520																		●				
AVI-0528E-TradeportDr																		●				
AVI-0528E-WBndry_DMS																		●				

● AVI data not available in this month

Table A-10 SR 528 Westbound AVI Sensor Deployment

Sensor ID	2012				2013												2014					
	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	5	6	7
AVI-0528W-Dallas_DMS																	●	●		●	●	
AVI-0528W-GoldenrodRd																●	●	●				
AVI-0528W-ICP																●	●	●				
AVI-0528W-NarcoosseDMS																●	●	●				
AVI-0528W-SR417														●	●	●	●	●				
AVI-0528W-SR436_W														●	●	●	●	●			●	●
AVI-0528W-SR520														●	●	●	●	●		●	●	●
AVI-0528W-SR520_DMS														●	●	●	●	●				
AVI-0528W-TradeportDr		●	●											●	●	●	●	●	●			
AVI-0528W-WBndry_DMS		●	●											●	●	●	●	●	●			

● AVI data not available in this month

APPENDIX B. AVI SYSTEM SEGMENTATION

Table B-1 SR 408 Eastbound AVI System Segmentation

Link	Up_station	Down_station	Up_milepost	Down_milepost	Direction
1	AVI-0408E-WBoundary	AVI-0408E-GoodHomesRd	1.456	2.155	EB
2	AVI-0408E-GoodHomesRd	AVI-0408E-HiawasseeRd	2.155	3.468	EB
3	AVI-0408E-HiawasseeRd	AVI-0408E-KirkmanRd	3.468	4.632	EB
4	AVI-0408E-KirkmanRd	AVI-0408E-PineHillsRd	4.632	5.937	EB
5	AVI-0408E-PineHillsRd	AVI-0408E-JYP	5.937	7.619	EB
6	AVI-0408E-JYP	AVI-0408E-TampaAve	7.619	8.338	EB
7	AVI-0408E-TampaAve	AVI-0408E-OBT	8.338	8.859	EB
8	AVI-0408E-OBT	AVI-0408E-I4	8.859	9.347	EB
9	AVI-0408E-OBT	AVI-0408E-I4_Ramp	8.859	9.347	EB
10	AVI-0408E-I4	AVI-0408E-Orange_Ramp	9.347	10.191	EB
11	AVI-0408E-Orange_Ramp	AVI-0408E-MillsAve	10.191	10.809	EB
12	AVI-0408E-MillsAve	AVI-0408E-MillsAve_DMS	10.809	11.099	EB
13	AVI-0408E-MillsAve_DMS	AVI-0408E-BumbyAve	11.099	11.447	EB
14	AVI-0408E-BumbyAve	AVI-0408E-ConwayRd	11.447	12.841	EB
15	AVI-0408E-ConwayRd	AVI-0408E-SemoranBlvd	12.841	13.328	EB
16	AVI-0408E-SemoranBlvd	AVI-0408E-Goldnrd_DMS	13.328	15.181	EB
17	AVI-0408E-Goldnrd_DMS	AVI-0408E-GoldenrodRd	15.181	15.614	EB
18	AVI-0408E-GoldenrodRd	AVI-0408E-ChickasawTr	15.614	16.416	EB
19	AVI-0408E-ChickasawTr	AVI-0408E-EconTr	16.416	17.966	EB
20	AVI-0408E-EconTr	AVI-0408E-DeanRd	17.966	18.472	EB
21	AVI-0408E-DeanRd	AVI-0408E-RouseRd	18.472	19.424	EB
22	AVI-0408E-RouseRd	AVI-0408E-AlafayaTr	19.424	20.669	EB
23	AVI-0408E-AlafayaTr	AVI-0408E-EColonialDr	20.669	22.266	EB

Table B-2 SR 408 Westbound AVI System Segmentation

Link	Up_station	Down_station	Up_milepost	Down_milepost	Direction
1	AVI-0408W-GoodHomesRd	AVI-0408W-WColonl_Ramp	2.2362	1.0522	WB
2	AVI-0408W-GoodHomesRd	AVI-0408W-WBoundary	2.2362	1.5222	WB
3	AVI-0408W-HiawasseeRd	AVI-0408W-GoodHomesRd	4.5232	2.2362	WB
4	AVI-0408W-Kirkman_DMS	AVI-0408W-HiawasseeRd	4.8552	4.5232	WB
5	AVI-0408W-KirkmanRd	AVI-0408W-Kirkman_DMS	5.4092	4.8552	WB
6	AVI-0408W-PineHillsRd	AVI-0408W-KirkmanRd	6.008	5.4092	WB
7	AVI-0408W-FergusonRd	AVI-0408W-PineHillsRd	7.347	6.008	WB
8	AVI-0408W-JYP	AVI-0408W-FergusonRd	8.072	7.347	WB
9	AVI-0408W-OBT	AVI-0408W-JYP	9.298	8.072	WB
10	AVI-0408W-I4	AVI-0408W-OBT	10.488	9.298	WB
11	AVI-0408W-SummerlinAve	AVI-0408W-I4	10.964	10.488	WB
12	AVI-0408W-SummerlinAve	AVI-0408W-I4_Ramp	10.964	10.488	WB
13	AVI-0408W-MillsAve	AVI-0408W-SummerlinAve	11.399	10.964	WB
14	AVI-0408W-BumbyAve	AVI-0408W-MillsAve	11.806	11.399	WB
15	AVI-0408W-CrystalLkDr	AVI-0408W-BumbyAve	12.605	11.806	WB
16	AVI-0408W-SemoranBlvd	AVI-0408W-CrystalLkDr	14.563	12.605	WB
17	AVI-0408W-OxalisAv_DMS	AVI-0408W-SemoranBlvd	15.245	14.563	WB
18	AVI-0408W-GoldenrodRd	AVI-0408W-OxalisAv_DMS	16.488	15.245	WB
19	AVI-0408W-SR417	AVI-0408W-GoldenrodRd	18.033	16.488	WB
20	AVI-0408W-DeanRd	AVI-0408W-SR417	18.538	18.033	WB
21	AVI-0408W-RouseRd	AVI-0408W-DeanRd	19.706	18.538	WB
22	AVI-0408W-AlafayaTr	AVI-0408W-RouseRd	20.815	19.706	WB
23	AVI-0408W-EColonialDr	AVI-0408W-AlafayaTr	22.331	20.815	WB

Table B-3 SR 414 Eastbound AVI System Segmentation

Link	Up_station	Down_station	Up_milepost	Down_milepost	Direction
1	AVI-0414E-MardenRd	AVI-0414E-KeeneRd	4.313	6.335	EB
2	AVI-0414E-KeeneRd	AVI-0414E-HiawasseeRd	6.335	7.263	EB
3	AVI-0414E-HiawasseeRd	AVI-0414E-OBT	7.263	8.9	EB

Table B-4 SR 414 Westbound AVI System Segmentation

Link	Up_station	Down_station	Up_milepost	Down_milepost	Direction
1	AVI-0414W-KeeneRd	AVI-0429S-WestRd	6.62	-0.191	WB
2	AVI-0414W-KeeneDMS	AVI-0414W-KeeneRd	6.97	6.62	WB
3	AVI-0414W-HiawasseeRd	AVI-0414W-KeeneDMS	8.127	6.97	WB
4	AVI-0414W-OBT	AVI-0414W-HiawasseeRd	9.59	8.127	WB

Table B-5 SR 417 Northbound AVI System Segmentation

Link	Up_station	Down_station	Up_milepost	Down_milepost	Direction
1	AVI-0417N-IDrive_DMS	AVI-0417N-JYP	6.453	9.43	NB
2	AVI-0417N-JYP	AVI-0417N-OBT	9.43	10.638	NB
3	AVI-0417N-OBT	AVI-0417N-LandstarBlvd	10.638	13.004	NB
4	AVI-0417N-LandstarBlvd	AVI-0417N-BoggyCrk_DMS	13.004	14.653	NB
5	AVI-0417N-BoggyCrk_DMS	AVI-0417N-BoggyCreek	14.653	16.663	NB
6	AVI-0417N-BoggyCreek	AVI-0417N-LakeNona	16.663	18.82	NB
7	AVI-0417N-LakeNona	AVI-0417N-Narcooss_DMS	18.82	20.581	NB
8	AVI-0417N-Narcooss_DMS	AVI-0417N-Narcoossee	20.581	21.332	NB
9	AVI-0417N-Narcoossee	AVI-0417N-MossParkRd	21.332	22.519	NB
10	AVI-0417N-MossParkRd	AVI-0417N-InnovationWy	22.519	23.602	NB
11	AVI-0417N-InnovationWy	AVI-0417N-SR528	23.602	24.905	NB
12	AVI-0417N-SR528	AVI-0417N-LeeVistaBlvd	24.905	27.203	NB
13	AVI-0417N-LeeVistaBlvd	AVI-0417N-CurryFordRd	27.203	29.515	NB
14	AVI-0417N-CurryFordRd	AVI-0417N-SR408	29.515	32.495	NB
15	AVI-0417N-SR408	AVI-0417N-University	32.495	36.343	NB
16	AVI-0417N-University	AVI-0417N-Seminole_DMS	36.343	37.796	NB

Table B-6 SR 417 Southbound AVI System Segmentation

Link	Up_station	Down_station	Up_milepost	Down_milepost	Direction
1	AVI-0417S-JYP_DMS	AVI-0417S-IDrive_DMS	8.057	6.447	SB
2	AVI-0417S-JYP	AVI-0417S-JYP_DMS	10.287	8.057	SB
3	AVI-0417S-OBT	AVI-0417S-JYP	11.294	10.287	SB
4	AVI-0417S-LandstarBlvd	AVI-0417S-OBT	13.871	11.294	SB
5	AVI-0417S-Landstar_DMS	AVI-0417S-LandstarBlvd	14.648	13.871	SB
6	AVI-0417S-BoggyCreek	AVI-0417S-Landstar_DMS	17.746	14.648	SB
7	AVI-0417S-BoggyCrk_DMS	AVI-0417S-BoggyCreek	18.243	17.746	SB
8	AVI-0417S-LakeNona	AVI-0417S-BoggyCrk_DMS	19.564	18.243	SB
9	AVI-0417S-NarcoosseeRd	AVI-0417S-LakeNona	22.14	19.564	SB
10	AVI-0417S-MossParkRd	AVI-0417S-NarcoosseeRd	23.527	22.14	SB
11	AVI-0417S-InnovationWy	AVI-0417S-MossParkRd	24.461	23.527	SB
12	AVI-0417S-SR528	AVI-0417S-InnovationWy	26.321	24.461	SB
13	AVI-0417S-LeeVistaBlvd	AVI-0417S-SR528	27.924	26.321	SB
14	AVI-0417S-CurryFordRd	AVI-0417S-LeeVistaBlvd	30.241	27.924	SB
15	AVI-0417S-CuryFord_DMS	AVI-0417S-CurryFordRd	30.936	30.241	SB
16	AVI-0417S-SR408_E	AVI-0417S-CuryFord_DMS	32.709	30.936	SB
17	AVI-0417S-EColonial	AVI-0417S-SR408_E	34.899	32.709	SB
18	AVI-0417S-EColonl_DMS	AVI-0417S-EColonial	35.277	34.899	SB
19	AVI-0417S-University	AVI-0417S-EColonl_DMS	36.99	35.277	SB
20	AVI-0417S-Seminole_DMS	AVI-0417S-University	37.79	36.99	SB

Table B-7 SR 429 Northbound AVI System Segmentation

Link	Up_station	Down_station	Up_milepost	Down_milepost	Direction
10	AVI-0429N-SeidelRd_DMS	AVI-0429N-Independence	11.808	14.734	NB
11	AVI-0429N-Independence	AVI-0429N-CR535	14.734	19.005	NB
12	AVI-0429N-CR535	AVI-0429N-CR535_DMS	19.005	20.710	NB
13	AVI-0429N-CR535_DMS	AVI-0429N-Turnpike_S	20.710	21.792	NB
14	AVI-0429N-Turnpike_S	AVI-0429N-Turnpike_N	21.792	22.496	NB
15	AVI-0429N-Turnpike_N	AVI-0429N-SR438	22.496	23.668	NB
16	AVI-0429N-Turnpike_S	AVI-0408E-WBoundary	21.792	25.252	NB
17	AVI-0429N-Trnpike_Ramp	AVI-0429N-SR438	22.795	23.668	NB
18	AVI-0429N-SR438	AVI-0429N-PlantSt_DMS	23.668	24.972	NB
19	AVI-0429N-PlantSt_DMS	AVI-0429N-WestRd	24.972	26.421	NB

Table B-8 SR 429 Southbound AVI System Segmentation

Link	Up_station	Down_station	Up_milepost	Down_milepost	Direction
1	AVI-0429S-Independence	AVI-0429S-SeidelRd	15.454	11.808	SB
2	AVI-0429S-CR535	AVI-0429S-Independence	19.990	15.454	SB
3	AVI-0429S-CR535_DMS	AVI-0429S-CR535	20.710	19.990	SB
4	AVI-0429S-Turnpike_S	AVI-0429S-CR535_DMS	21.909	20.710	SB
5	AVI-0429S-Turnpike_N	AVI-0408E-WBoundary	22.927	18.971	SB
6	AVI-0429S-Turnpike_N	AVI-0429S-Turnpike_S	22.927	21.909	SB
7	AVI-0429S-WColonialDr	AVI-0429S-Turnpike_N	23.541	22.927	SB
8	AVI-0429S-SR438	AVI-0429S-WColonialDr	24.692	23.541	SB
9	AVI-0429S-WestRd	AVI-0429S-SR438	27.076	24.692	SB

Table B-9 SR 528 Eastbound AVI System Segmentation

Link	Up_station	Down_station	Up_milepost	Down_milepost	Direction
1	AVI-0528E-WBndry_DMS	AVI-0528E-TradeportDr	8.659	8.988	EB
2	AVI-0528E-TradeportDr	AVI-0528E-SR436	8.988	10.257	EB
3	AVI-0528E-SR436	AVI-0528E-GoldenrodRd	10.257	11.663	EB
4	AVI-0528E-GoldenrodRd	AVI-0528E-NarcoosseeRd	11.663	13.128	EB
5	AVI-0528E-NarcoosseeRd	AVI-0528E-SR417	13.128	15	EB
6	AVI-0528E-SR417	AVI-0528E-ICP	15	19.467	EB
7	AVI-0528E-ICP	AVI-0528E-DallasBlvd	19.467	23.519	EB
8	AVI-0528E-DallasBlvd	AVI-0528E-SR520	23.519	30.577	EB

Table B-10 SR 528 Westbound AVI System Segmentation

Link	Up_station	Down_station	Up_milepost	Down_milepost	Direction
1	AVI-0528W-TradeportDr	AVI-0528W-WBndry_DMS	9.82	8.501	WB
2	AVI-0528W-SR436_W	AVI-0528W-TradeportDr	10.806	9.82	WB
3	AVI-0528W-GoldenrodRd	AVI-0528W-SR436_W	12.475	10.806	WB
4	AVI-0528W-NarcoosseDMS	AVI-0528W-GoldenrodRd	14.019	12.475	WB
5	AVI-0528W-SR417	AVI-0528W-NarcoosseDMS	16.253	14.019	WB
6	AVI-0528W-ICP	AVI-0528W-SR417	20.139	16.253	WB
7	AVI-0528W-Dallas_DMS	AVI-0528W-ICP	23.246	20.139	WB
8	AVI-0528W-SR520	AVI-0528W-Dallas_DMS	30.843	23.246	WB
9	AVI-0528W-SR520_DMS	AVI-0528W-SR520	31.704	30.843	WB

APPENDIX C. MVDS SYSTEM AND LANE MANAGEMENT

Table C-1 SR 408 Eastbound MVDS System and Lane Management

Eastbound		Number of lanes			Eastbound		Number of lanes		
ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp	ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp
1	1.2			2	30	11.5	5		1
2	1.4	2			31	12.1	5		
3	1.7	2		2	32	12.5	5		1
4	2.2	3		1	33	12.9	5		2
5	2.4	3		1	34	13.3	5		2
6	2.7	3	2		35	13.7	3	3	
7	3.2	2	1		36	14.2	3	2	
8	3.6	2		1	37	14.5	4		
9	4.3	3		1	38	14.7	4		2
10	4.6	4			39	15	5		
11	4.9	3		1	40	15.7	4		2
12	5.3	3		1	41	15.8	4		1
13	6	3	2	1	42	16.1	4		1
14	6.4	3	1		43	16.5	5		
15	6.8	3			44	17.3	3		3
16	7	3		1	45	17.7	2		1
17	7.4	3			46	18	2		1
18	7.6	3		1	47	18.4	2		1
19	8	3		1	48	18.8	2		1
20	8.4	3		1	49	19	2	2	
21	8.9	3		1	50	19.4	2	1	
22	9.2	3		1	51	19.5	2		1
23	9.4	4		1	52	20.1	2		1
24	9.6	3		1	53	20.3	2		
25	9.7			1	54	20.8	2		1
26	10.3	3		1	55	21.8	2		
27	10.6	4		1	56	22.3	2		2
28	10.8	5		1	57	22.7	2		
29	11.2	5		1					

Table C-2 SR 408 Westbound MVDS System and Lane Management

Westbound		Number of lanes			Westbound		Number of lanes		
ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp	ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp
1	1.2			2	29	11.6	4		1
2	1.4	2			30	12.1	5		
3	1.6	3		2	31	12.6	5		2
4	2	3		1	32	13	5		1
5	2.4	3		1	33	13.3	3	2	
6	2.7	2	1		34	13.6	3	4	1
7	3.2	2	2		35	14.2	5		1
8	3.6	2		1	36	14.4	4		1
9	4.3	3		2	37	14.5	5		
10	4.6	4			38	15.2	5		
11	4.9	3		1	39	15.7	5		1
12	5.3	3		1	40	15.9	4		1
13	5.9	3	2	1	41	16.1	4		2
14	6.3	3	2		42	16.5	5		
15	6.8	3			43	17	3		2
16	7.3	3		1	44	17.8	3		1
17	7.4	4			45	18	3		1
18	7.6	3		1	46	18.4	2		1
19	8.1	3		1	47	18.8	2		1
20	8.4	3		1	48	19	2	1	
21	8.9	3		1	49	19.4	2	2	
22	9.2	3		1	50	19.7	3		1
23	9.7	3		1	51	19.9	2		1
24	9.9	2		2	52	20.7	3		
25	10.3	3		1	53	20.8	2		1
26	10.6	4			54	21.8	2		
27	10.9	4		2	55	22.3	2		1
28	11.3	5		1	56	22.7	2		1

Table C-3 SR 414 Eastbound MVDS System and Lane Management

Eastbound		Number of lanes		
ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp
1	3.6	2		3
2	3.8	2		2
3	4.3	3		1
4	4.9	3		
5	5.4	3	2	
6	5.8	3	1	
7	6.3	3		
8	6.6	3		1
9	7.2	3		
10	7.4	3		1
11	8.1	3		1
12	8.3	4		
13	8.9	3		2
14	9.3	2		1

Table C-4 SR 414 Westbound MVDS System and Lane Management

Westbound		Number of lanes		
ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp
1	3.8	2		3
2	4.3	3		1
3	4.9	3		
4	5.4	3	1	
5	5.8	3	2	
6	6.3	3		
7	6.6	3		1
8	7.2	3		
9	7.4	3		1
10	8.1	3		2
11	8.3	4		
12	9.2			2
13	9.3	3		1

Table C-5 SR 417 Northbound MVDS System and Lane Management

Northbound		Number of lanes			Northbound		Number of lanes		
ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp	ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp
1	5.9	2			29	23.9	2		1
2	6.2	2		2	30	24.5	2		
3	7.2	2	2		31	25	2		1
4	7.5	2	1		32	26.1	2		3
5	8.2	2			33	26.9	4		
6	9.4	2		1	34	27.3	3		2
7	10.1	2		1	35	27.9	3		1
8	10.6	2		1	36	28.1	3	2	
9	11	2		2	37	28.5	3	1	
10	12.2	2			38	28.7	4		
11	13.1	3		2	39	29.5	3		1
12	13.9	2		1	40	30.2	2		1
13	14.5	2			41	31.2	2		
14	15.2	4			42	31.9	2		
15	15.6	2	1		43	32.5	2		1
16	16.4	2			44	33			1
17	16.6	2		1	45	33.3	4		1
18	17.9	2		1	46	33.6	4		
19	18.2	2			47	34	3		2
20	18.8	2		1	48	34.6	3		1
21	19.3	2		1	49	35.2	3		
22	20.4	2			50	35.5	2	2	
23	20.9	2			51	36	3	2	
24	21.3	2		1	52	36.4	4		2
25	22	2		1	53	36.7	3		1
26	22.5	2		1	54	36.9	3		1
27	23	2		1	55	37.2	3		
28	23.6	2		1	56	37.7	2		

Table C-6 SR 417 Southbound MVDS System and Lane Management

Southbound		Number of lanes			Southbound		Number of lanes		
ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp	ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp
1	5.9	2			29	24.2	2		1
2	6.2	2		2	30	24.5	2		1
3	7.2	2	1		31	24.9	2		1
4	7.5	2	2		32	26.1	3		2
5	8.2	2			33	26.9	4		
6	9.4	2		1	34	27.3	3		1
7	10.3	2		2	35	27.9	4		1
8	10.7	2		1	36	28.1	3	1	
9	11.2	3		1	37	28.5	3	2	
10	12.2	2			38	28.7	4		
11	13.2	2		1	39	29.5	3		1
12	13.9	2		1	40	30.2	2		1
13	14.7	2			41	31.2	2		
14	15.2	3			42	31.9	2		
15	15.6	2	2		43	32.5	2		1
16	16.4	2			44	32.9			1
17	16.6	2		1	45	33.1	3		2
18	17.7	2		1	46	33.6	3		2
19	18.2	2			47	34.5	3		1
20	18.8	2		1	48	34.8	3		1
21	19.5	2		1	49	35.2	3		
22	20.4	2			50	35.5	2	1	
23	20.9	2			51	36	2	2	
24	21.3	2		1	52	36.4	3		1
25	22.2	2		1	53	36.7	2		1
26	23	3			54	37	2		1
27	23.2	2		1	55	37.2	2		
28	23.5	2		1	56	37.7	2		

Table C-7 SR 429 Northbound MVDS System and Lane Management

Northbound		Number of lanes			Northbound		Number of lanes		
ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp	ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp
1	10.9	2			16	22.8	2		1
2	13.7	2			17	23.2	2		2
3	14.6	2		1	18	23.6	3		2
4	15.3	2		1	19	24.5	2		1
5	16.1	2			20	24.7	2		
6	16.7	2	1		21	26	2		
7	17.2	2	1		22	26.3	2		1
8	18.4	2			23	26.8	2		1
9	18.9	2		1	24	27.7	2	2	
10	19.8	2		1	25	27.9	2	1	
11	20.4	2			26	28.9	2		1
12	21.7	2		1	27	29.4	2		1
13	21.9	2		2	28	29.6	3		
14	22.4	2		1	29	30	2		2
15	22.6			3					

Table C-8 SR 429 Southbound MVDS System and Lane Management

Southbound		Number of lanes			Southbound		Number of lanes		
ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp	ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp
1	10.9	2			16	22.7	2		2
2	11.5	2			17	23.2	2		1
3	14.6	2		1	18	24.2	2		1
4	15.3	2		1	19	24.5	3		
5	16.1	2			20	24.7	2		
6	16.7	2	1		21	26	2		
7	17.2	2	2		22	26.3	2		1
8	18.4	2			23	26.8	2		1
9	18.9	2		1	24	27.7	2	1	
10	19.8	2		1	25	27.9	2	2	
11	20.7	2			26	28.9	2		1
12	21.9	2		1	27	29.4	3		1
13	22.2			2	28	29.6	4		
14	22.4	2		1	29	29.8	2		2
15	22.5			2					

Table C-9 SR 528 Eastbound MVDS System and Lane Management

Eastbound		Number of lanes			Eastbound		Number of lanes		
ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp	ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp
1	8.5	3		1	16	15.3			3
2	9	3		1	17	15.7			2
3	9.5	3		1	18	15.9	2		2
4	9.8	3			19	16.6	2	2	
5	10.3	2		3	20	17.2	2	2	
6	10.7	2		1	21	19.5	2		1
7	10.8			1	22	20.2	2		1
8	11.1	2		1	23	23.2	2		
9	11.7	3		1	24	23.5	2		1
10	12.5	3		1	25	25.9	2	2	
11	12.8	4			26	26.3	2	1	
12	13.2	3		2	27	28.6	2		
13	13.8	2		1	28	30.6	2		1
14	14.5	2			29	31.9	2		
15	15	2		2					

Table C-10 SR 528 Westbound MVDS System and Lane Management

Westbound		Number of lanes			Westbound		Number of lanes		
ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp	ID	Milepost	Mainline (w/ TP Express)	TP Cash	Ramp
1	8.5	3		1	16	15.3	2		2
2	9.4	3		1	17	15.6	2		1
3	9.5	3		1	18	15.9	2		2
4	9.8	3			19	16.6	2	2	
5	10.3	4			20	17.2	2	2	
6	10.5	2		2	21	19.5	2		1
7	10.9	2		1	22	20.2	2		1
8	11	3		2	23	23.3	2		
9	12	4		1	24	23.5	2		1
10	12.2	3		1	25	25.9	2	1	
11	12.5	3		1	26	26.3	2	2	
12	12.8	3			27	28.6	2		
13	13.2	3		1	28	30.6	2		1
14	13.8	3		1	29	31.9	2		
15	14.5	2							

APPENDIX D. DMS LOCATIONS ON EXPRESSWAYS

Table D-1 DMS Locations on Expressway System

ID	DMS ID	Expressway	Direction	Milepost	Type
1	SR 408 EB @ MM 01.0 Ramp	SR 408	EB	1.0	Ramp
2	SR 408 EB @ MM 01.4	SR 408	EB	1.4	Mainline
3	SR 408 EB @ MM 04.4	SR 408	EB	4.4	Mainline
4	SR 408 EB @ MM 07.7	SR 408	EB	7.7	Mainline
5	SR 408 EB @ MM 11.1	SR 408	EB	11.1	Mainline
6	SR 408 EB @ MM 15.2	SR 408	EB	15.2	Mainline
7	SR 408 EB @ MM 20.6	SR 408	EB	20.6	Mainline
8	SR 408 WB @ MM 04.9	SR 408	WB	4.9	Mainline
9	SR 408 WB @ MM 09.3	SR 408	WB	9.3	Mainline
10	SR 408 WB @ MM 11.8	SR 408	WB	11.8	Mainline
11	SR 408 WB @ MM 15.2	SR 408	WB	15.2	Mainline
12	SR 408 WB @ MM 20.6	SR 408	WB	20.6	Mainline
13	SR 414 WB @ MM 09.6	SR 414	WB	9.6	Mainline
14	SR 417 NB @ MM 06.5	SR 417	NB	6.5	Mainline
15	SR 417 NB @ MM 14.7	SR 417	NB	14.7	Mainline
16	SR 417 NB @ MM 20.6	SR 417	NB	20.6	Mainline
17	SR 417 NB @ MM 27.0	SR 417	NB	27.0	Mainline
18	SR 417 NB @ MM 33.4	SR 417	NB	33.4	Mainline
19	SR 417 SB @ MM 08.1	SR 417	SB	8.1	Mainline
20	SR 417 SB @ MM 14.7	SR 417	SB	14.7	Mainline
21	SR 417 SB @ MM 18.2	SR 417	SB	18.2	Mainline
22	SR 417 SB @ MM 30.9	SR 417	SB	30.9	Mainline
23	SR 417 SB @ MM 35.3	SR 417	SB	35.3	Mainline
24	SR 417 SB @ MM 37.8	SR 417	SB	37.8	Mainline
25	SR 429 NB @ MM 11.8	SR 429	NB	11.8	Mainline
26	SR 429 NB @ MM 20.7	SR 429	NB	20.7	Mainline
27	SR 429 NB @ MM 25.0	SR 429	NB	25.0	Mainline
28	SR 429 SB @ MM 20.7	SR 429	SB	20.7	Mainline
29	SR 429 SB @ MM 25.0	SR 429	SB	25.0	Mainline
30	SR 451 SB @ MM 01.5	SR 451	SB	1.5	Mainline
31	SR 520 WB @ SR 528	SR 520	WB	--	Mainline
32	SR 528 EB @ MM 08.6	SR 528	EB	8.6	Mainline
33	SR 528 EB @ MM 11.8	SR 528	EB	11.8	Mainline
34	SR 528 EB @ MM 23.2	SR 528	EB	23.2	Mainline
35	SR 528 WB @ MM 14.0	SR 528	WB	14	Mainline
36	SR 528 WB @ MM 23.2	SR 528	WB	23.2	Mainline
37	SR 528 WB @ MM 31.7	SR 528	WB	31.7	Mainline

APPENDIX E. EXPRESSWAY MAINLINE OPERATION OVERVIEW

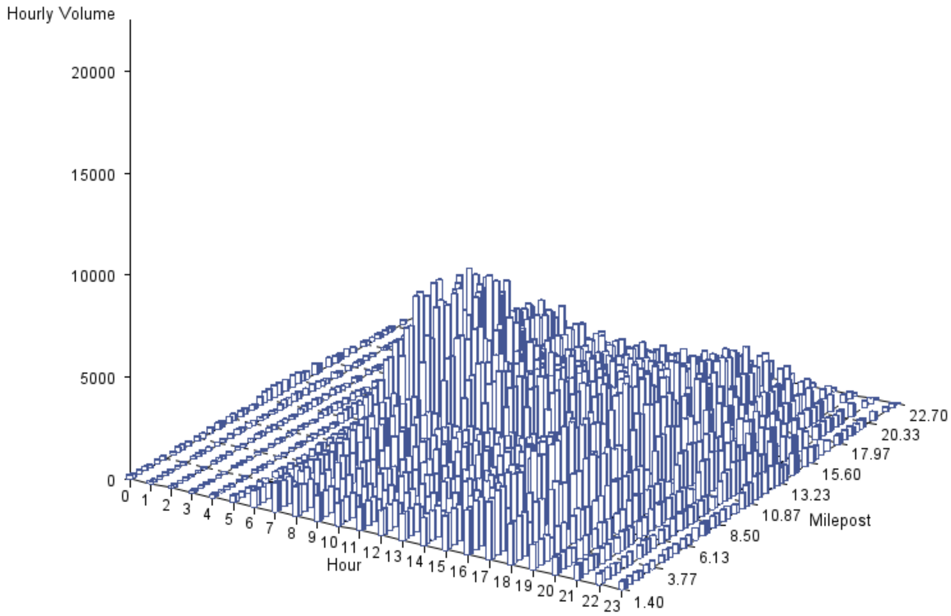


Figure E-1 Weekday Hourly Volume along SR 408 Westbound

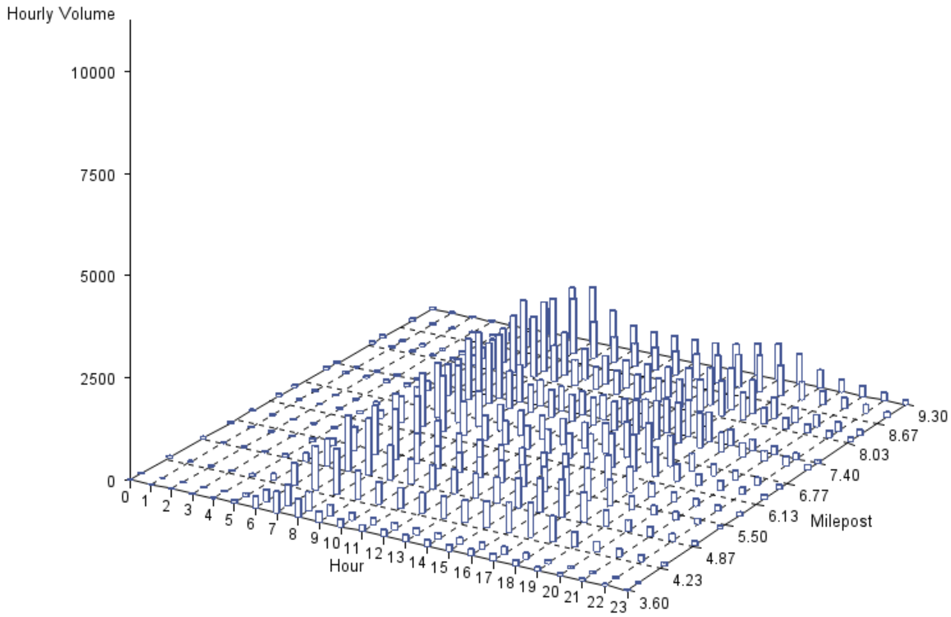


Figure E-2 Weekday Hourly Volume along SR 414 Eastbound

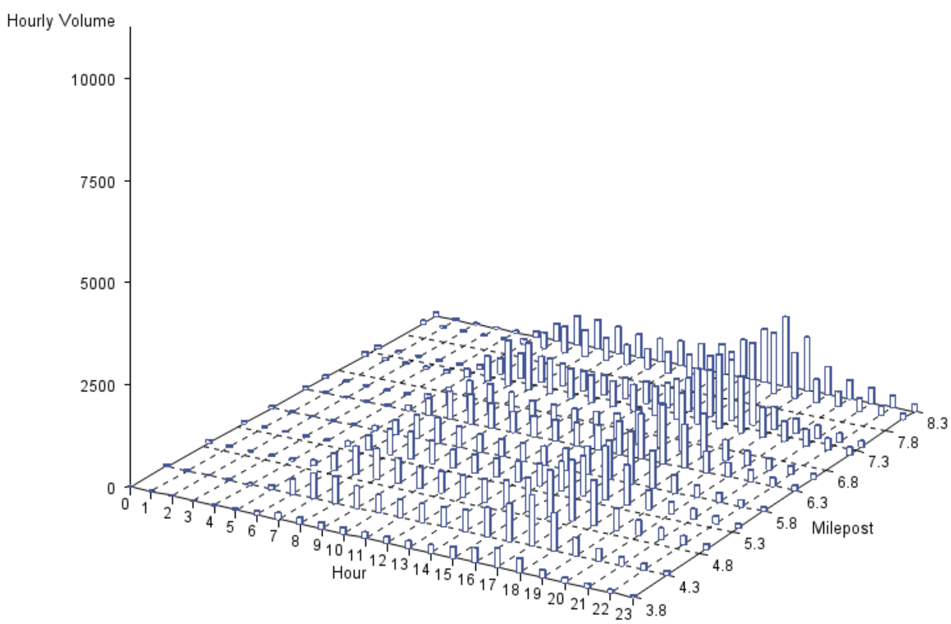


Figure E-3 Weekday Hourly Volume along SR 414 Westbound

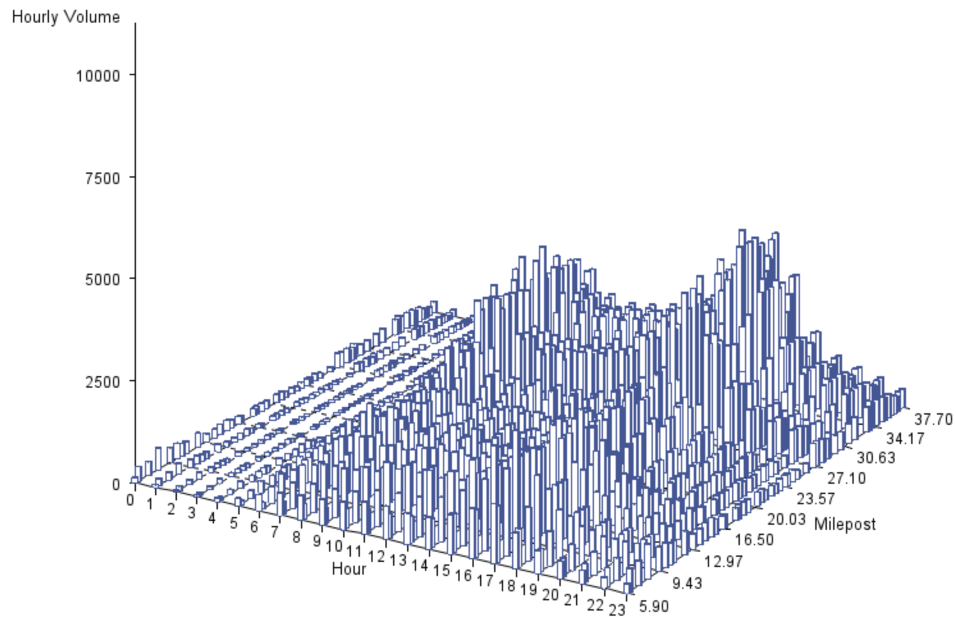


Figure E-4 Weekday Hourly Volume along SR 417 Northbound

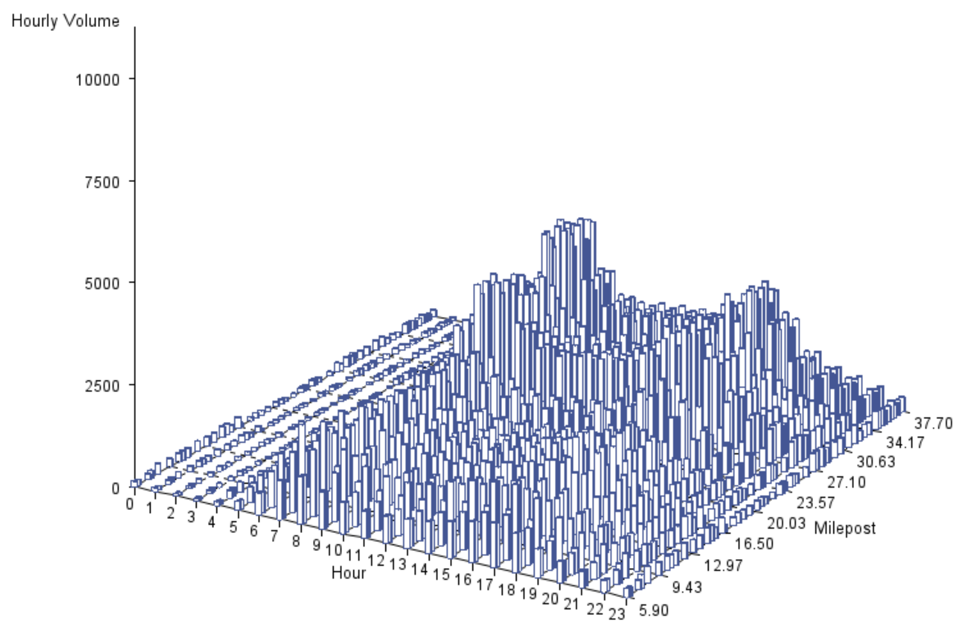


Figure E-5 Weekday Hourly Volume along SR 417 Southbound

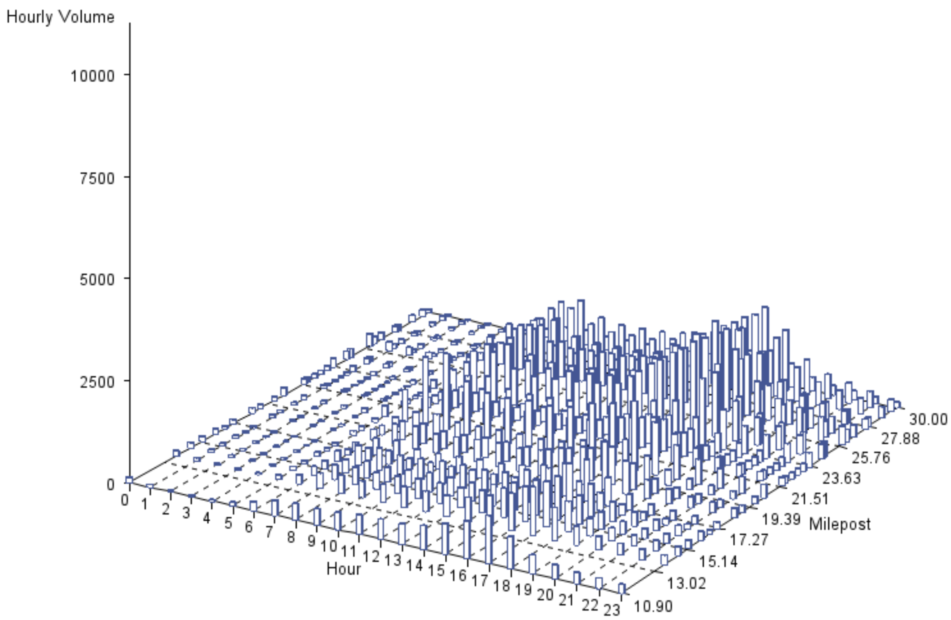


Figure E-6 Weekday Hourly Volume along SR 429 Northbound

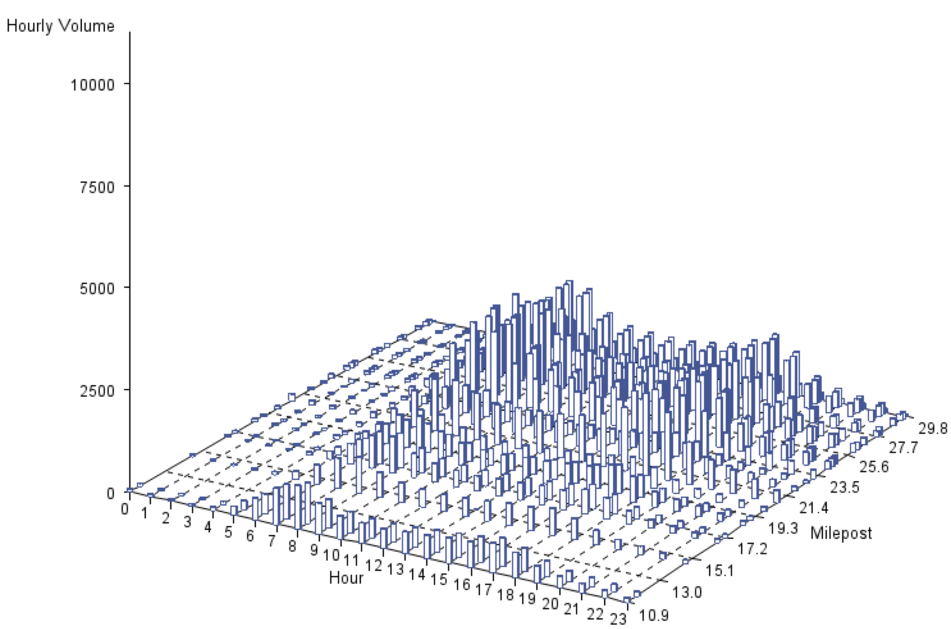


Figure E-7 Weekday Hourly Volume along SR 429 Southbound

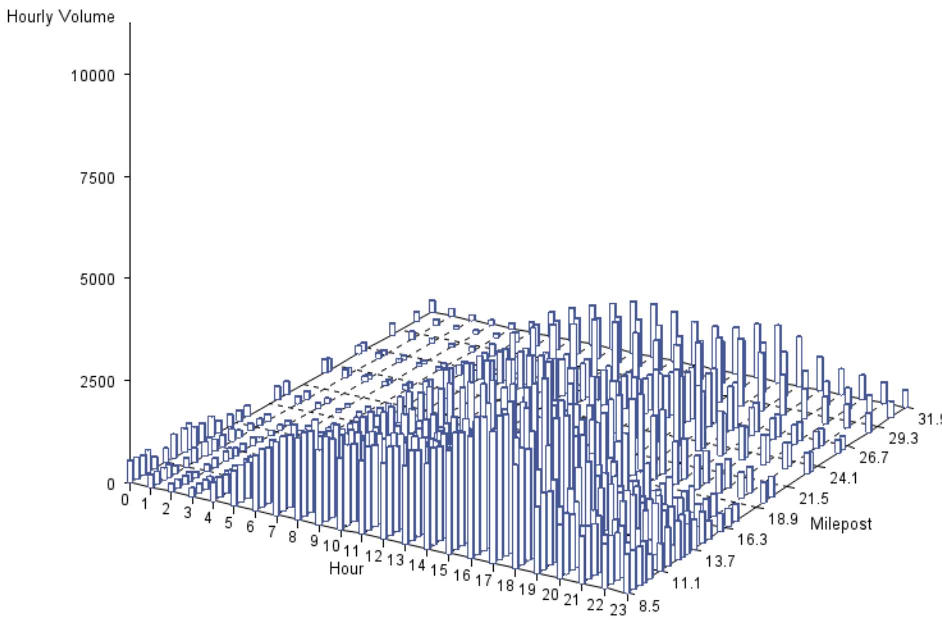


Figure E-8 Weekday Hourly Volume along SR 528 Eastbound

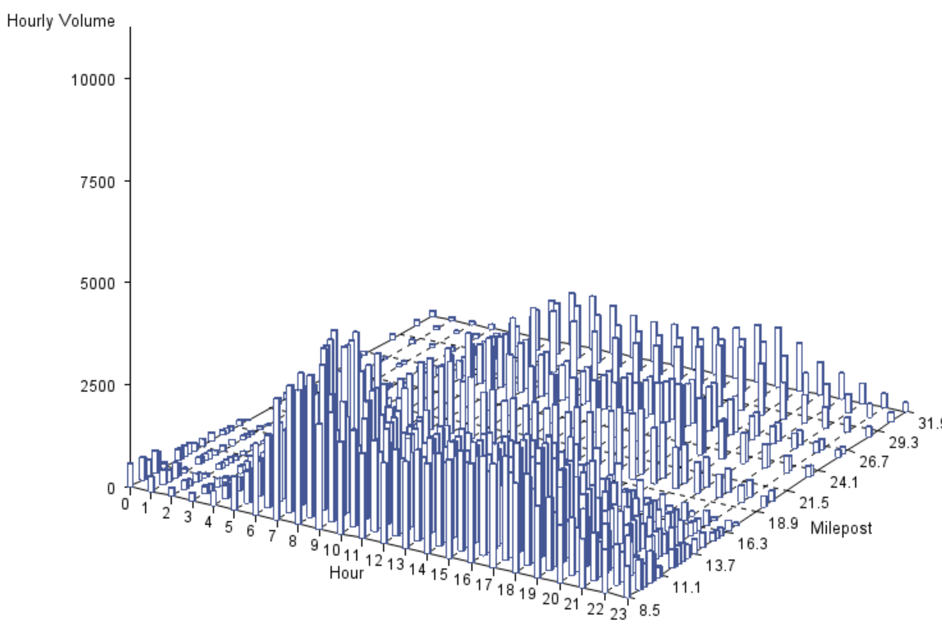
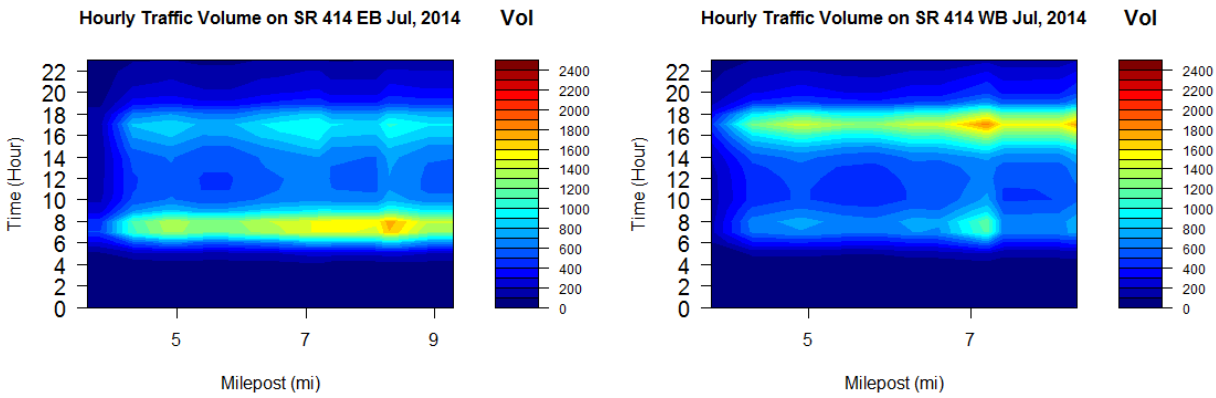


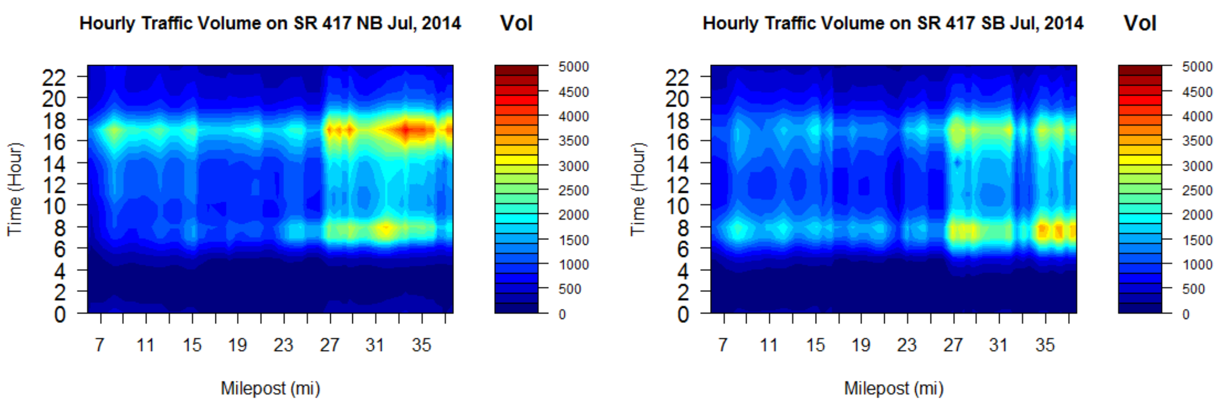
Figure E-9 Weekday Hourly Volume along SR 528 Westbound

APPENDIX F. EXPRESSWAY MAINLINE TRAFFIC PATTERN



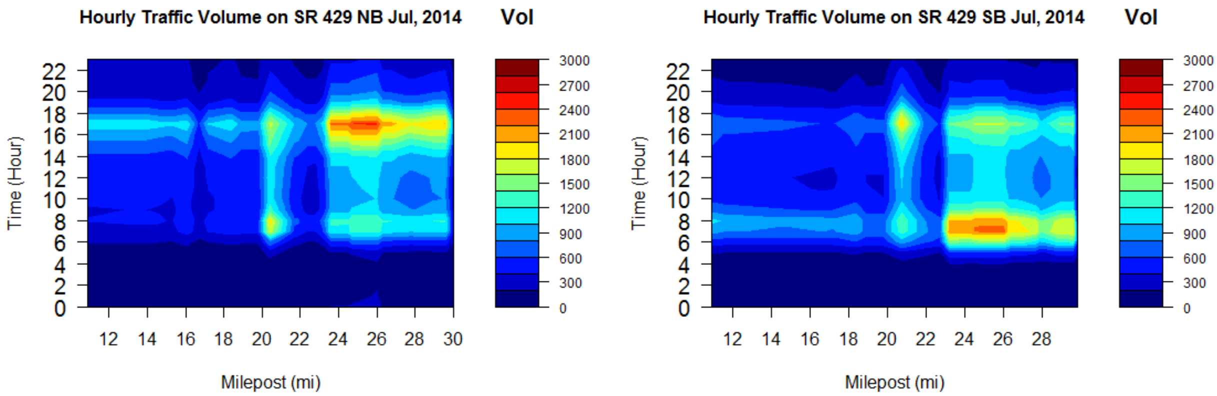
(a) (b)

Figure F-1 Spatial-Temporal Hourly Volume Distribution on SR 414 (a) Eastbound and (b) Westbound



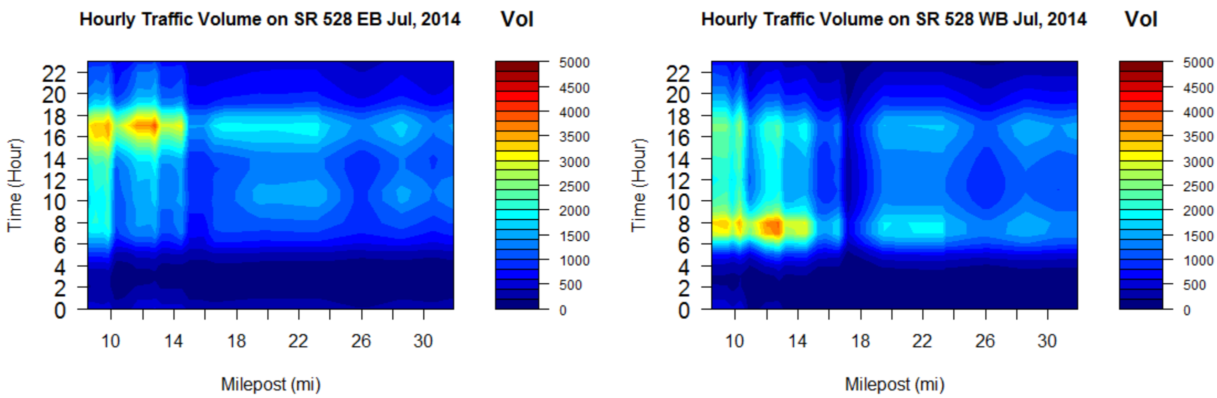
(a) (b)

Figure F-2 Spatial-Temporal Hourly Volume Distribution on SR 417 (a) Northbound and (b) Southbound



(a) (b)

Figure F-3 Spatial-Temporal Hourly Volume Distribution on SR 429 (a) Northbound and (b) Southbound



(a) (b)

Figure F-4 Spatial-Temporal Hourly Volume Distribution on SR 528 (a) Eastbound and (b) Westbound

APPENDIX G. MAINLINE TOLL PLAZA CASH LANES TRAFFIC VOLUME

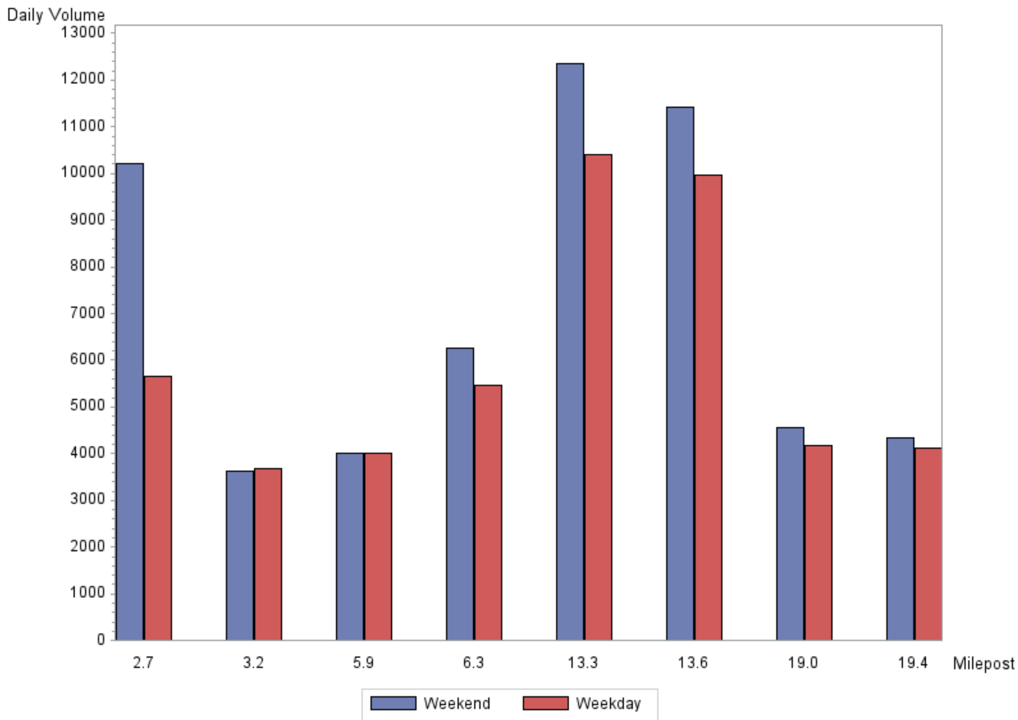


Figure G-1 SR 408 Westbound Toll Plaza Cash Lanes Traffic Volume

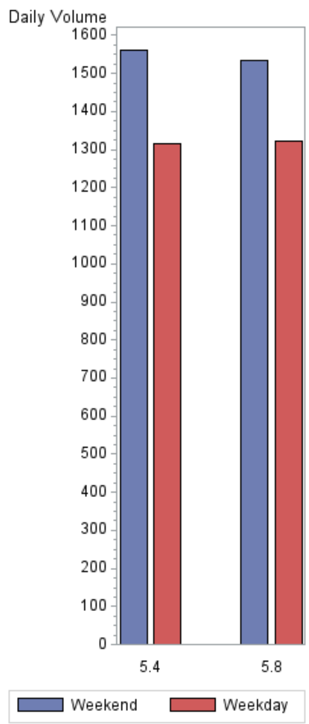


Figure G-2 SR 414 Eastbound Toll Plaza Cash Lanes Traffic Volume

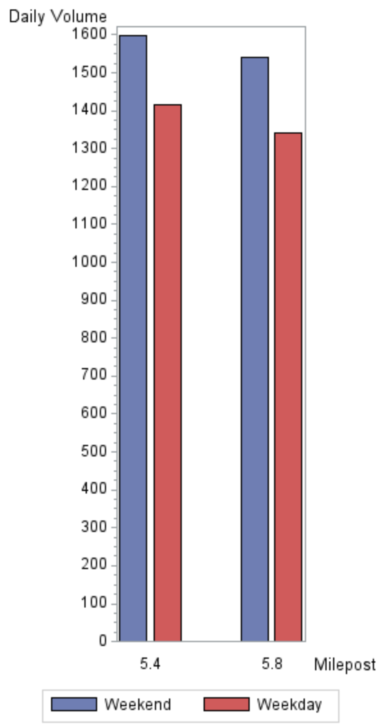


Figure G-3 SR 414 Westbound Toll Plaza Cash Lanes Traffic Volume

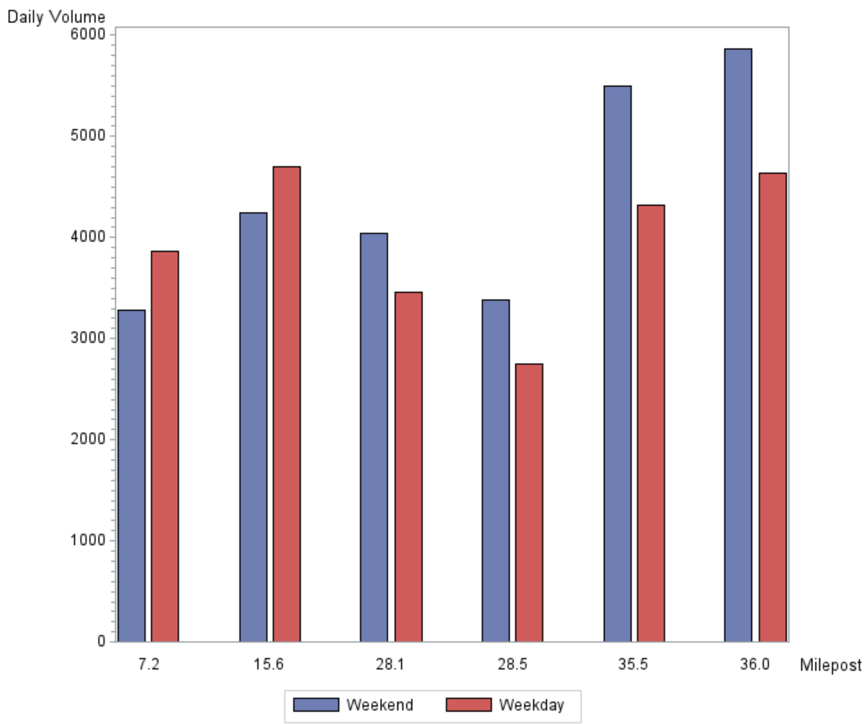


Figure G-4 SR 417 Northbound Toll Plaza Cash Lanes Traffic Volume

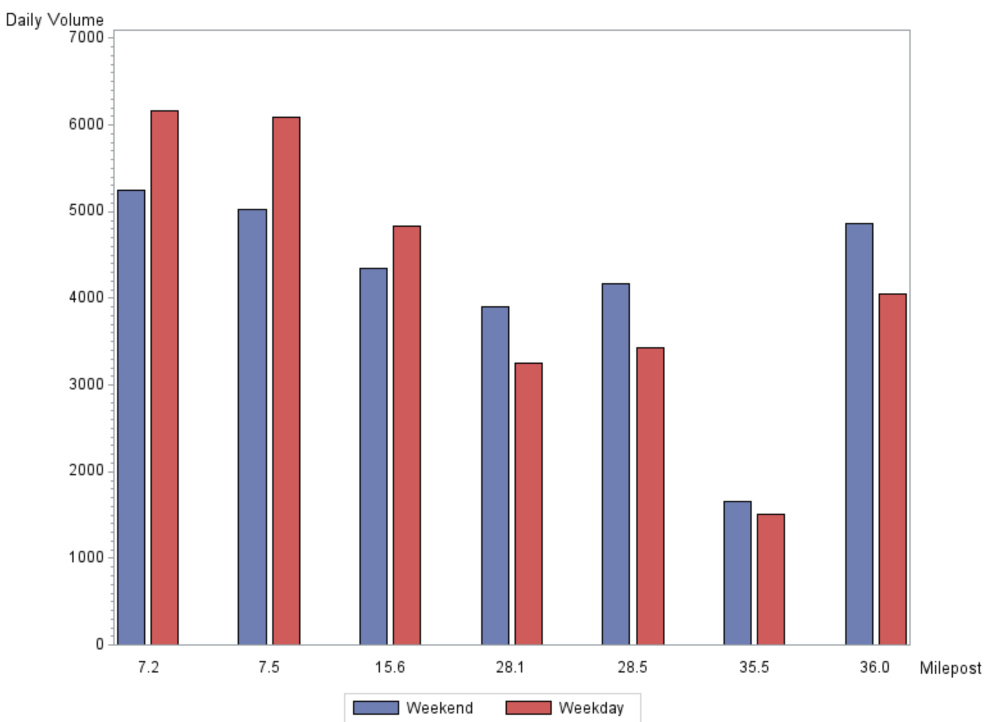


Figure G-5 SR 417 Southbound Toll Plaza Cash Lanes Traffic Volume

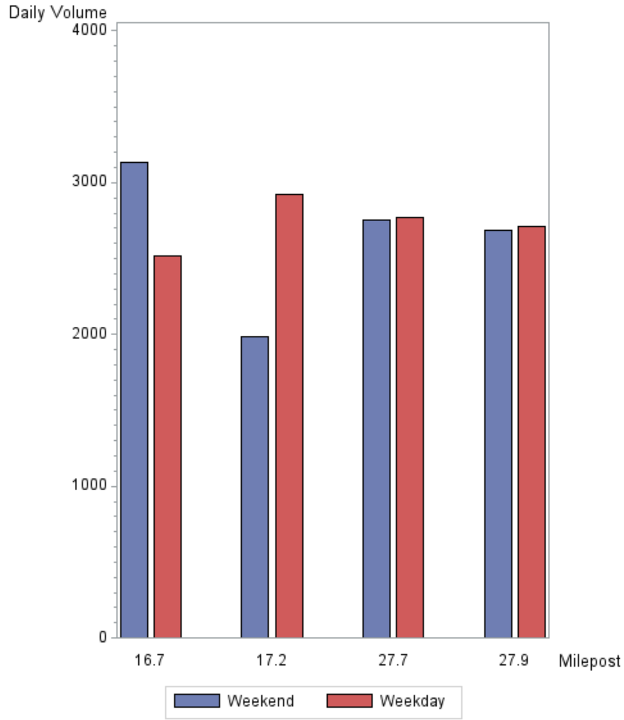


Figure G-6 SR 429 Northbound Toll Plaza Cash Lanes Traffic Volume

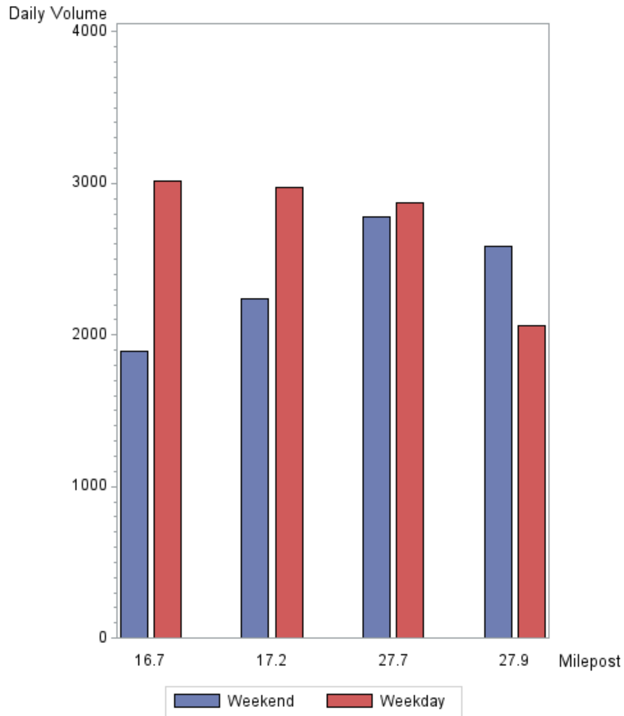


Figure G-7 SR 429 Southbound Toll Plaza Cash Lanes Traffic Volume

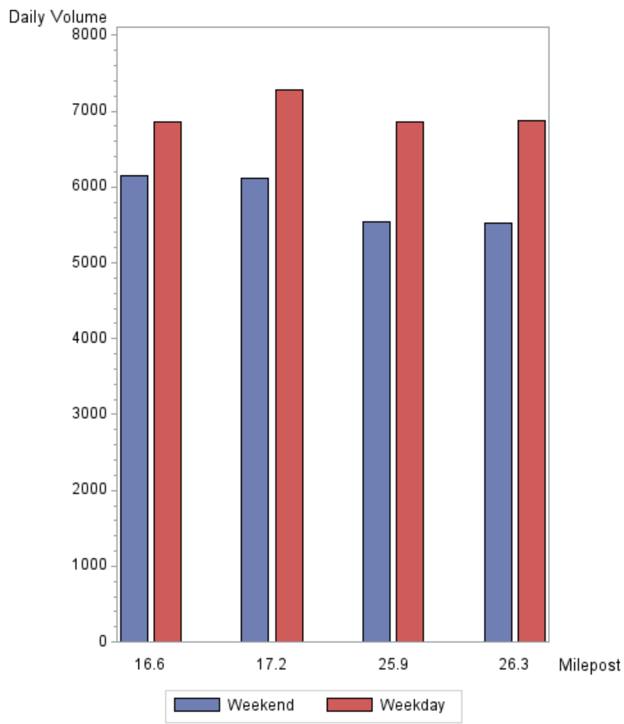


Figure G-8 SR 528 Eastbound Toll Plaza Cash Lanes Traffic Volume

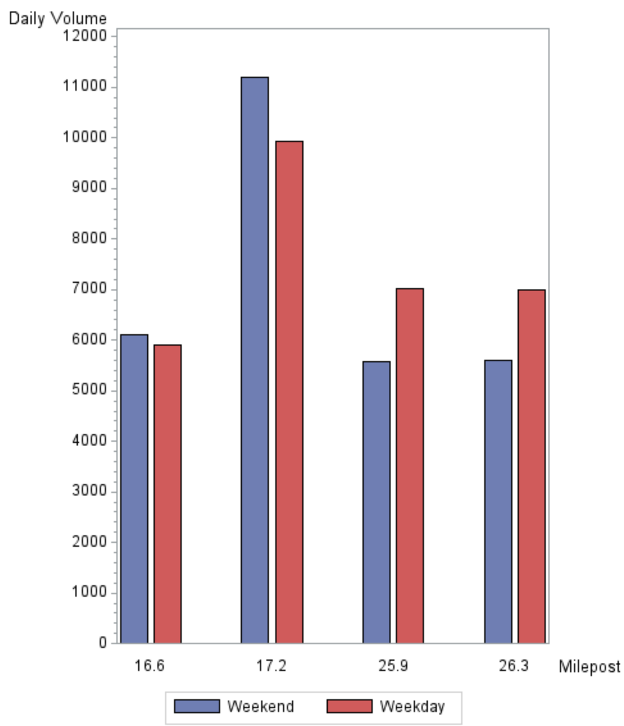


Figure G-9 SR 528 Westbound Toll Plaza Cash Lanes Traffic Volume

APPENDIX H. EXPRESSWAY RAMP WEEKDAY TRAFFIC

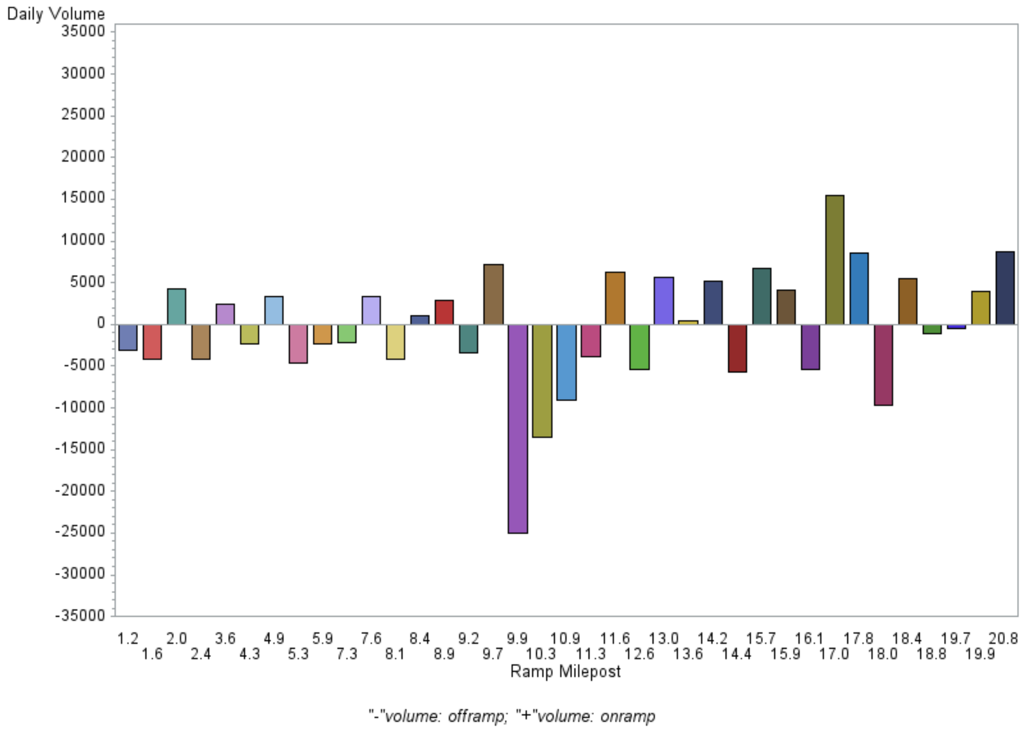
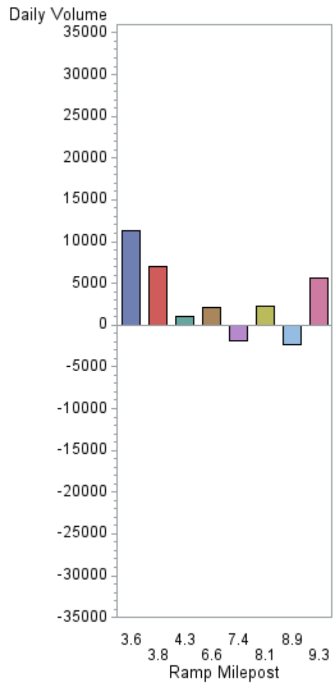
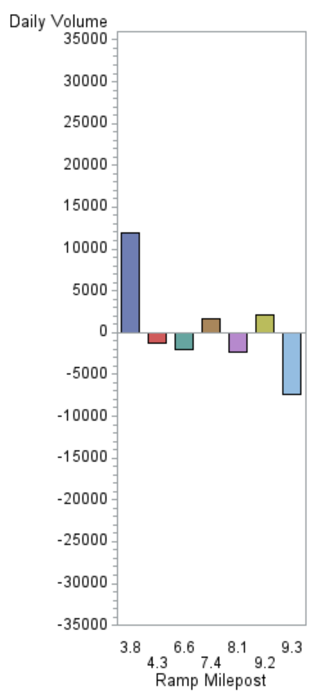


Figure H-1 SR 408 Westbound Weekday Ramp Traffic Volume



"-"volume: offramp; "+"volume: onramp

Figure H-2 SR 414 Eastbound Weekday Ramp Traffic Volume



"-"volume: offramp; "+"volume: onramp

Figure H-3 SR 414 Westbound Weekday Ramp Traffic Volume

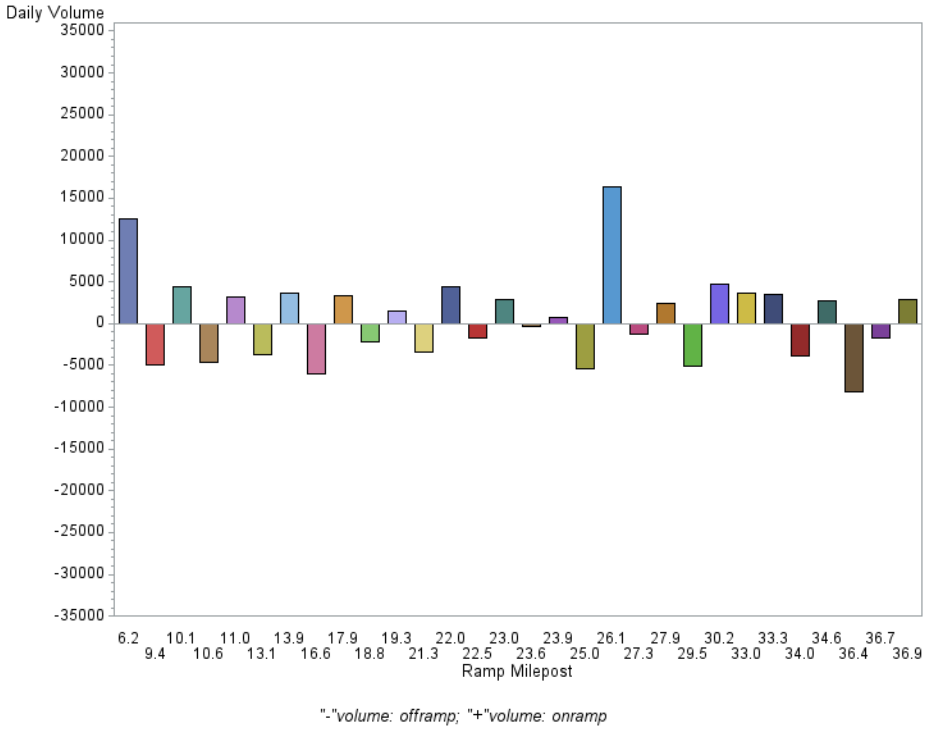


Figure H-4 SR 417 Northbound Weekday Ramp Traffic Volume

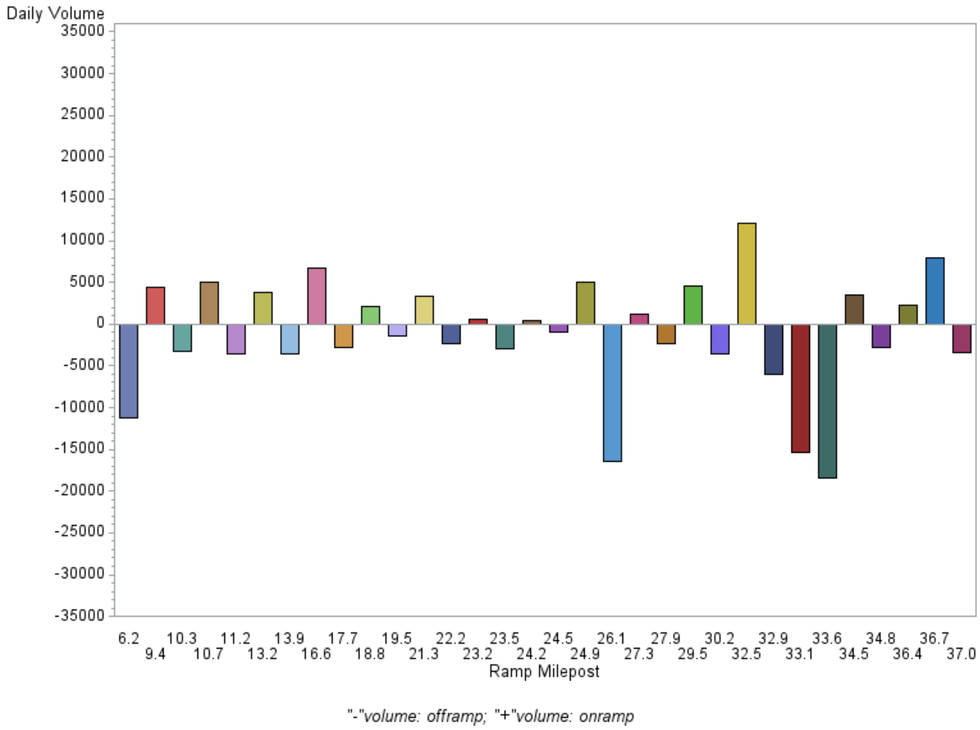


Figure H-5 SR 417 Southbound Weekday Ramp Traffic Volume

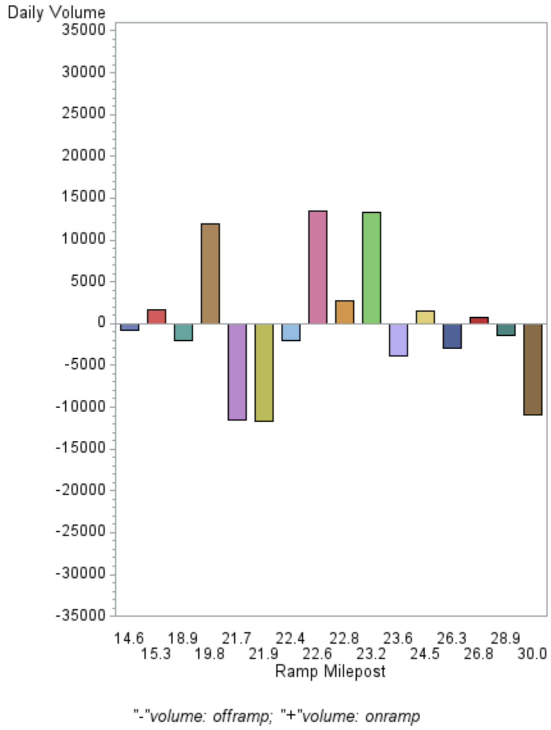


Figure H-6 SR 429 Northbound Weekday Ramp Traffic Volume

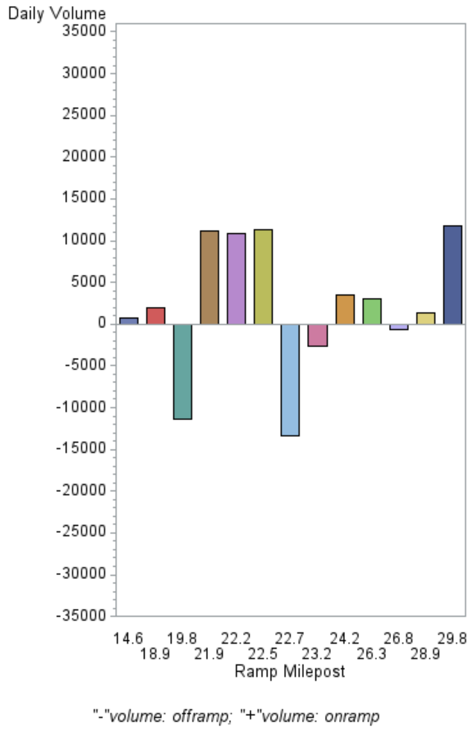


Figure H-7 SR 429 Southbound Weekday Ramp Traffic Volume

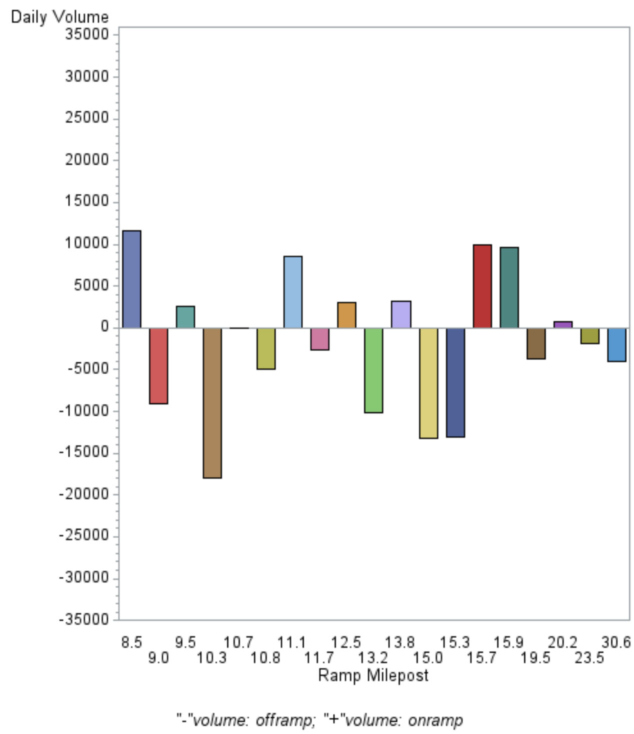


Figure H-8 SR 528 Eastbound Weekday Ramp Traffic Volume

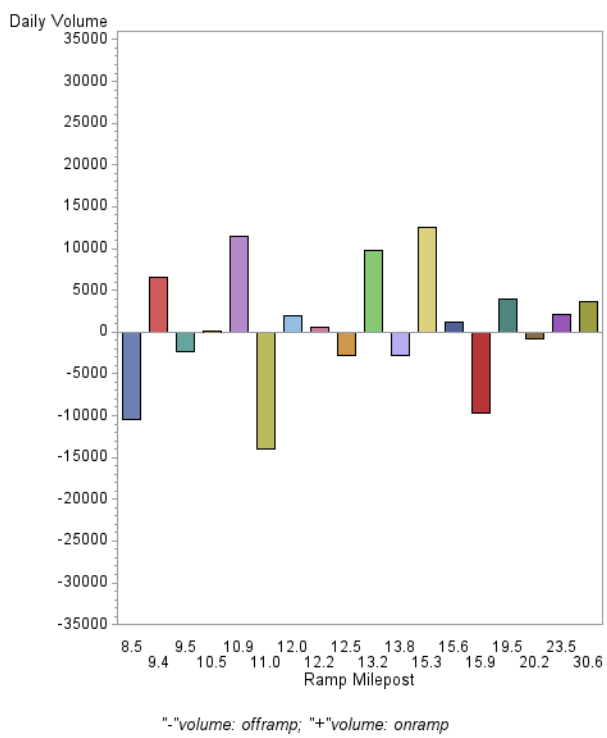
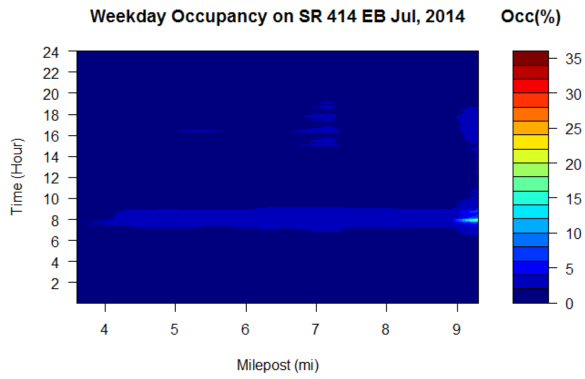
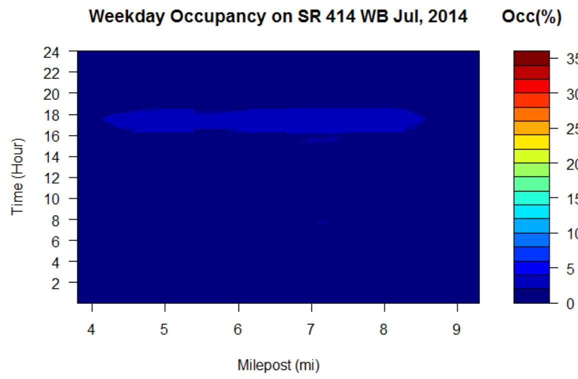


Figure H-9 SR 528 Westbound Weekday Ramp Traffic Volume

APPENDIX I. MAINLINE CONGESTION MEASUREMENT (1) OCCUPANCY

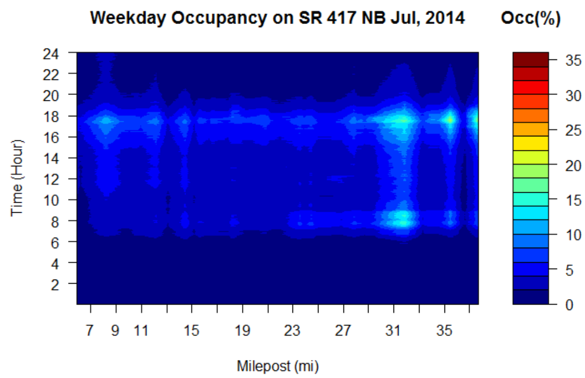


(a)

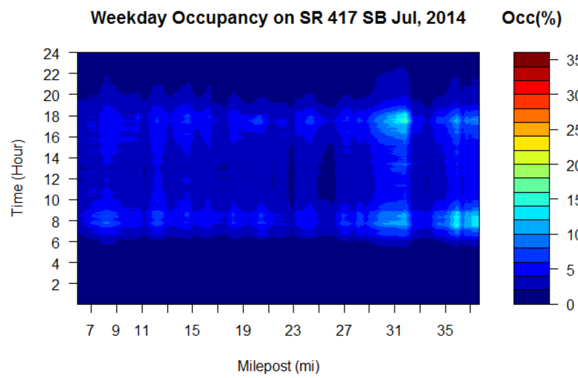


(b)

Figure I-1 Mainline Weekday Occupancy of SR 414 (a) Eastbound and (b) Westbound

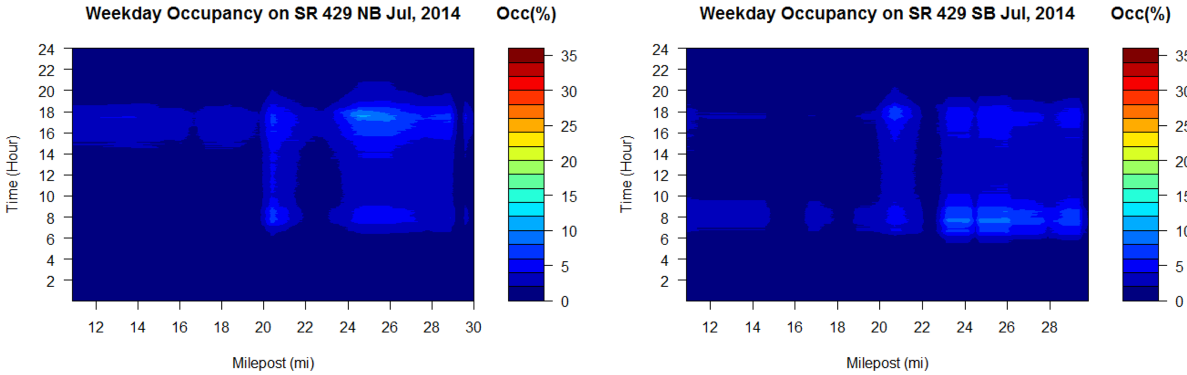


(a)



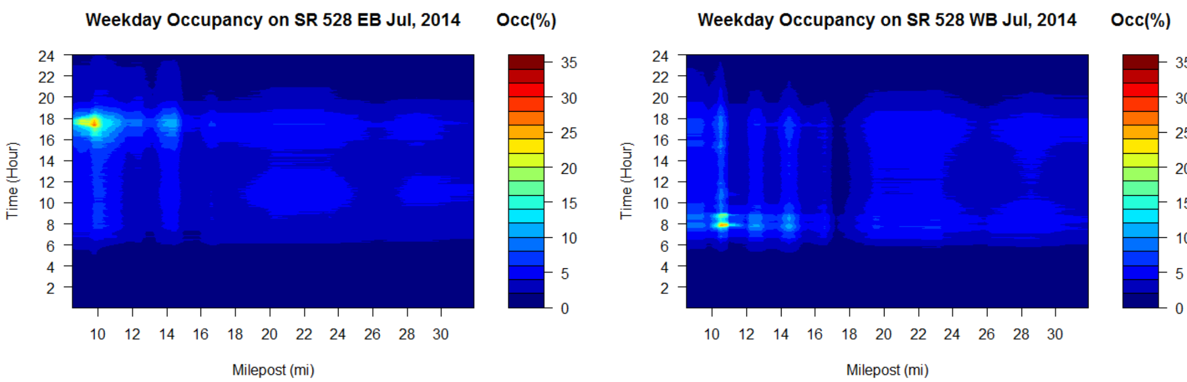
(b)

Figure I-2 Mainline Weekday Occupancy of SR 417 (a) Northbound and (b) Southbound



(a) (b)

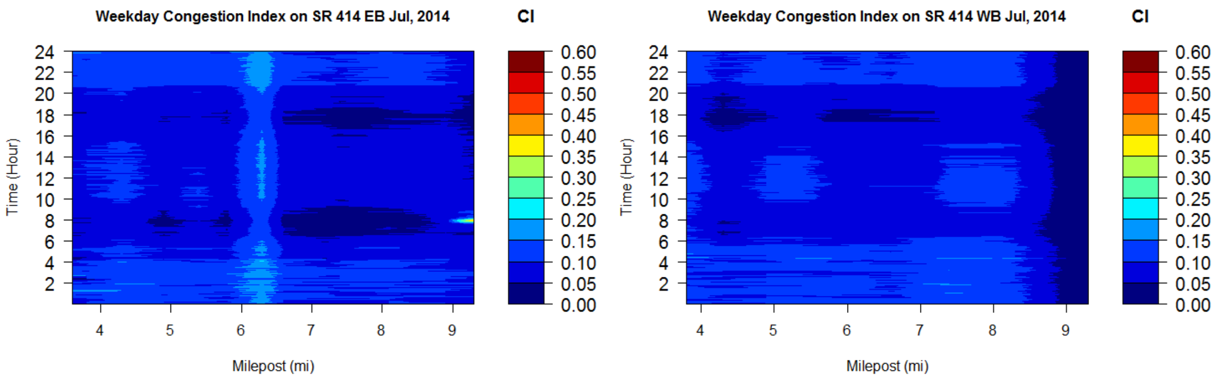
Figure I-3 Mainline Weekday Occupancy of SR 429 (a) Northbound and (b) Southbound



(a) (b)

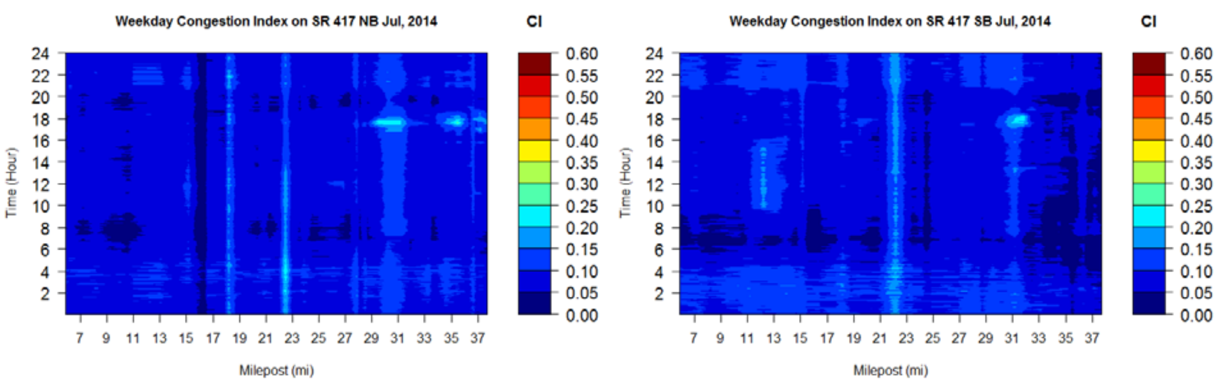
Figure I-4 Mainline Weekday Occupancy of SR 528 (a) Eastbound and (b) Westbound

APPENDIX J. MAINLINE CONGESTION MEASUREMENT (2) CONGESTION INDEX



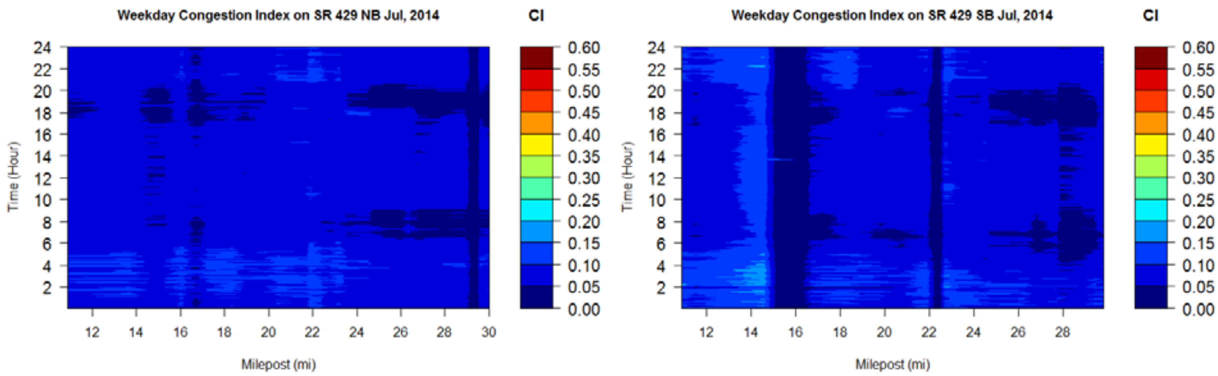
(a) (b)

Figure J-1 Mainline Weekday Congestion Index of SR 414 (a) Eastbound and (b) Westbound



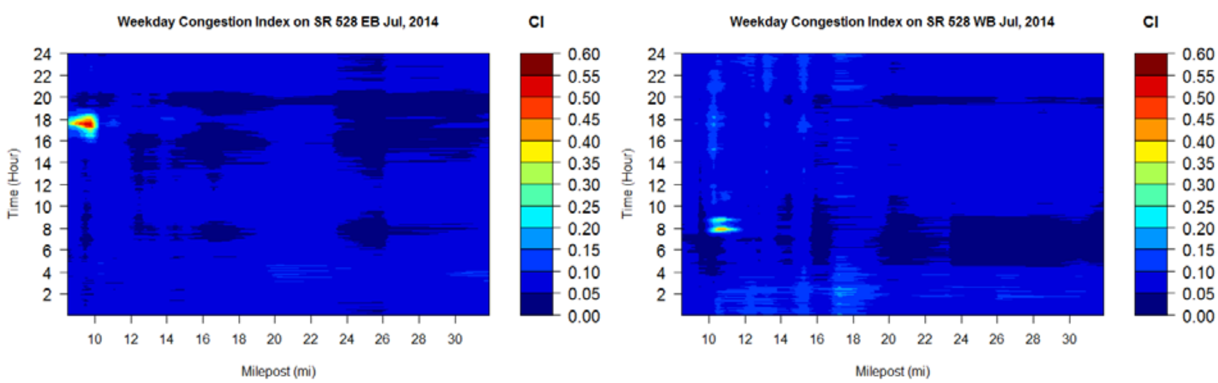
(a) (b)

Figure J-2 Mainline Weekday Congestion Index of SR 417 (a) Northbound and (b) Southbound



(a) (b)

Figure J-3 Mainline Weekday Congestion Index of SR 429 (a) Northbound and (b) Southbound



(a) (b)

Figure J-4 Mainline Weekday Congestion Index of SR 528 (a) Eastbound and (b) Westbound

APPENDIX K. MAINLINE SYSTEM OCCUPANCY AND TREND OF CONGESTION

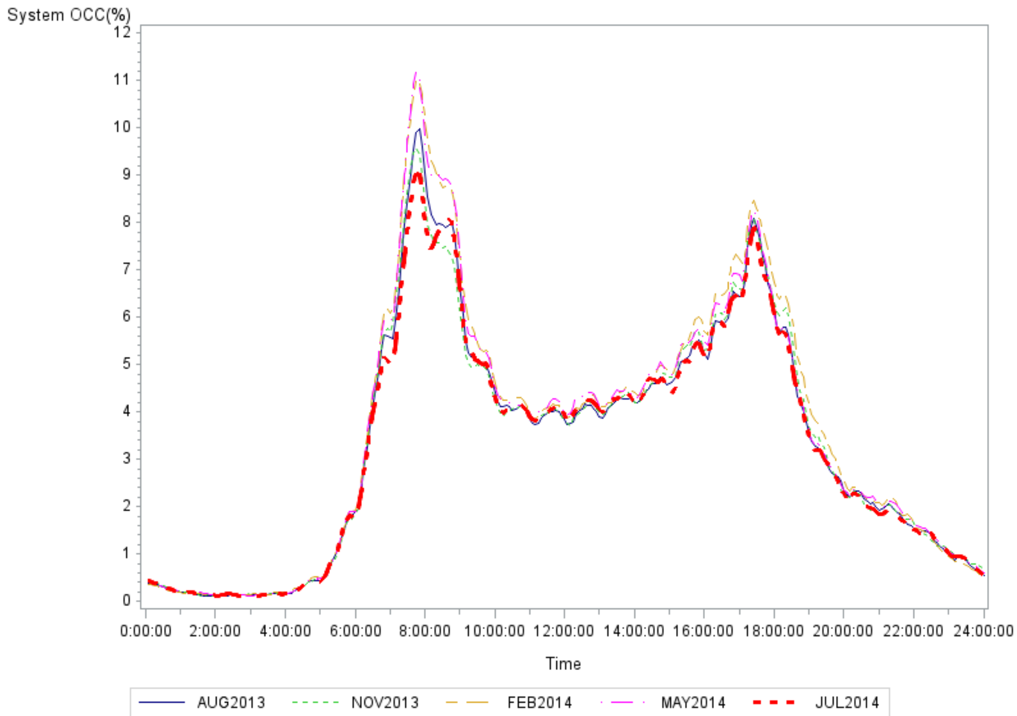


Figure K-1 SR 408 Westbound System Occupancy and Trend of Congestion

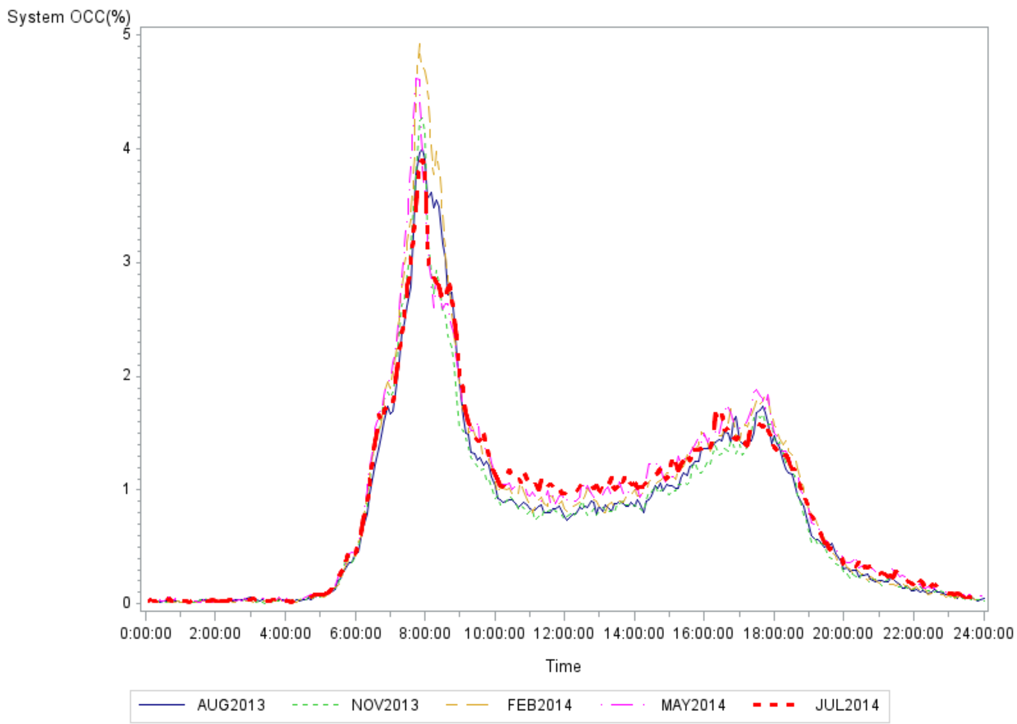


Figure K-2 SR 414 Eastbound System Occupancy and Trend of Congestion

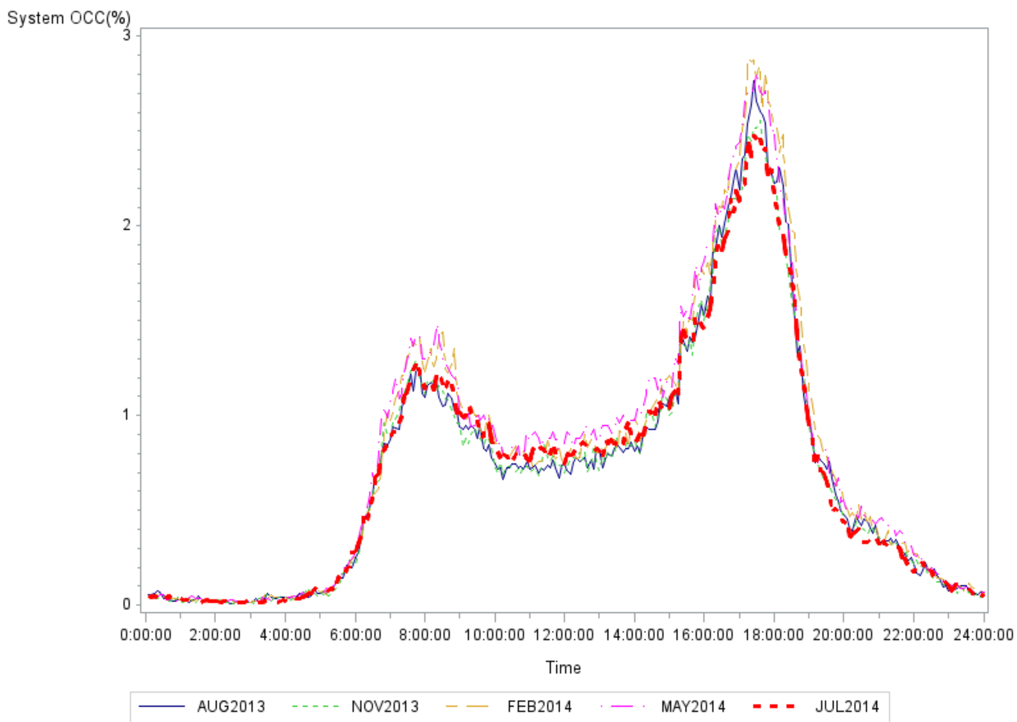


Figure K-3 SR 414 Westbound System Occupancy and Trend of Congestion

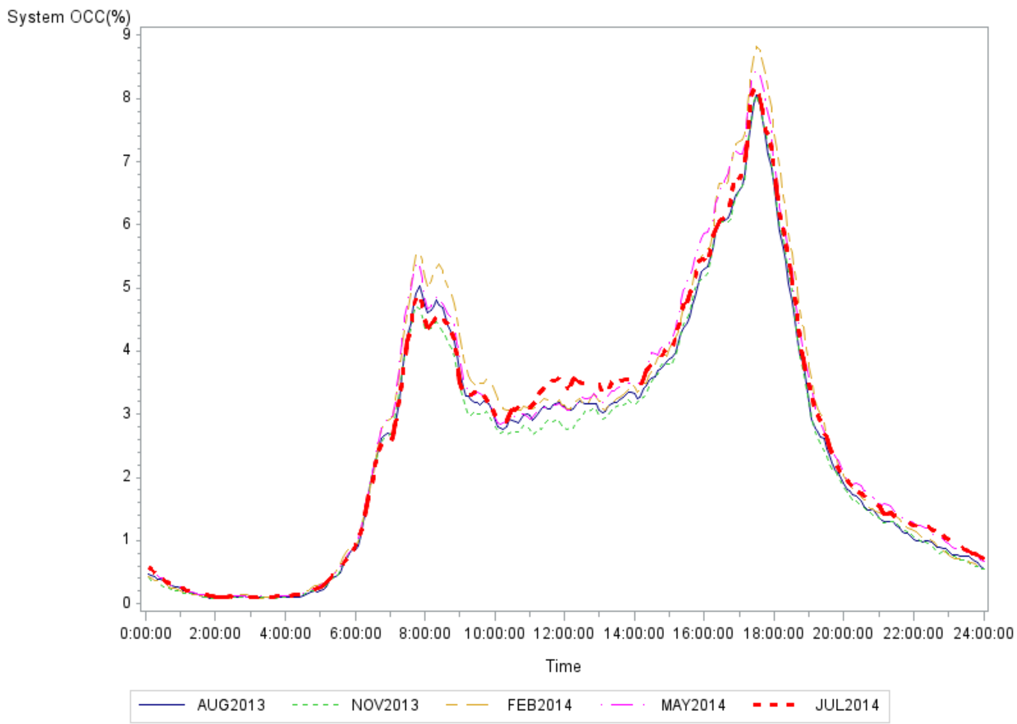


Figure K-4 SR 417 Northbound System Occupancy and Trend of Congestion

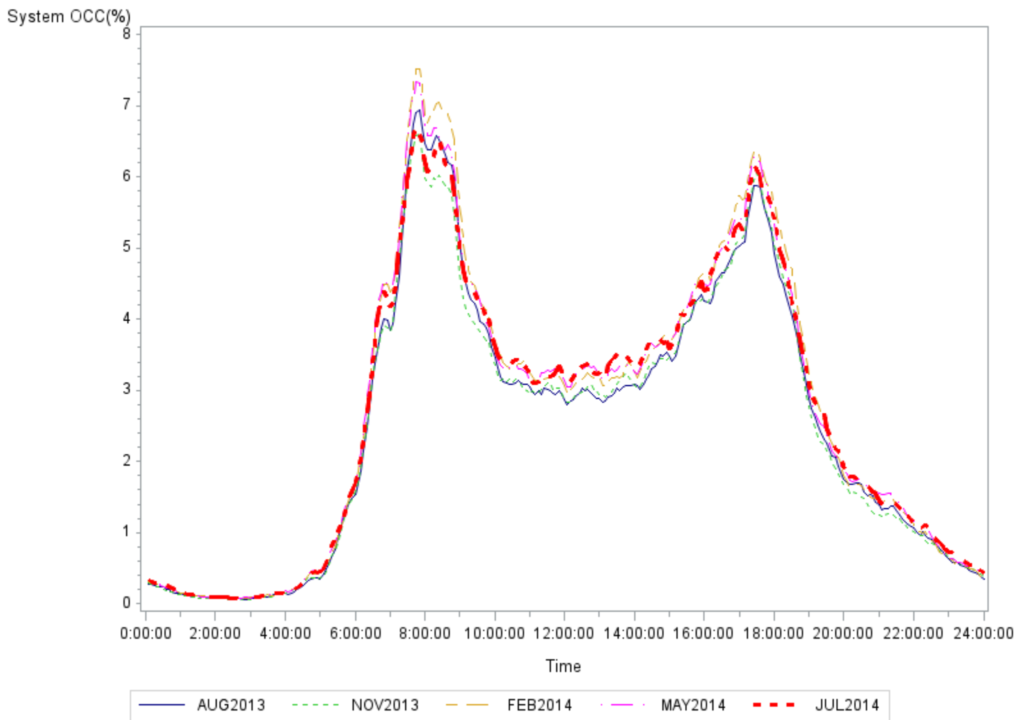


Figure K-5 SR 417 Southbound System Occupancy and Trend of Congestion

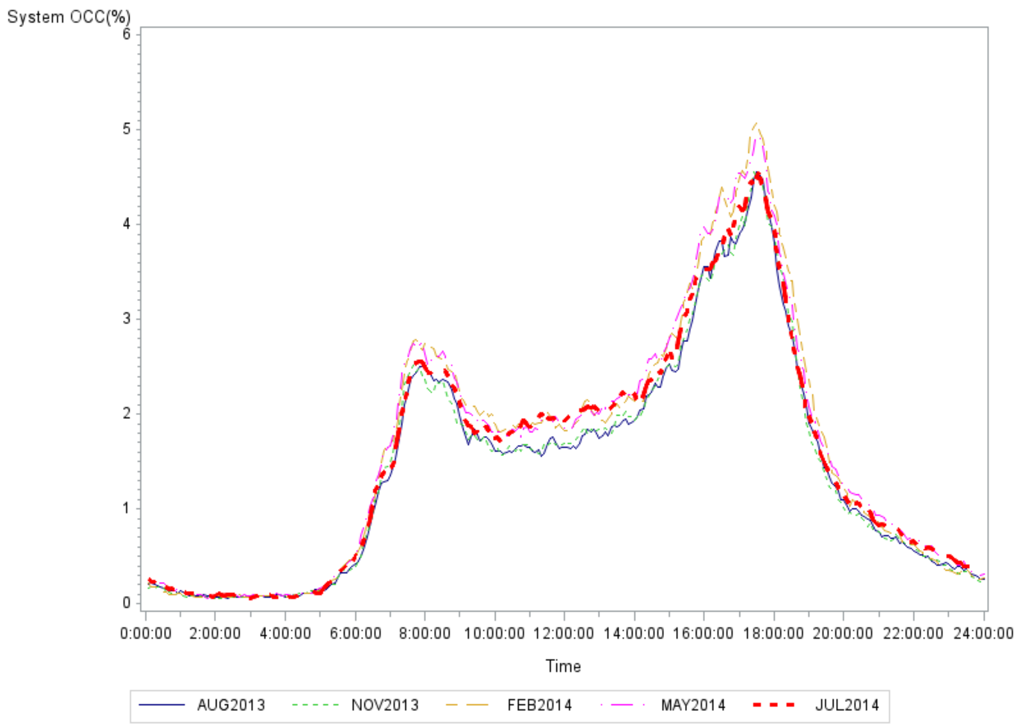


Figure K-6 SR 429 Northbound System Occupancy and Trend of Congestion

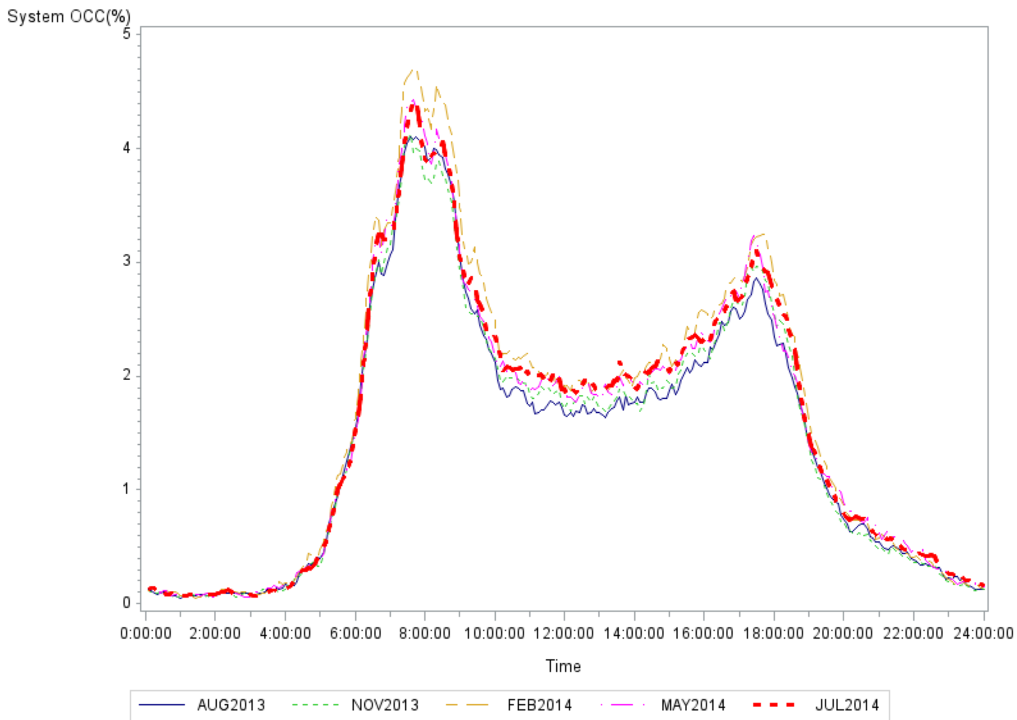


Figure K-7 SR 429 Southbound System Occupancy and Trend of Congestion

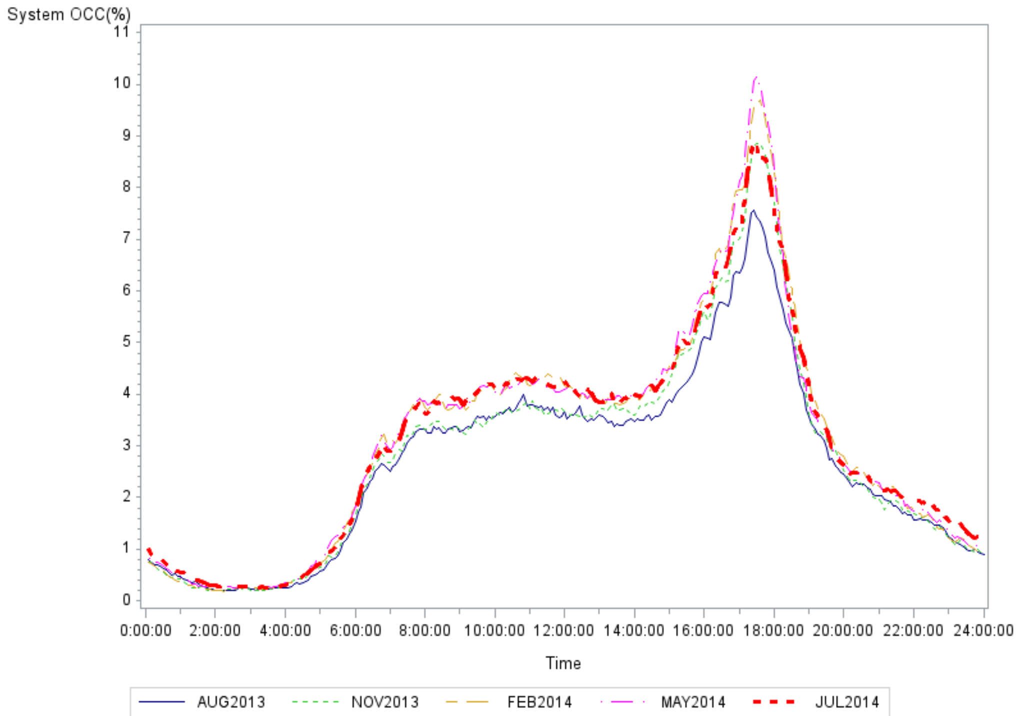


Figure K-8 SR 528 Eastbound System Occupancy and Trend of Congestion

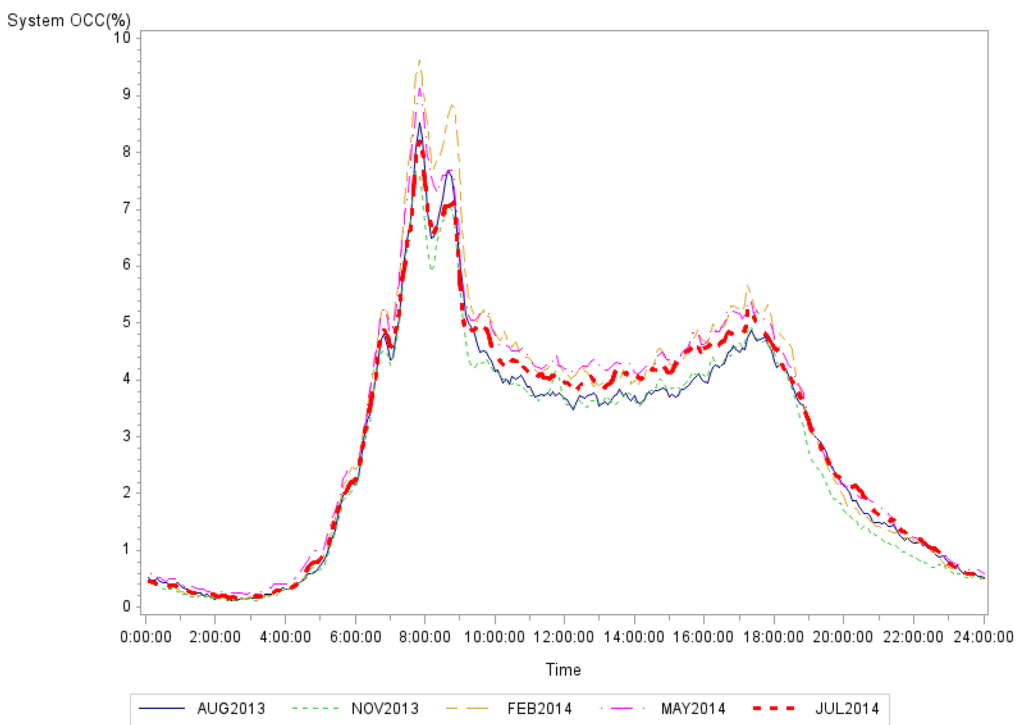


Figure K-9 SR 528 Westbound System Occupancy and Trend of Congestion

APPENDIX L. PEAK HOUR OCCUPANCY PROFILE AND TREND OF CONGESTION

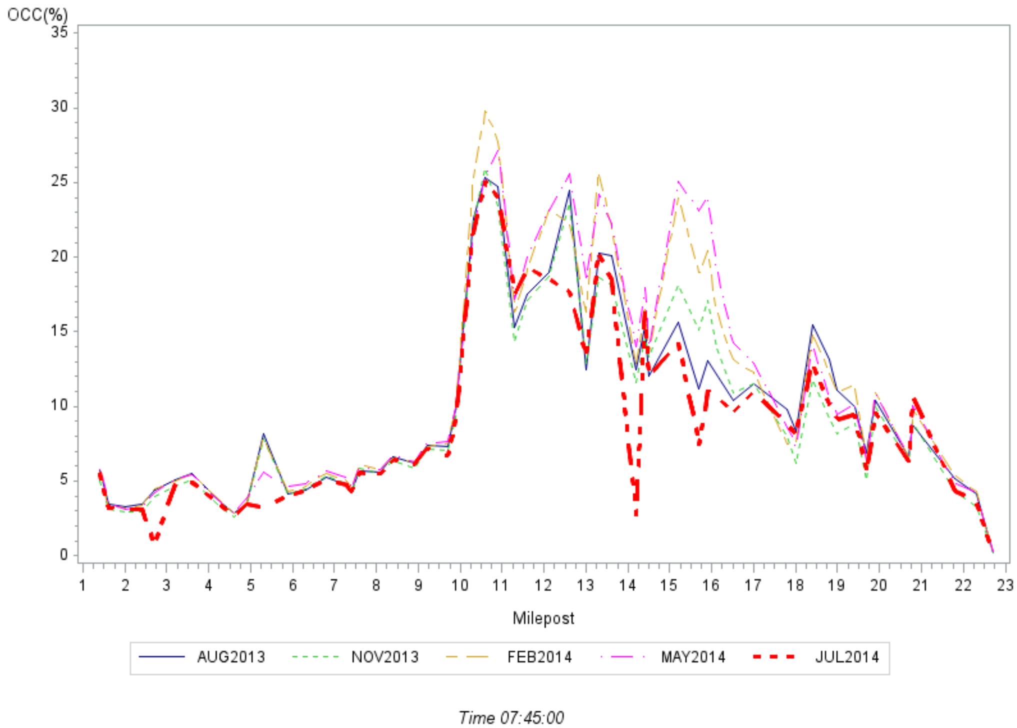


Figure L-1 SR 408 Westbound Peak Hour Occupancy and Trend of Congestion

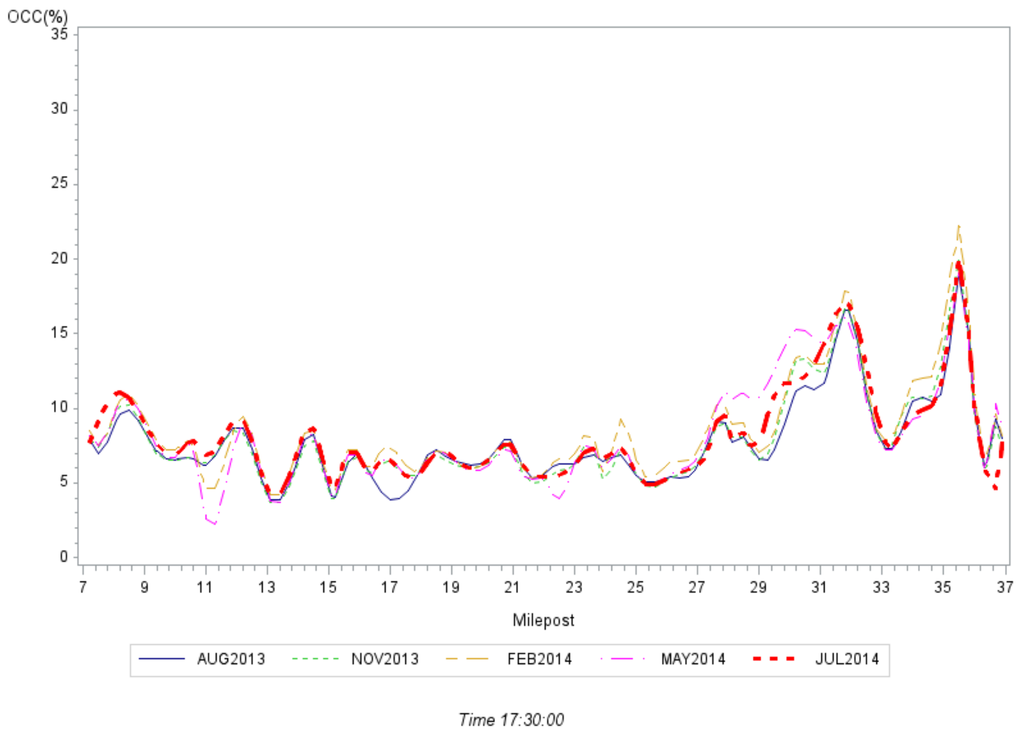


Figure L-2 SR 417 Northbound Peak Hour Occupancy and Trend of Congestion

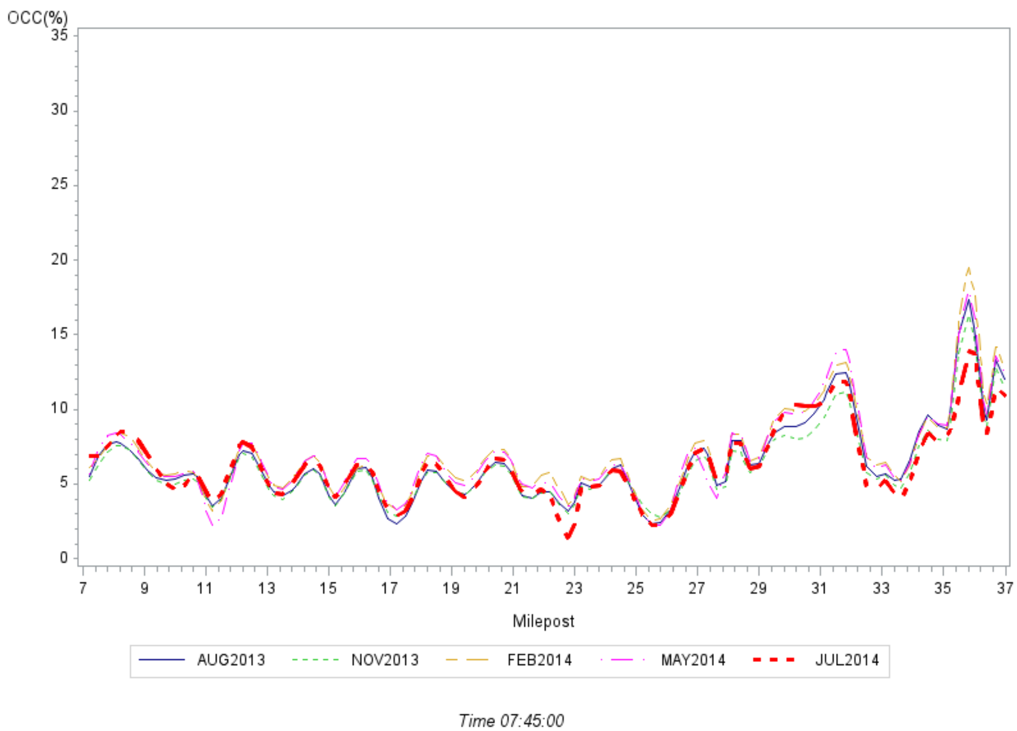


Figure L-3 SR 417 Southbound Peak Hour Occupancy and Trend of Congestion

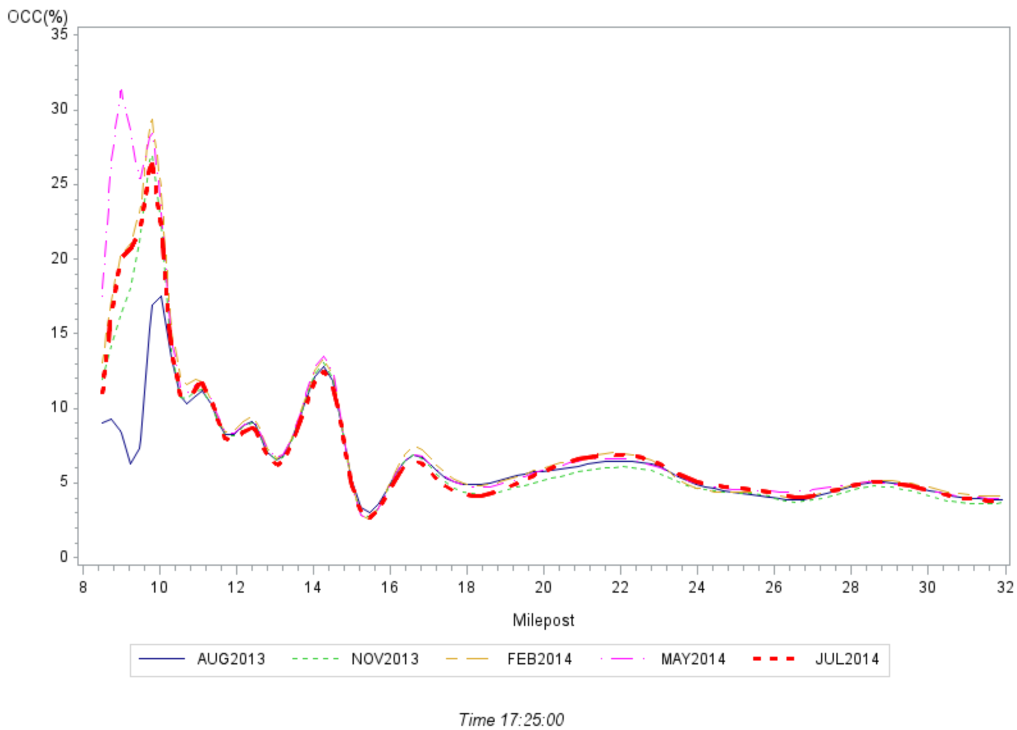


Figure L-4 SR 528 Eastbound Peak Hour Occupancy and Trend of Congestion

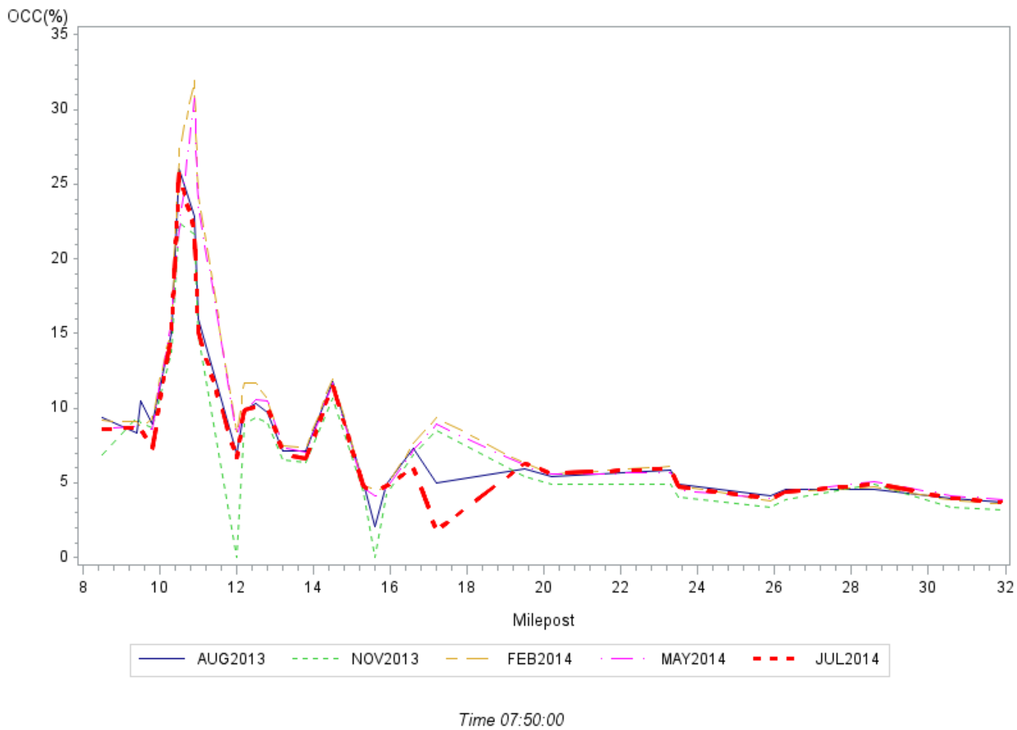


Figure L-5 SR 528 Westbound Peak Hour Occupancy and Trend of Congestion

APPENDIX M. MAINLINE SYSTEM CONGESTION INDEX AND TREND OF CONGESTION

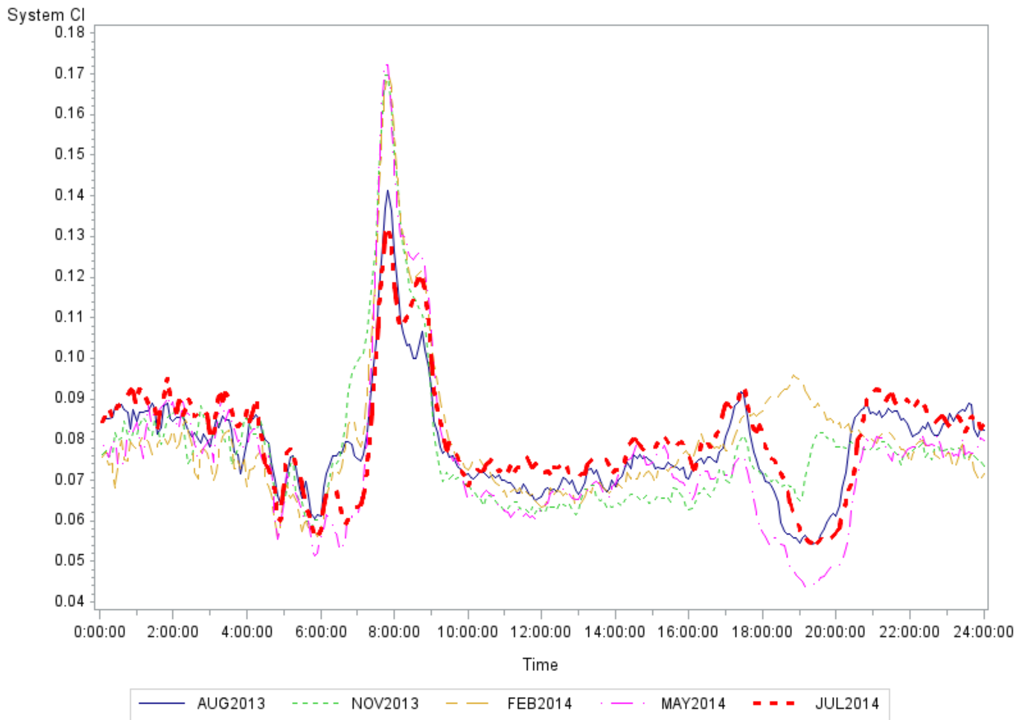


Figure M-1 SR 408 Westbound System Congestion Index and Trend of Congestion

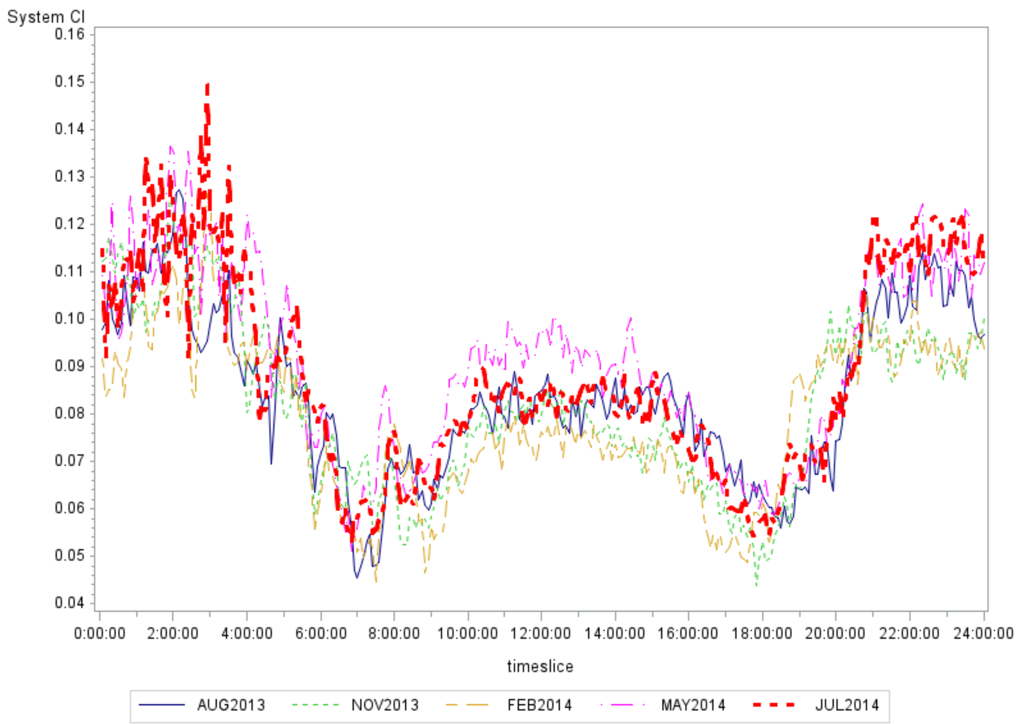


Figure M-2 SR 414 Eastbound System Congestion Index and Trend of Congestion

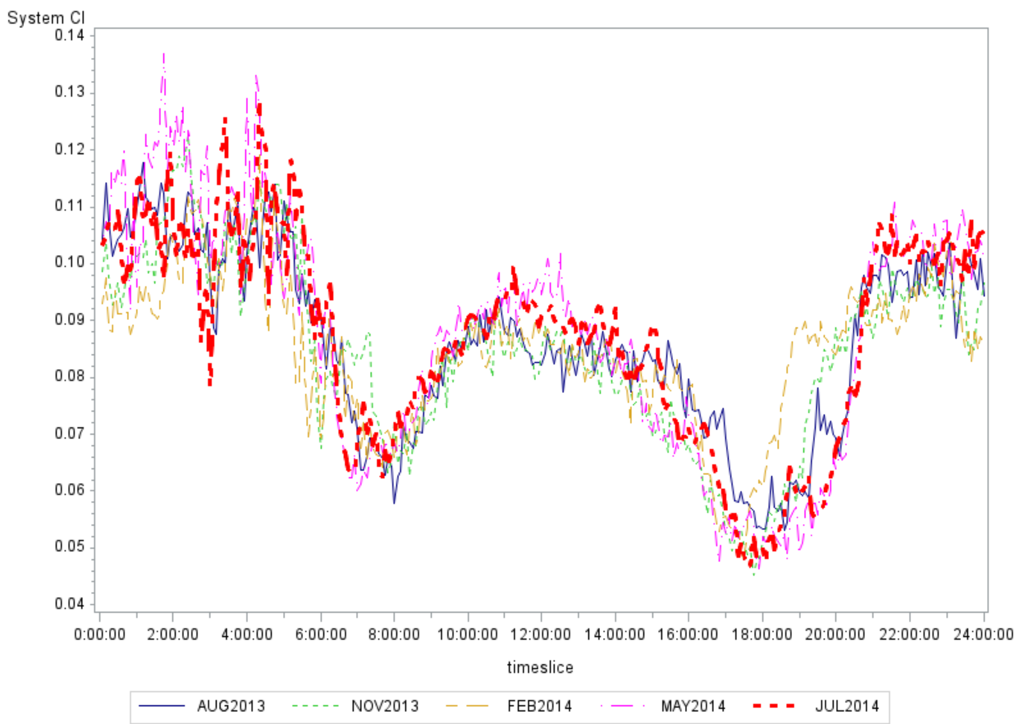


Figure M-3 SR 414 Westbound System Congestion Index and Trend of Congestion

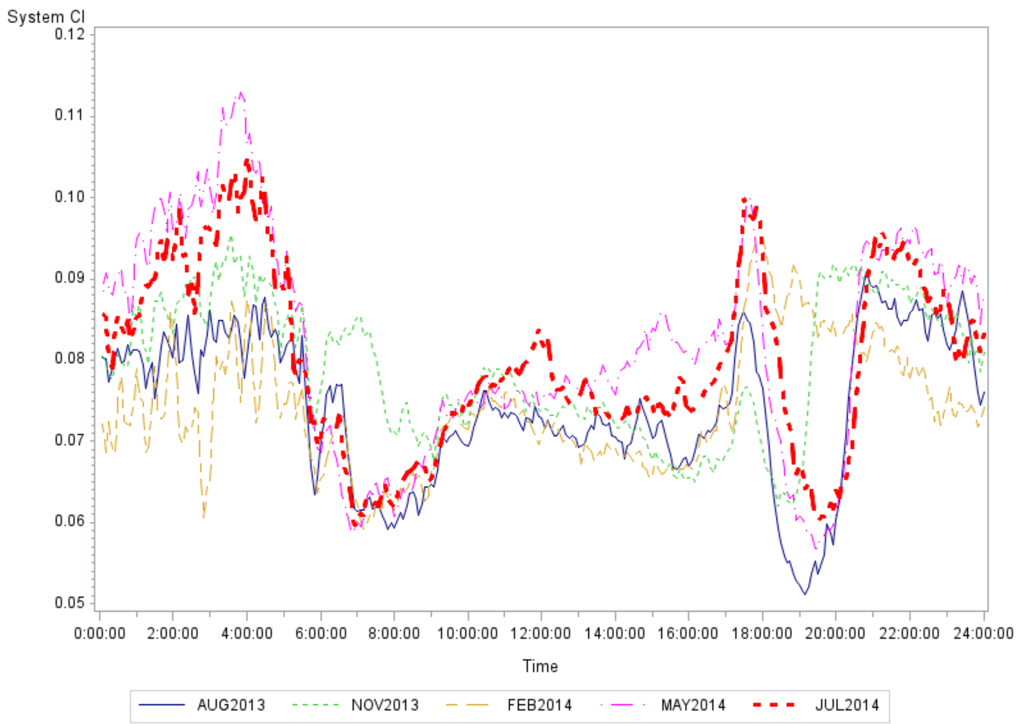


Figure M-4 SR 417 Northbound System Congestion Index and Trend of Congestion

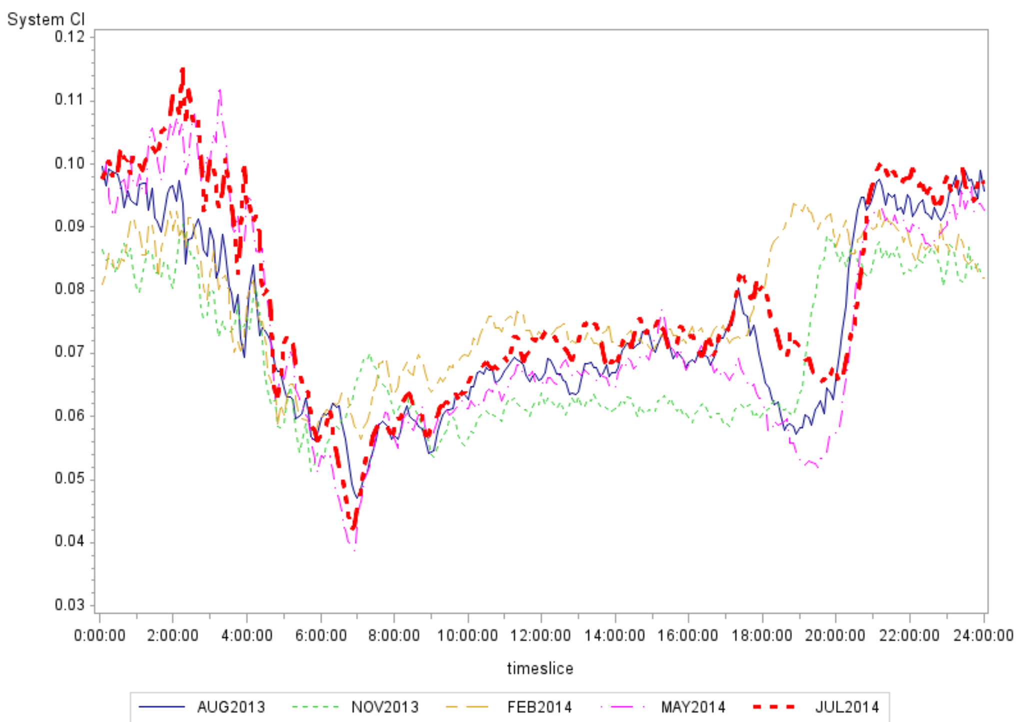


Figure M-5 SR 417 Southbound System Congestion Index and Trend of Congestion

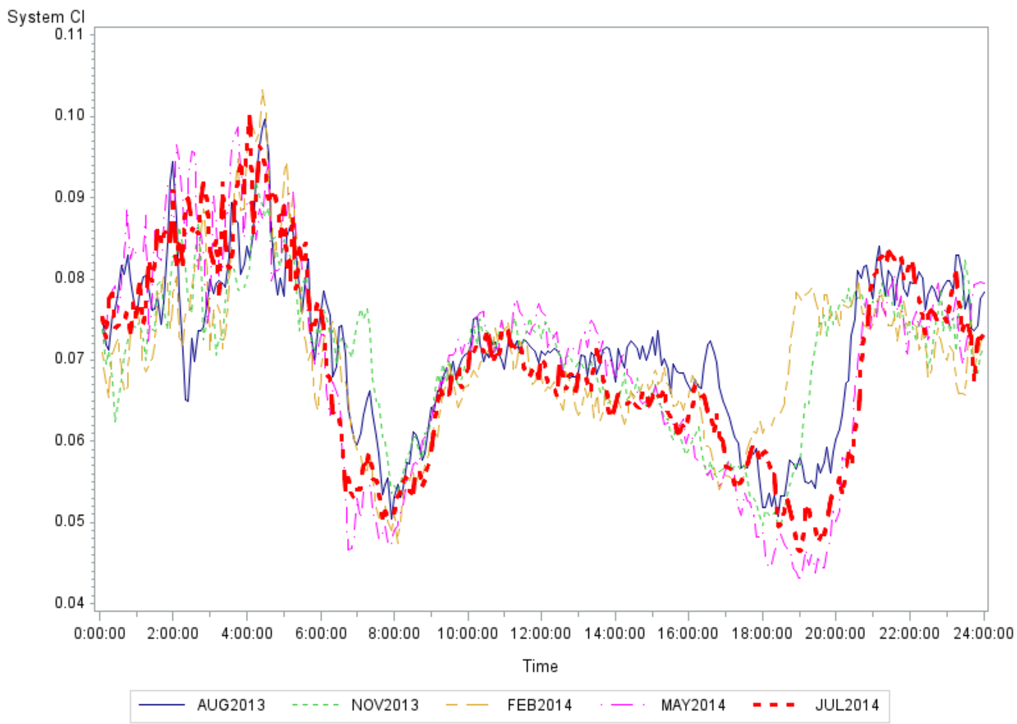


Figure M-6 SR 429 Northbound System Congestion Index and Trend of Congestion

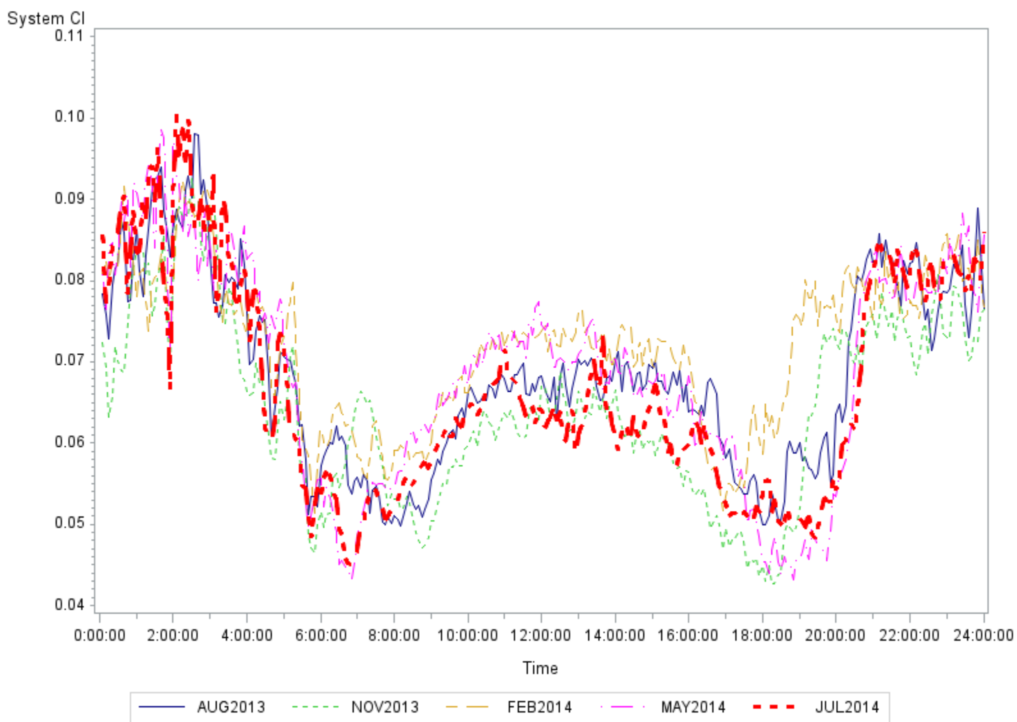


Figure M-7 SR 429 Southbound System Congestion Index and Trend of Congestion

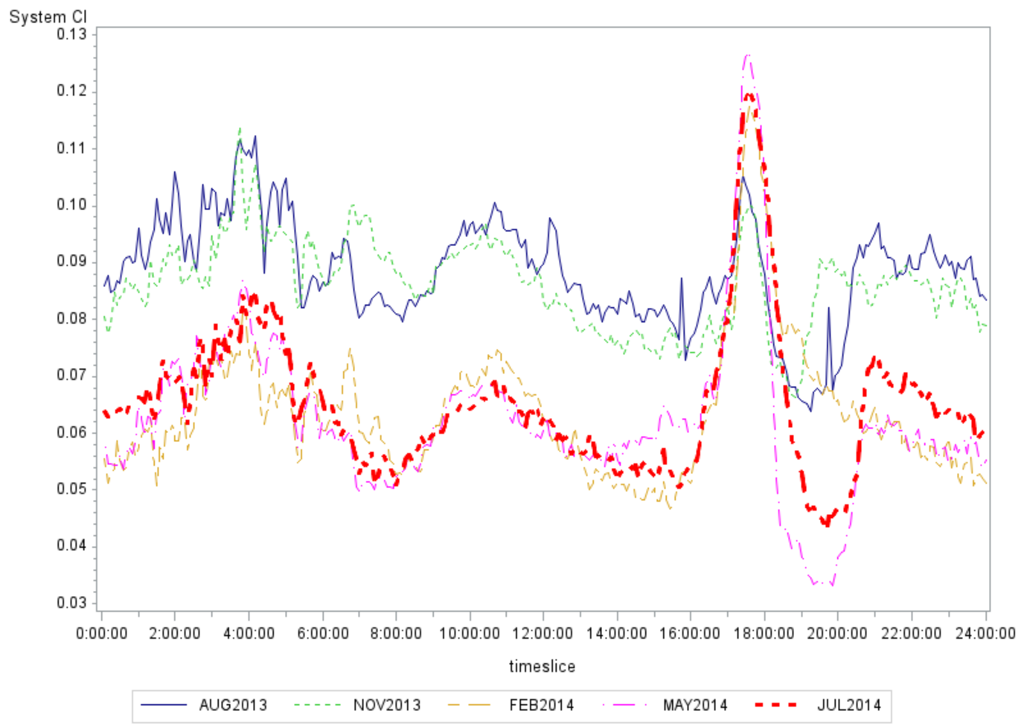


Figure M-8 SR 528 Eastbound System Congestion Index and Trend of Congestion

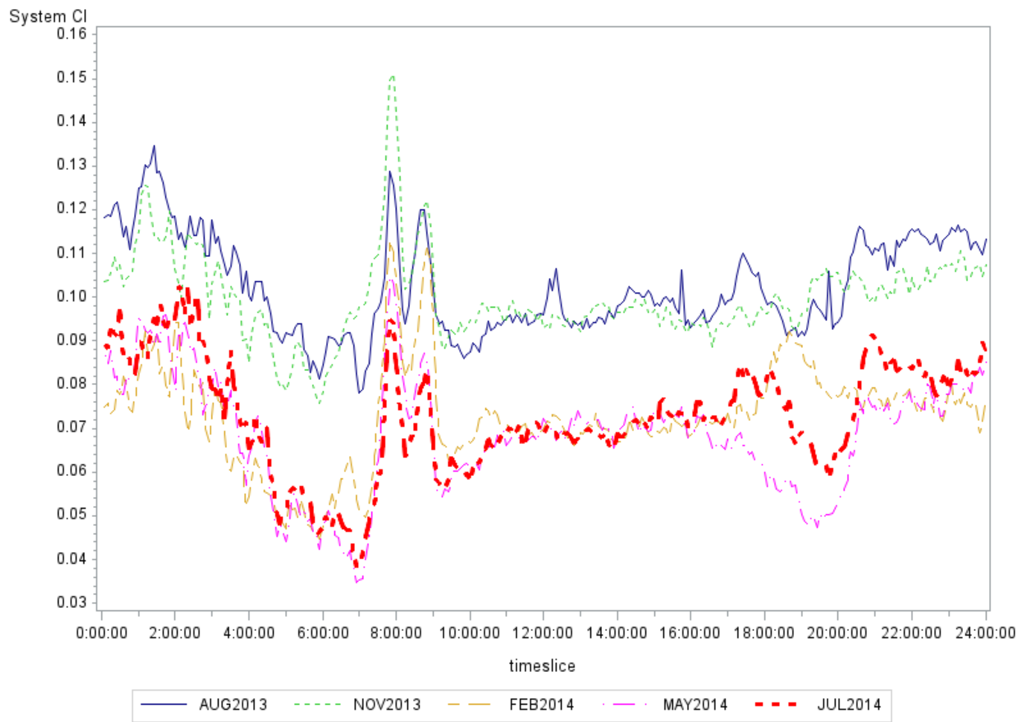


Figure M-9 SR 528 Westbound System Congestion Index and Trend of Congestion

APPENDIX N. PEAK HOUR CONGESTION INDEX PROFILE AND TREND OF CONGESTION

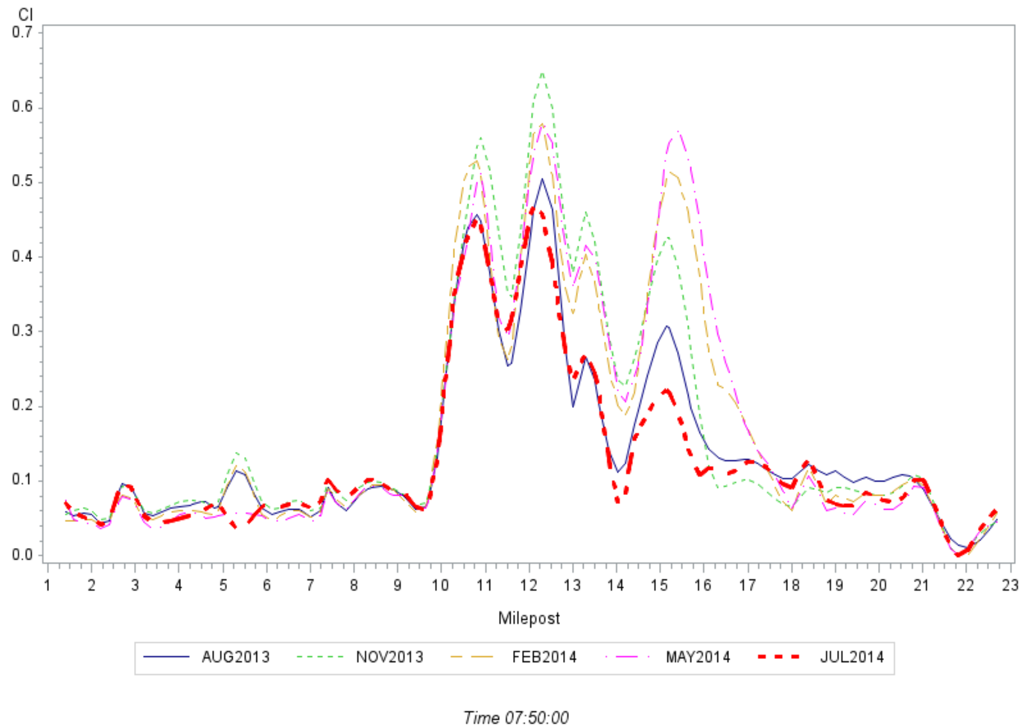


Figure N-1 SR 408 Westbound Peak Hour Congestion Index and Trend of Congestion

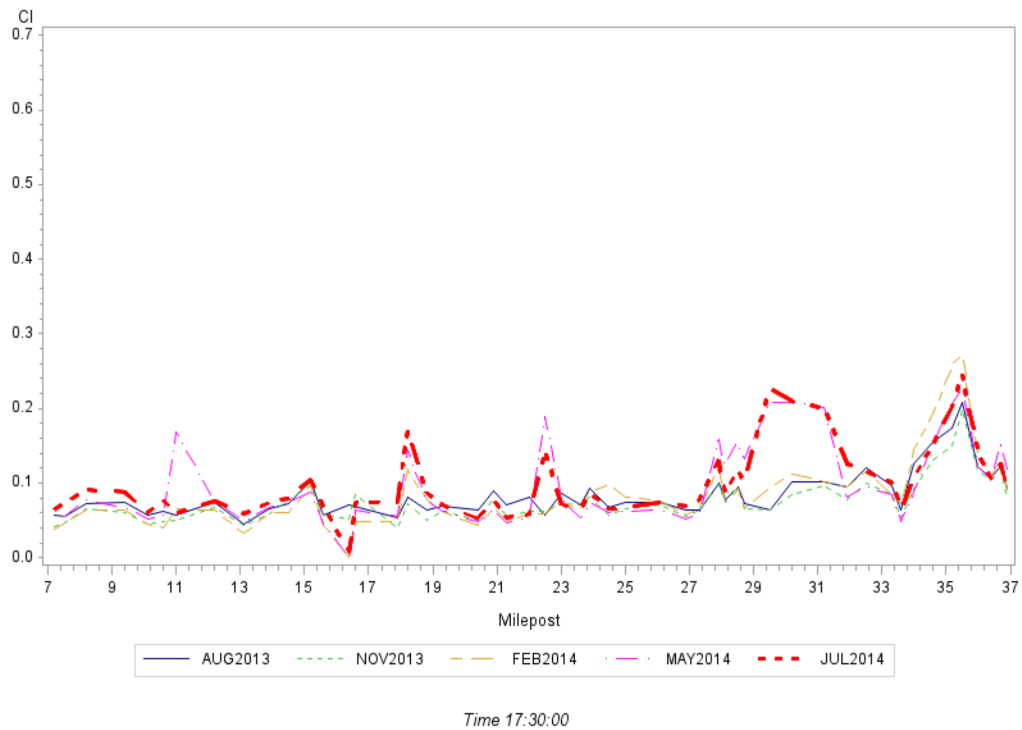


Figure N-2 SR 417 Northbound Peak Hour Congestion Index and Trend of Congestion

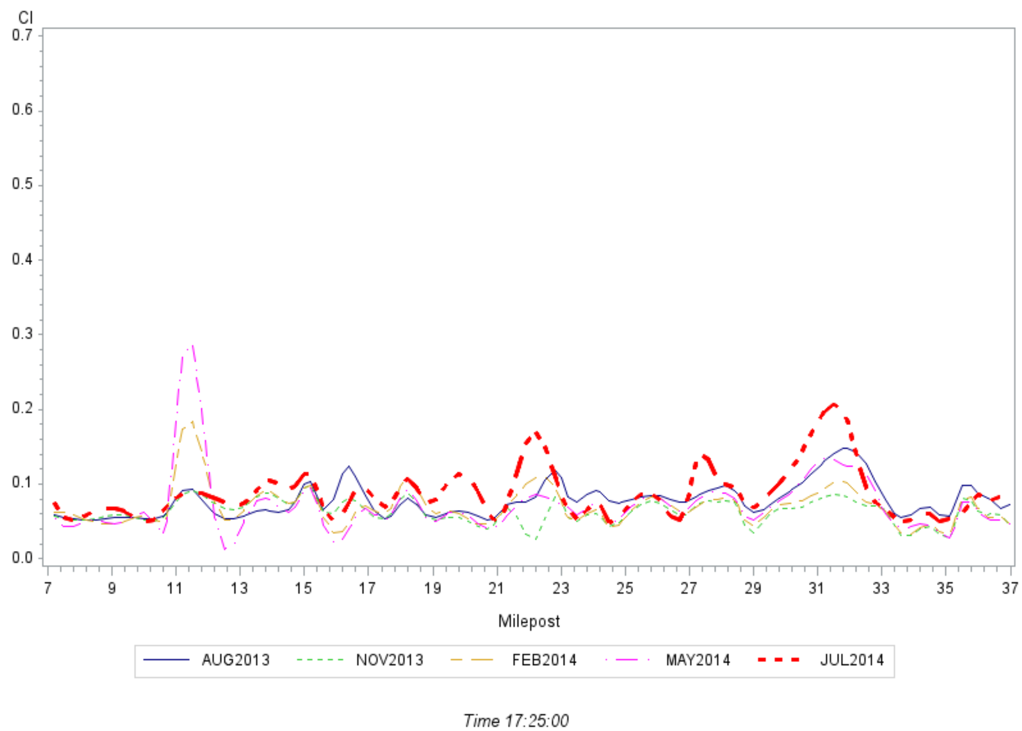


Figure N-3 SR 417 Southbound Peak Hour Congestion Index and Trend of Congestion

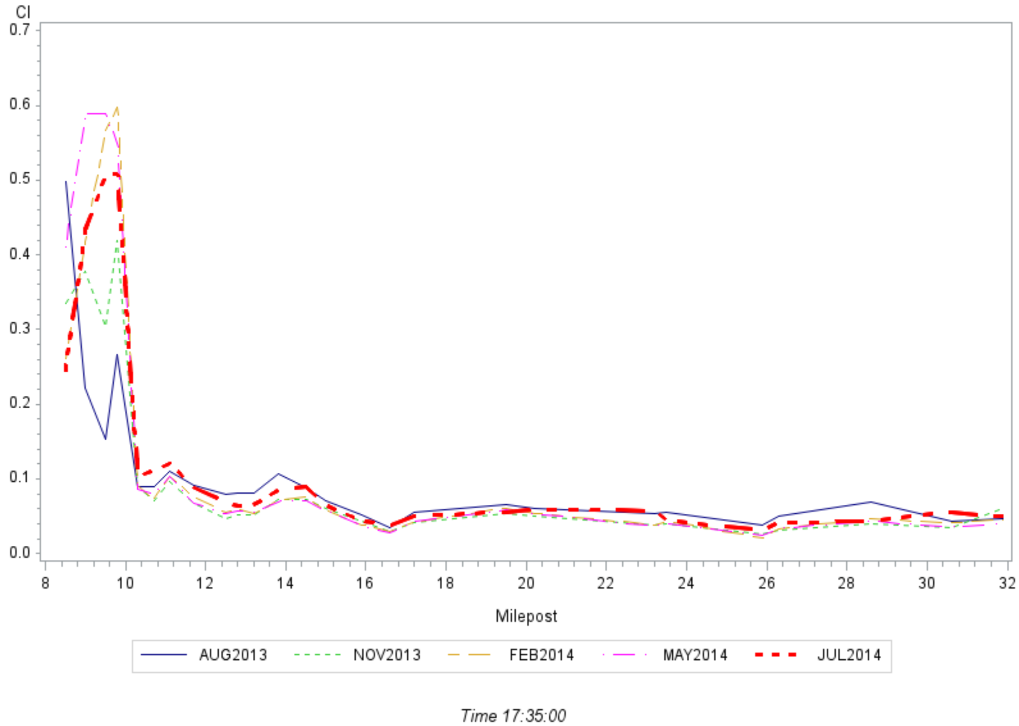


Figure N-4 SR 528 EB Peak Hour Congestion Index and Trend of Congestion

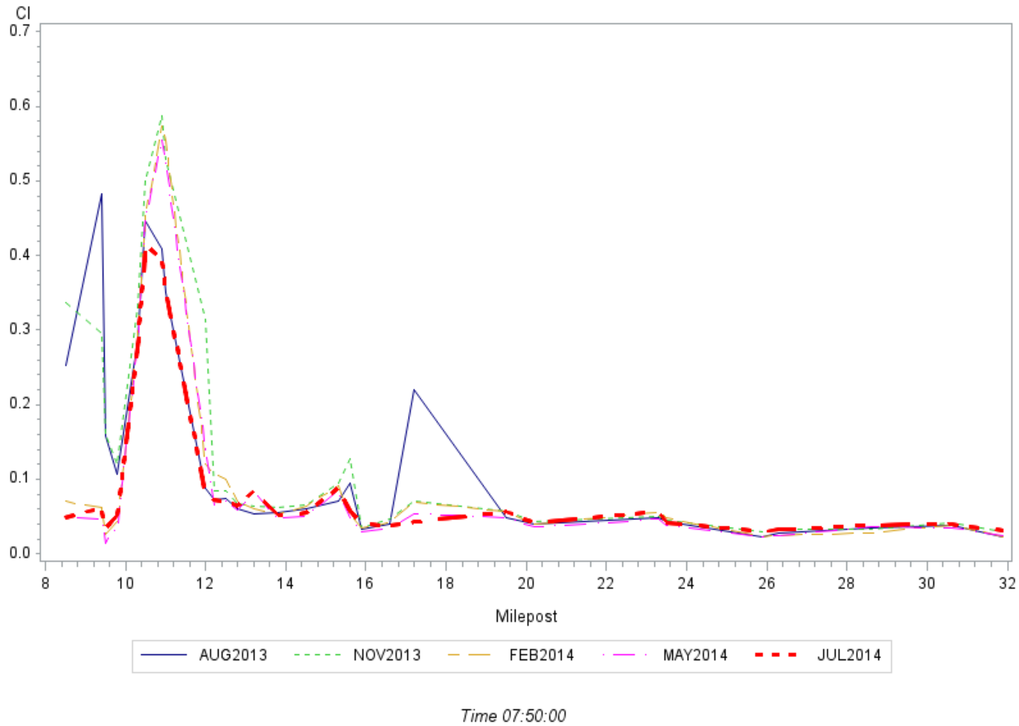


Figure N-5 SR 528 WB Peak Hour Congestion Index and Trend of Congestion

APPENDIX O. RAMP OCCUPANCY PROFILE

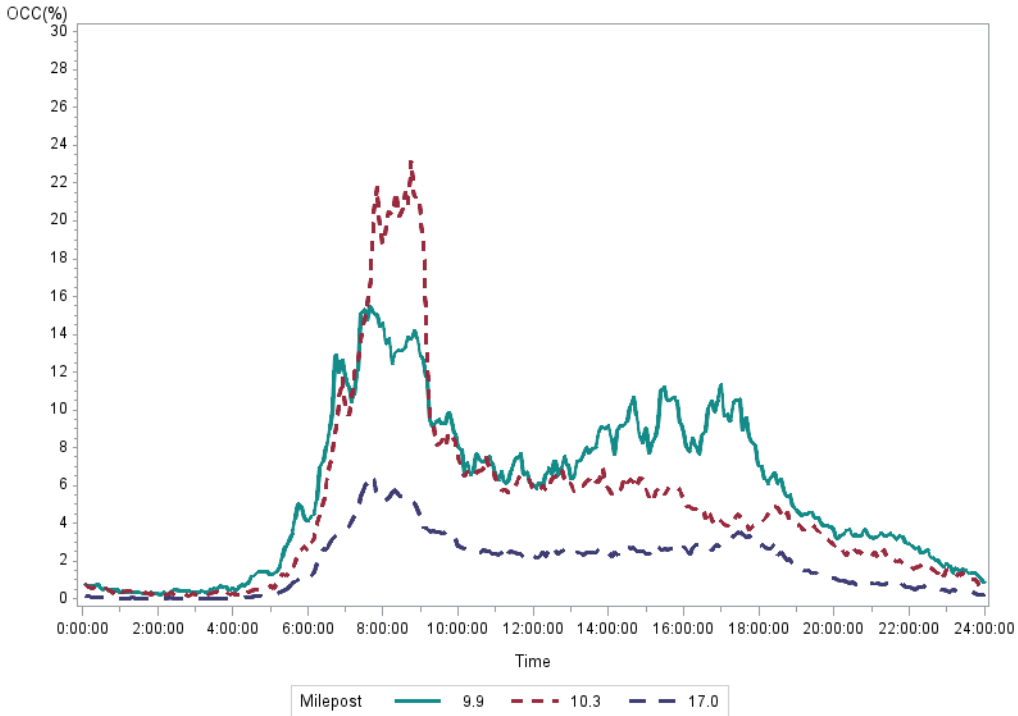


Figure O-1 SR 408 WB Ramp Occupancy Profile

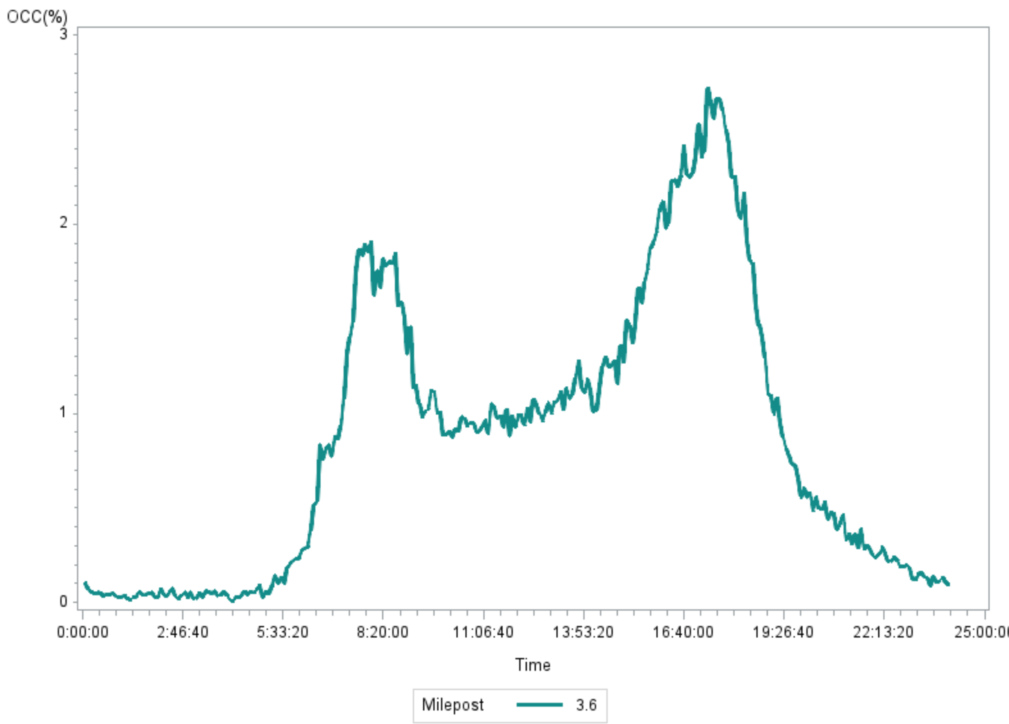


Figure O-2 SR 414 EB Ramp Occupancy Profile

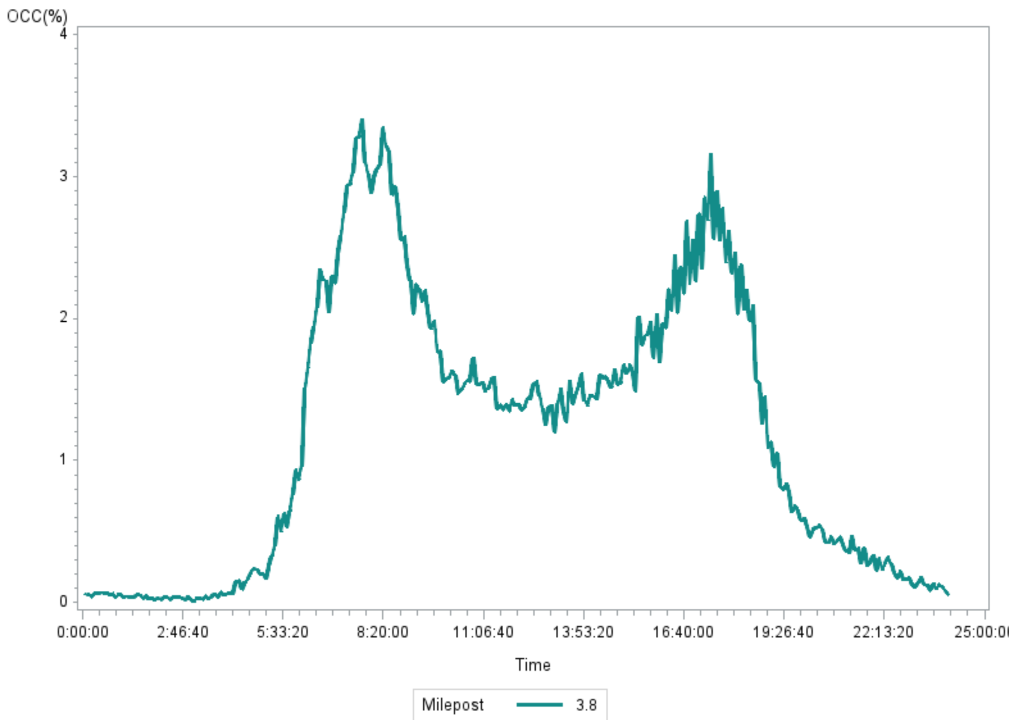


Figure O-3 SR 414 WB Ramp Occupancy Profile

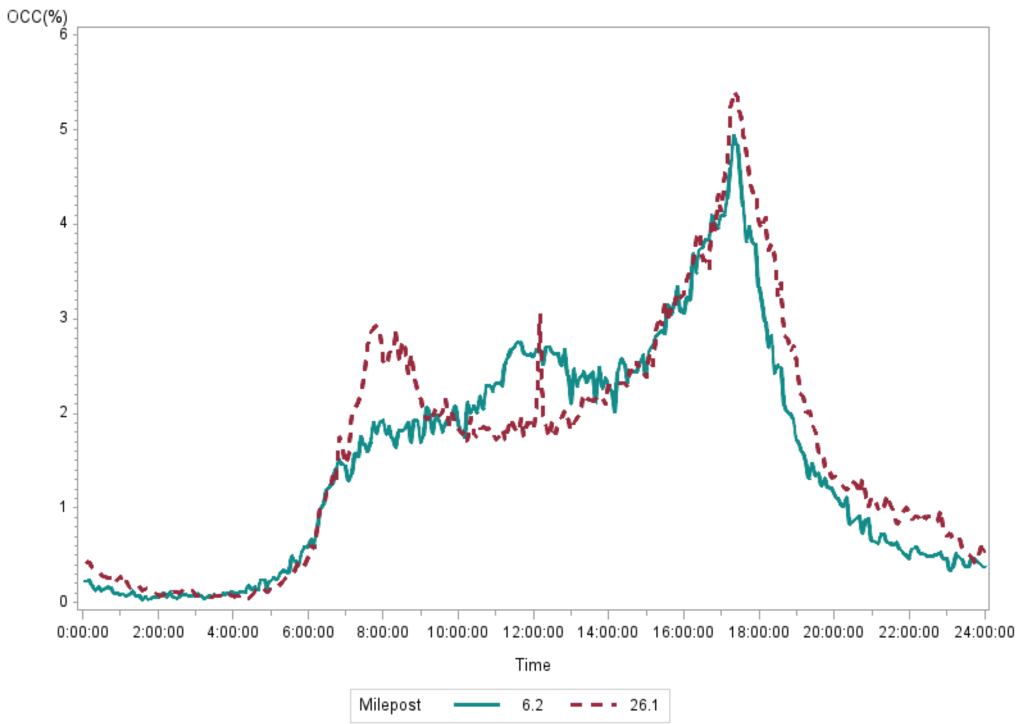


Figure O-4 SR 417 NB Ramp Occupancy Profile

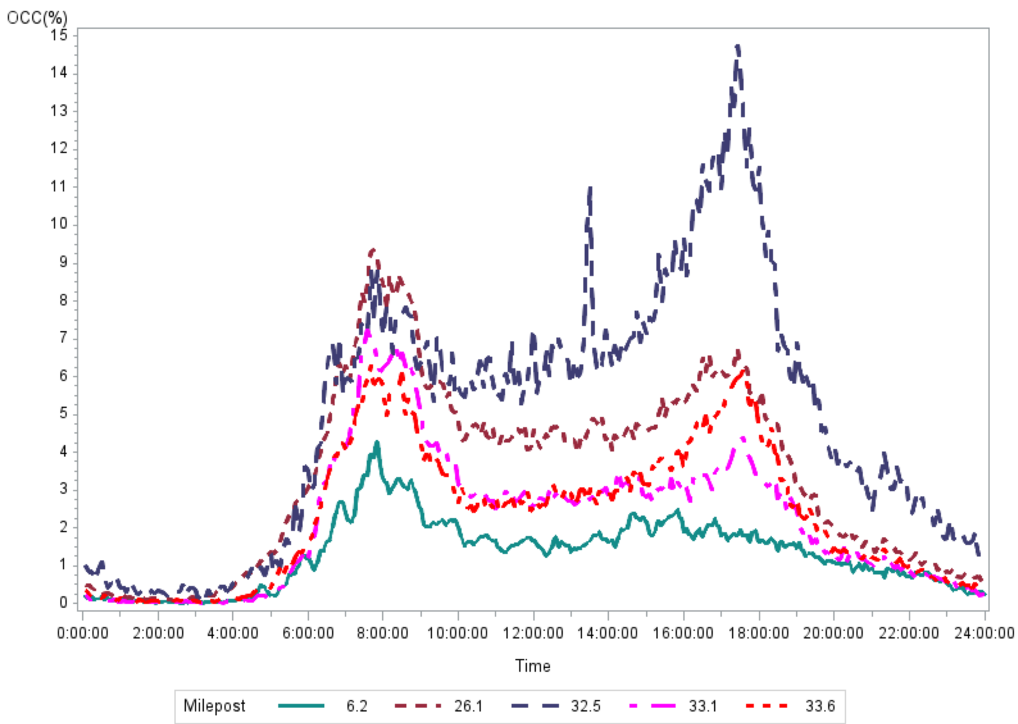


Figure O-5 SR417 SB Ramp Occupancy Profile

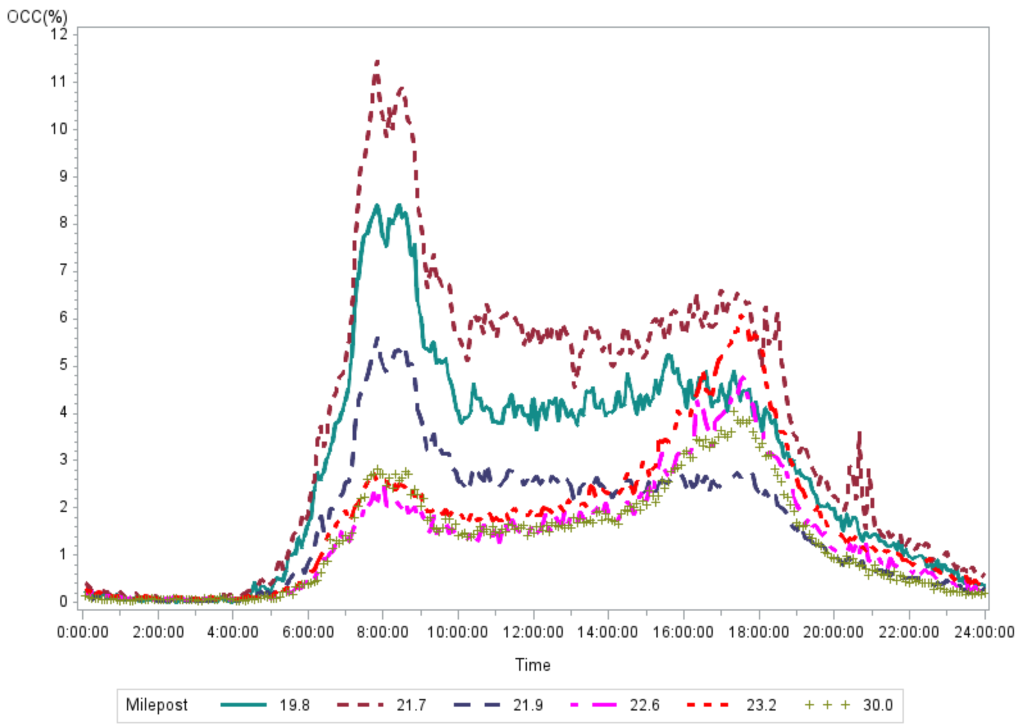


Figure O-6 SR 429 NB Ramp Occupancy Profile

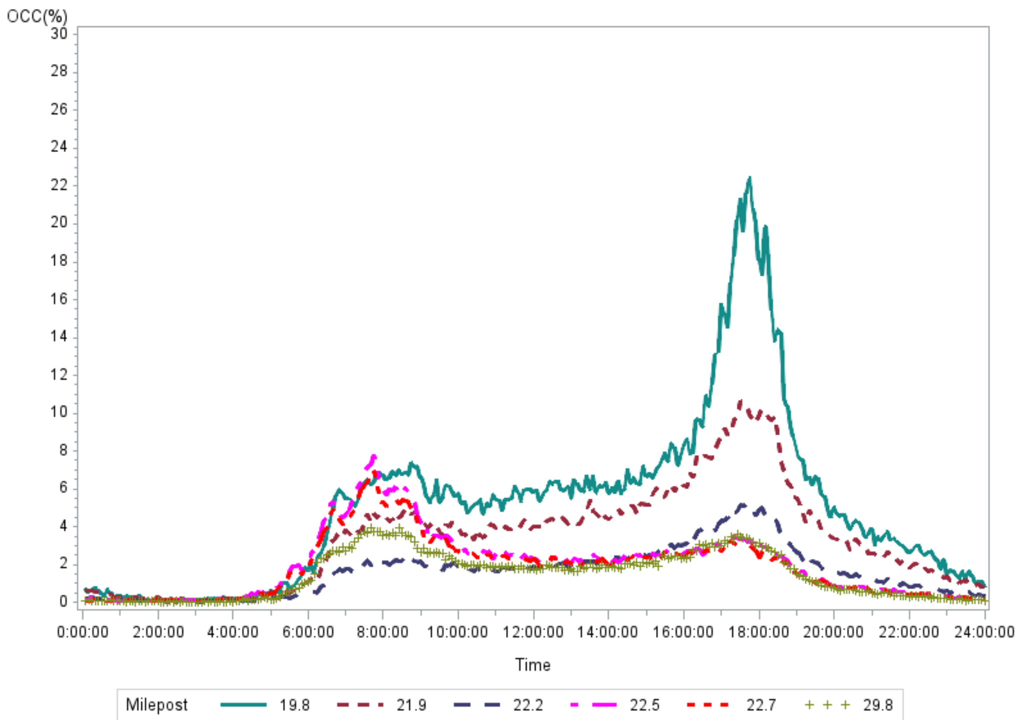


Figure O-7 SR 429 SB Ramp Occupancy Profile

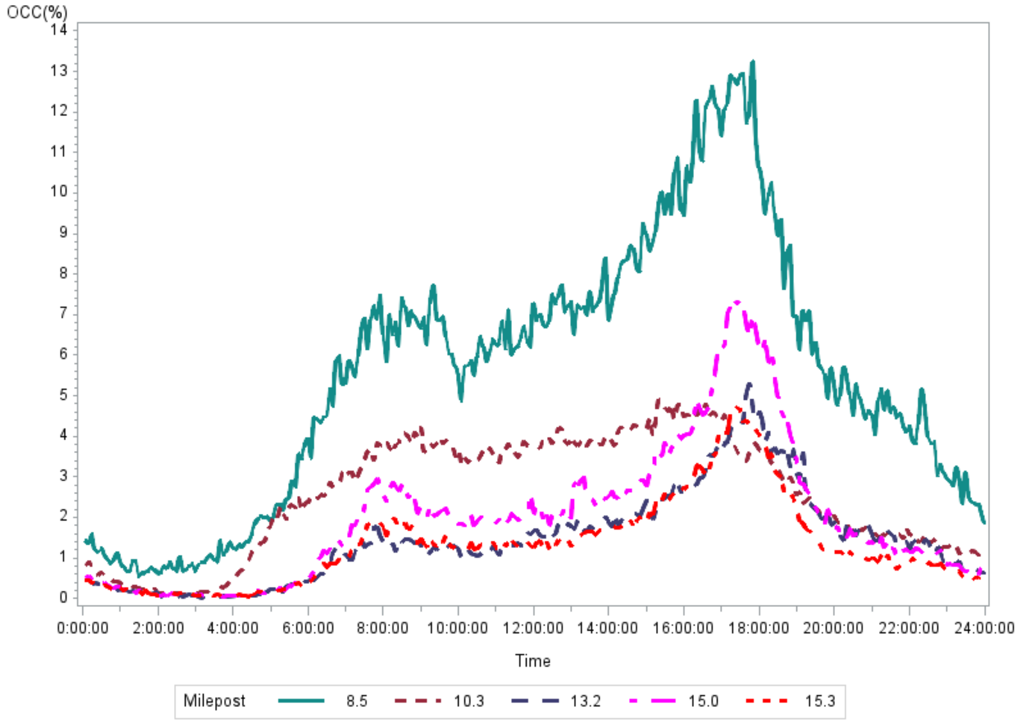


Figure O-8 SR 528 EB Ramp Occupancy Profile

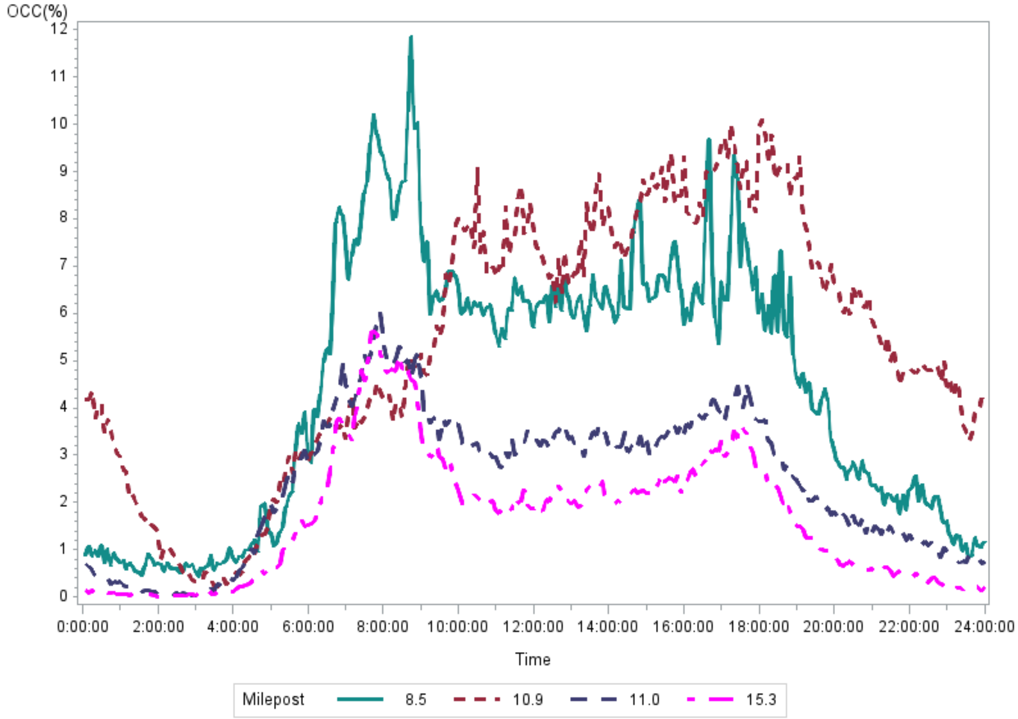


Figure O-9 SR 528 WB Ramp Occupancy Profile

APPENDIX P. RAMP CONGESTION INDEX PROFILE

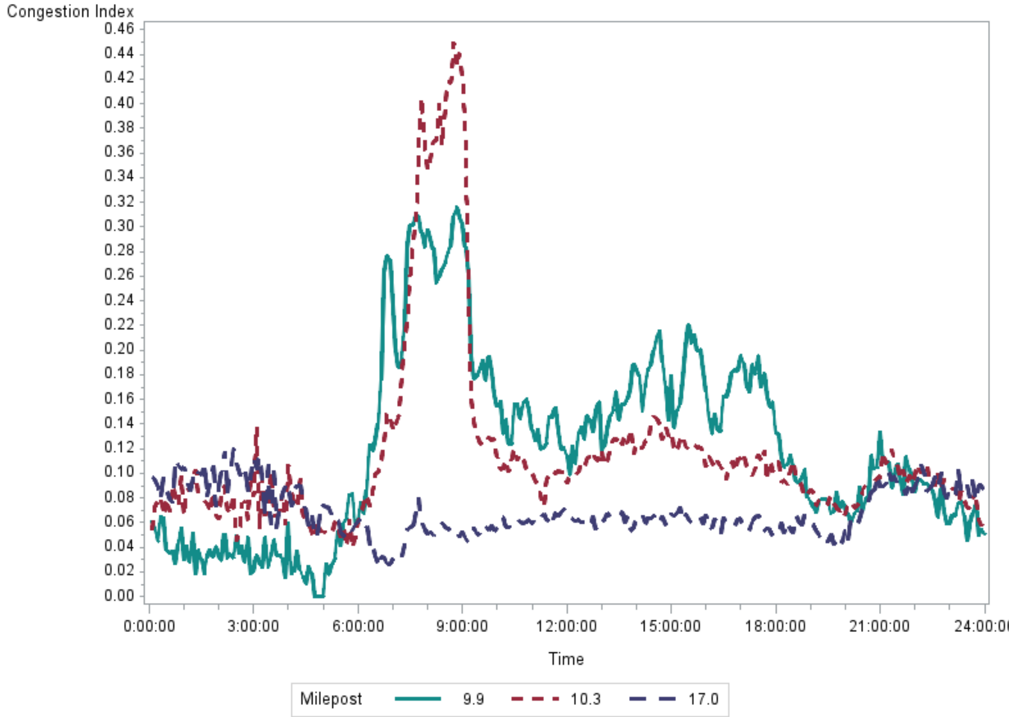


Figure P-1 SR 408 Westbound Ramp Congestion Index Profile

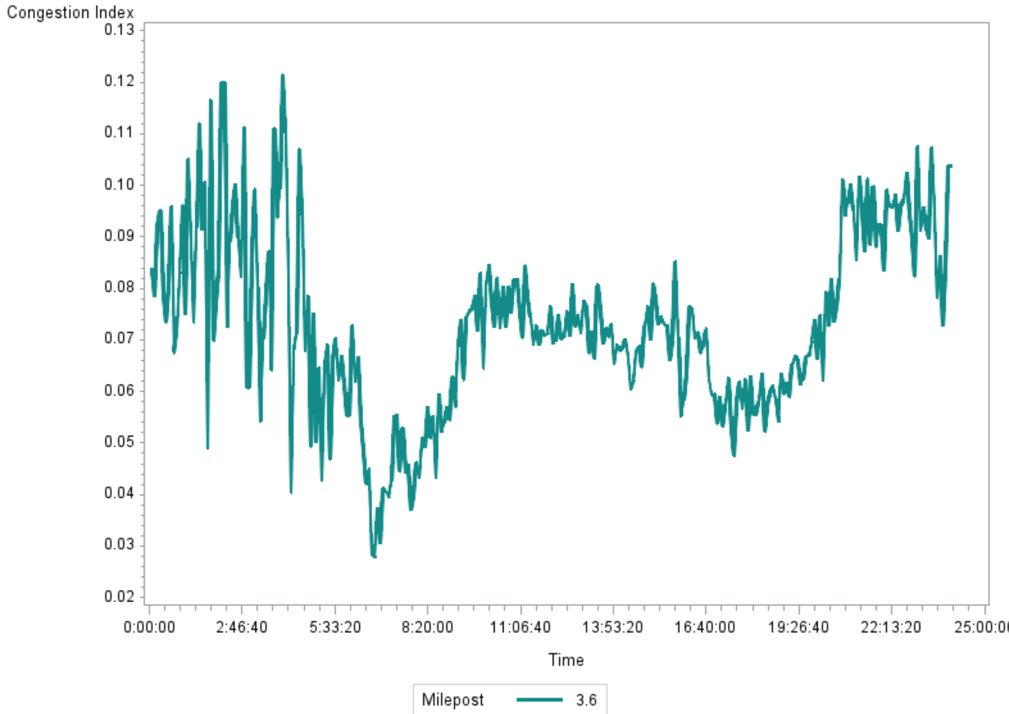


Figure P-2 SR 414 Eastbound Ramp Congestion Index Profile

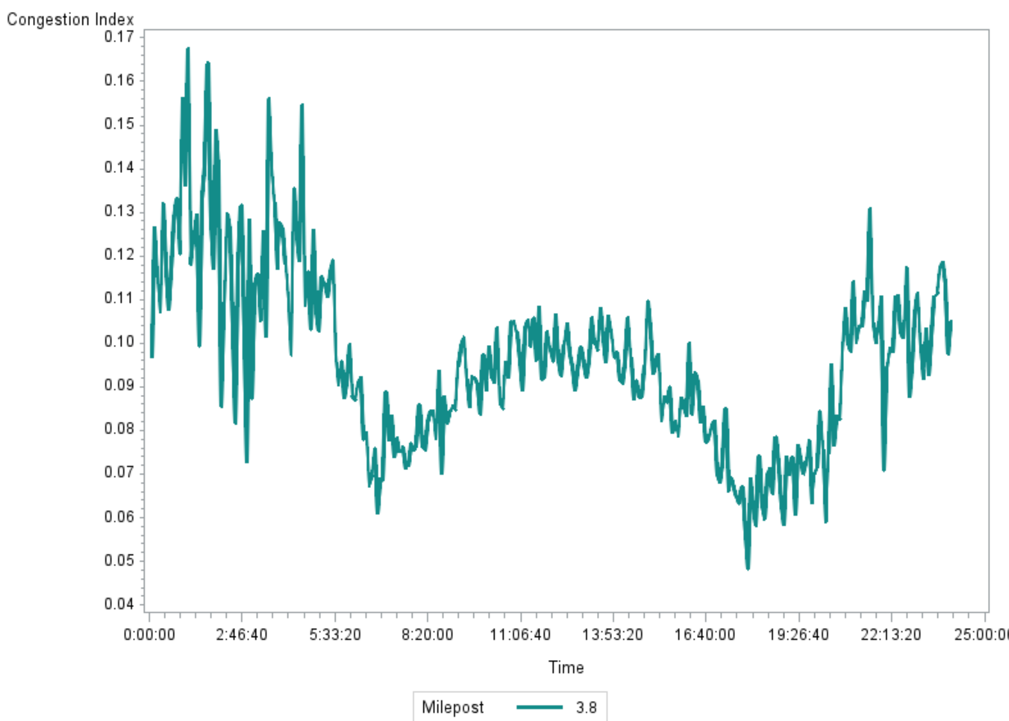


Figure P-3 SR 414 Westbound Ramp Congestion Index Profile

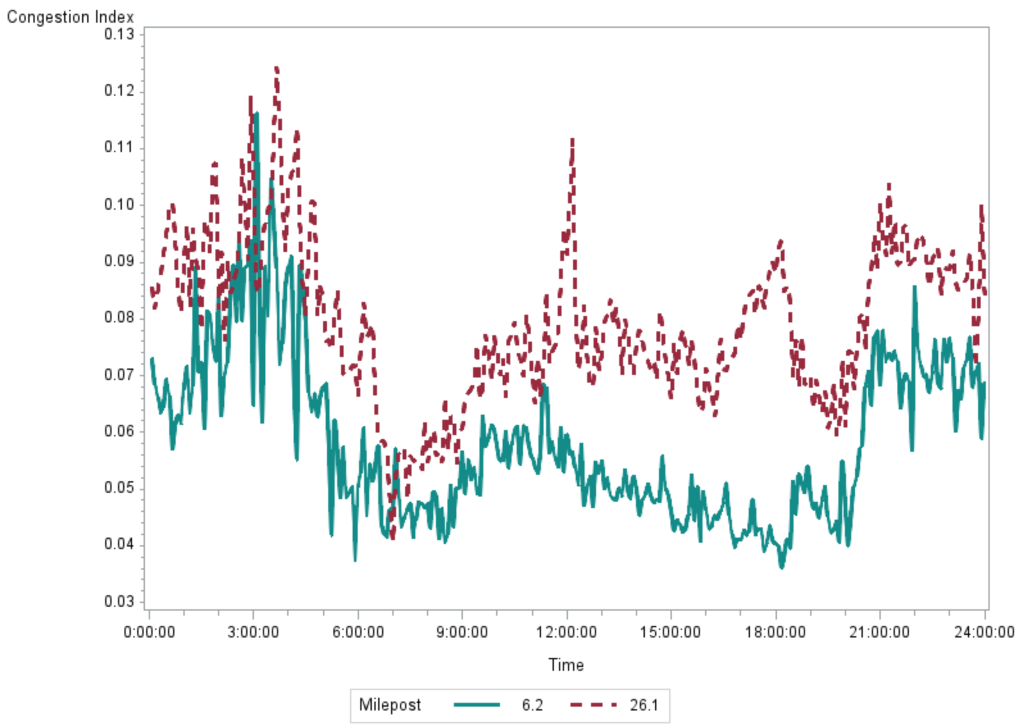


Figure P-4 SR 417 Northbound Ramp Congestion Index Profile

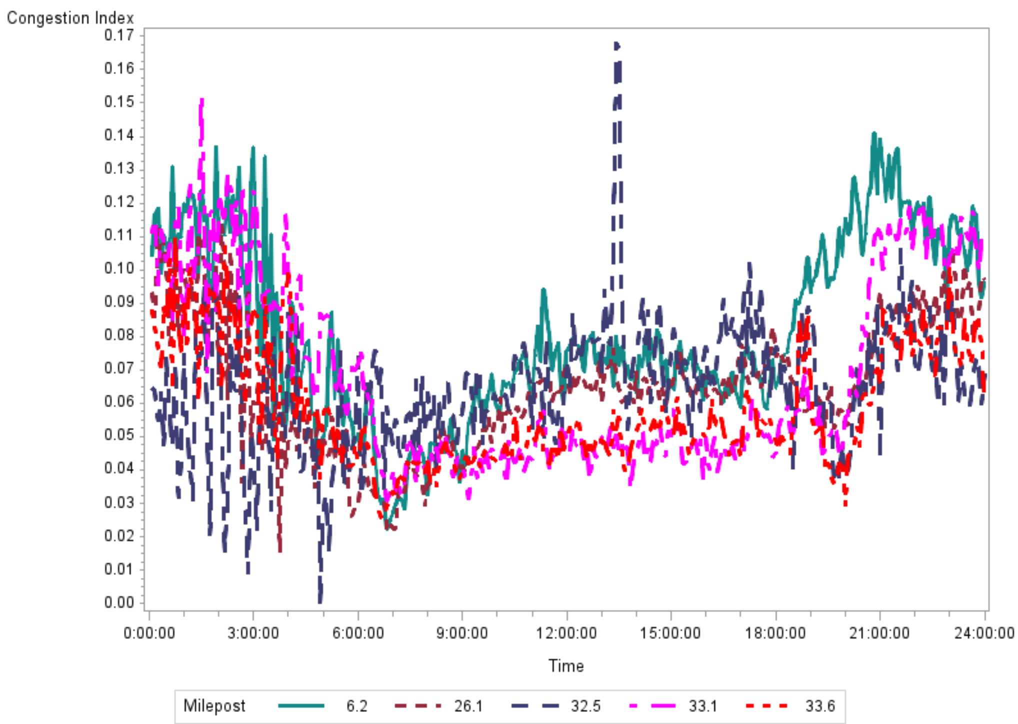


Figure P-5 SR 417 Southbound Ramp Congestion Index Profile

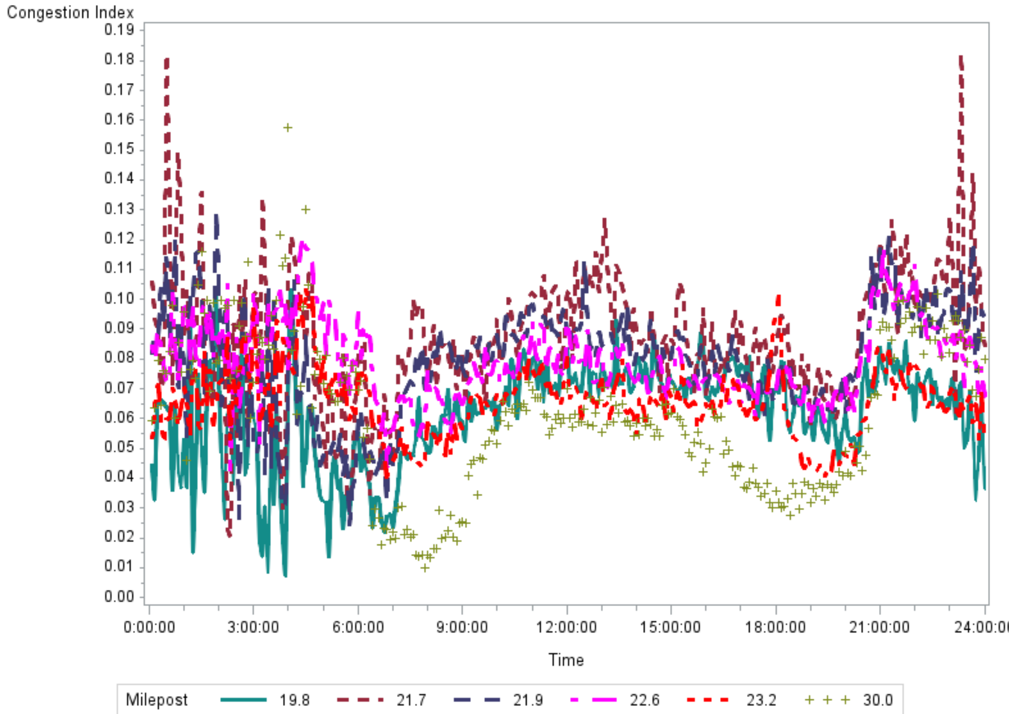


Figure P-6 SR 429 Northbound Ramp Congestion Index Profile

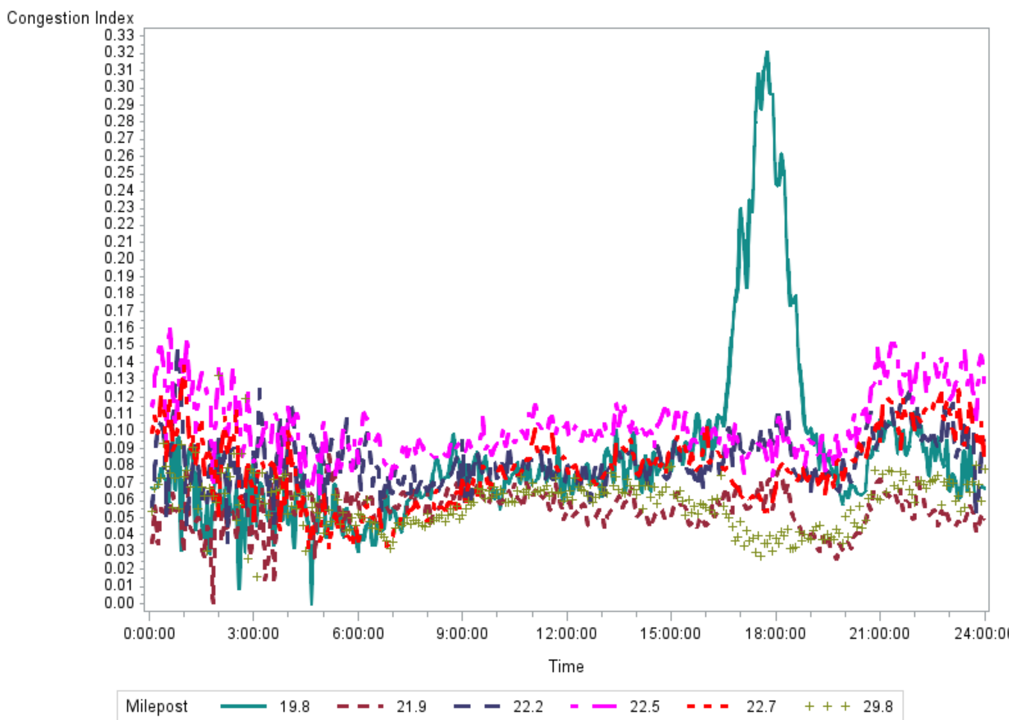


Figure P-7 SR 429 Southbound Ramp Congestion Index Profile

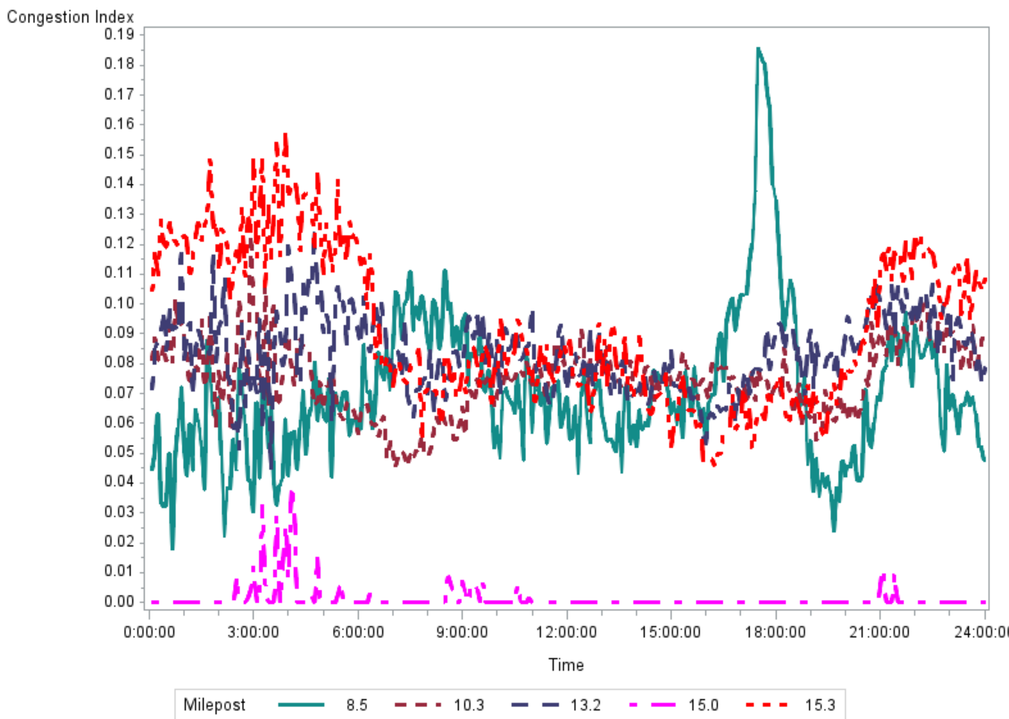


Figure P-8 SR 528 Eastbound Ramp Congestion Index Profile

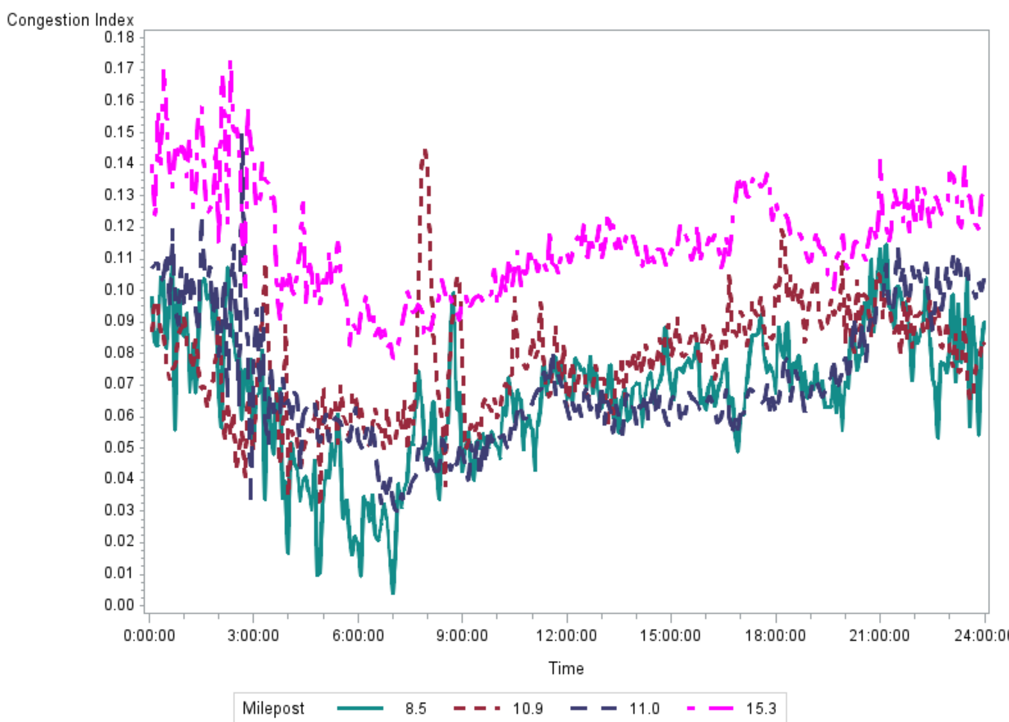


Figure P-9 SR 528 Westbound Ramp Congestion Index Profile

APPENDIX Q. EXPRESSWAY CONGESTION AREA IDENTIFICATION AND DMS SUGGESTION

Table Q-1 SR 414 Eastbound Congestion Area

Hour	7		8
Minute	50	55	0
Congested Location	9.3	9.3	9.3

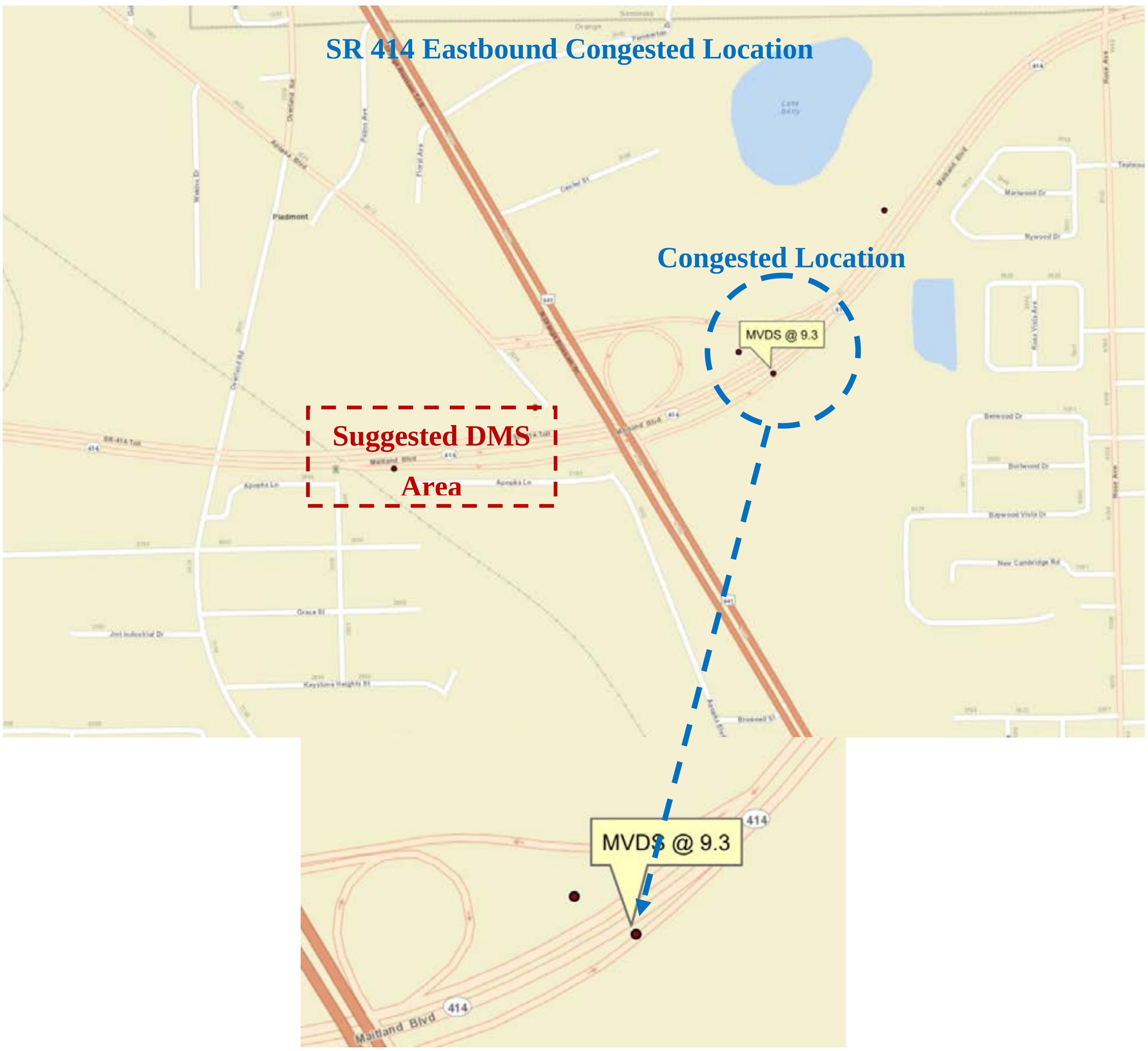


Figure Q-1 SR 414 Eastbound Congested Location and Suggested DMS Area

Table Q-2 SR 417 Northbound Congestion Area

Hour	17							
Minute	20	25	30	35	40	45	50	55
Beginning of Queue	35.2	35.2	35.2	35.2	35.2	35.2	35.2	35.2
End of Queue	35.5	35.5	35.5	35.5	35.5	35.5	35.5	35.5
Congested Location	37.7	37.7	37.7	37.7	37.7	37.7	37.7	37.7

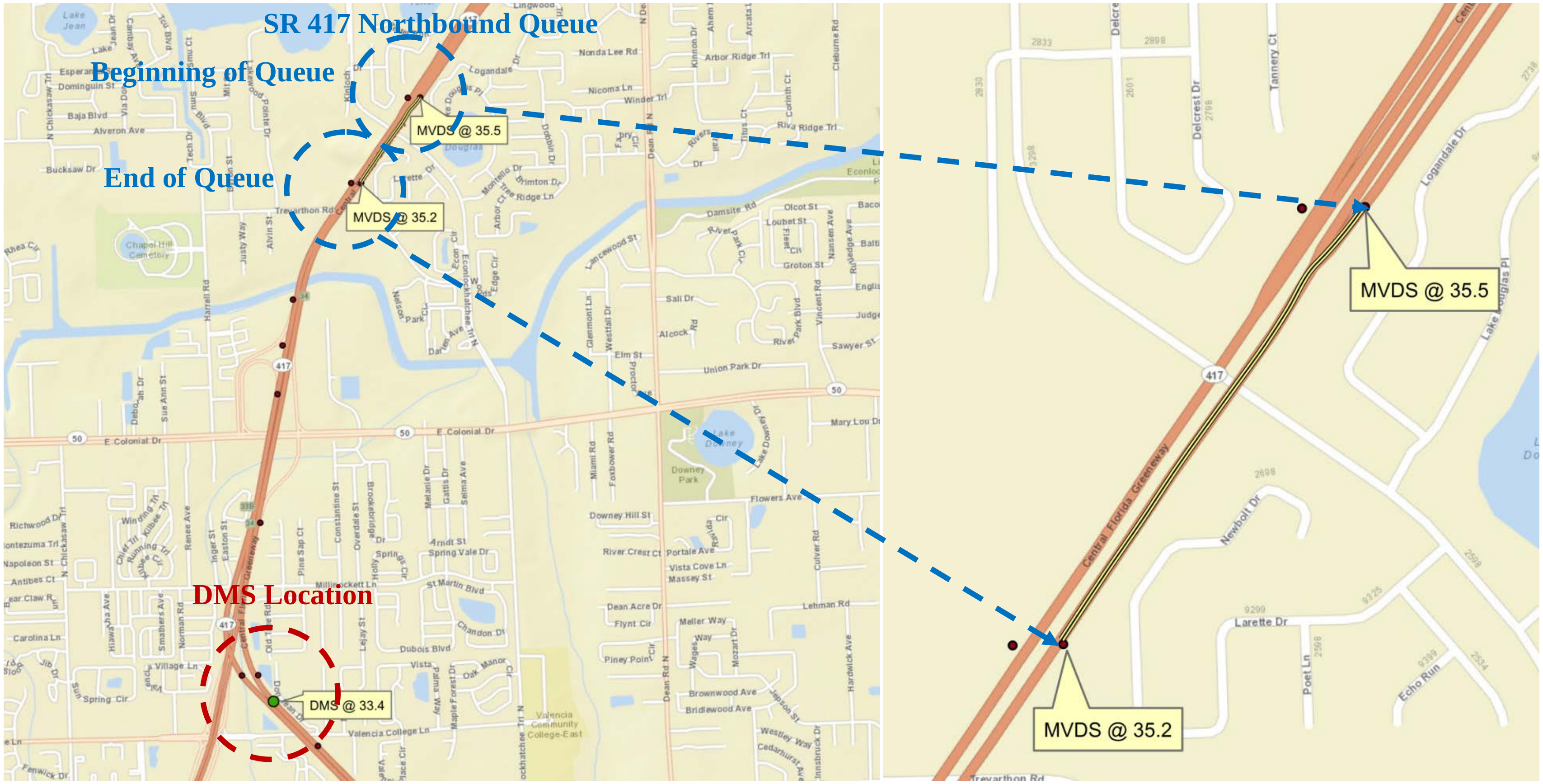


Figure Q-2 SR 417 Northbound Congested Segment and DMS Location

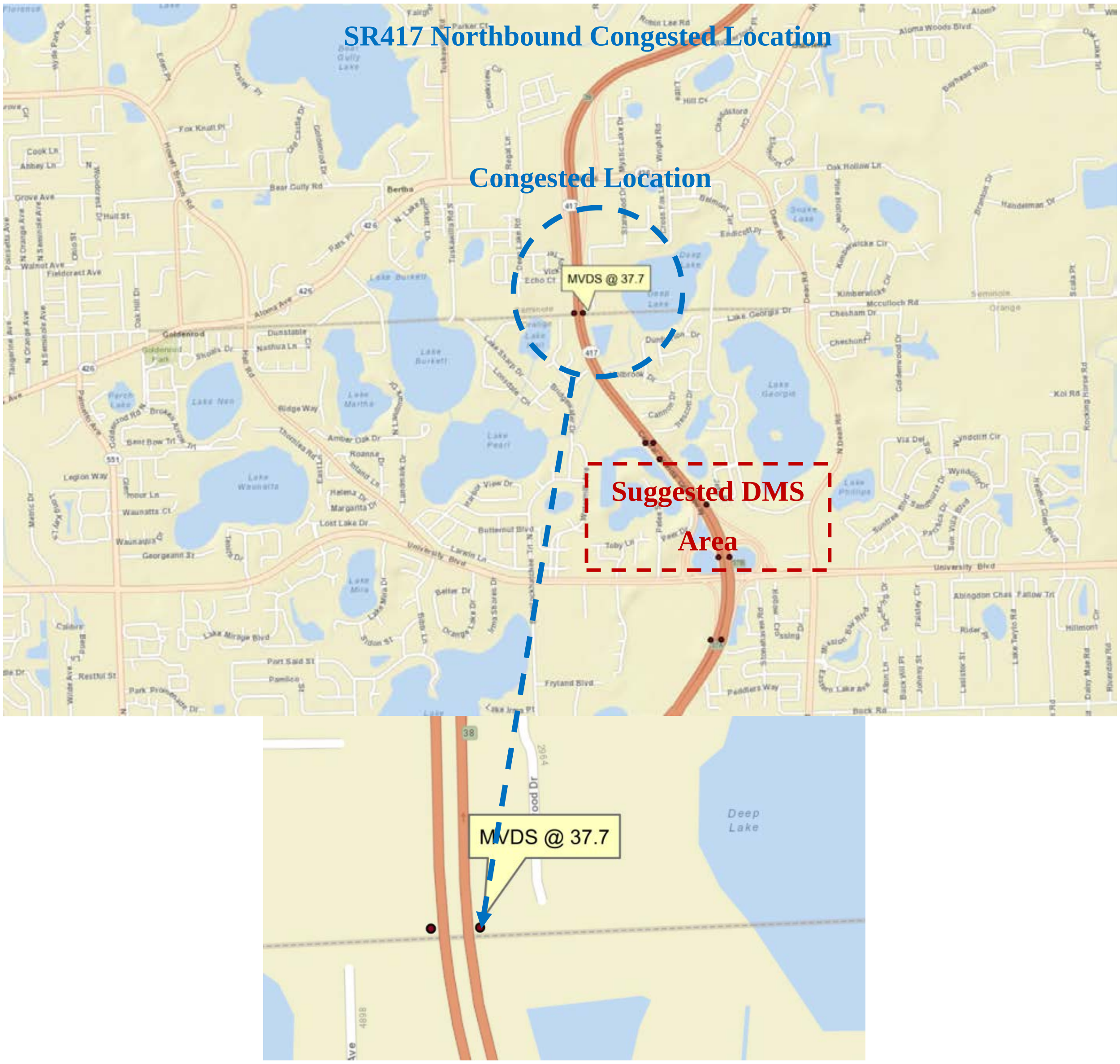


Figure Q-3 SR 417 Northbound Congested Location and Suggested DMS Area

Table Q-3 SR 417 Southbound Congestion Area

Hour	17							
Minute	20	25	30	35	40	45	50	55
Congested Location	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9

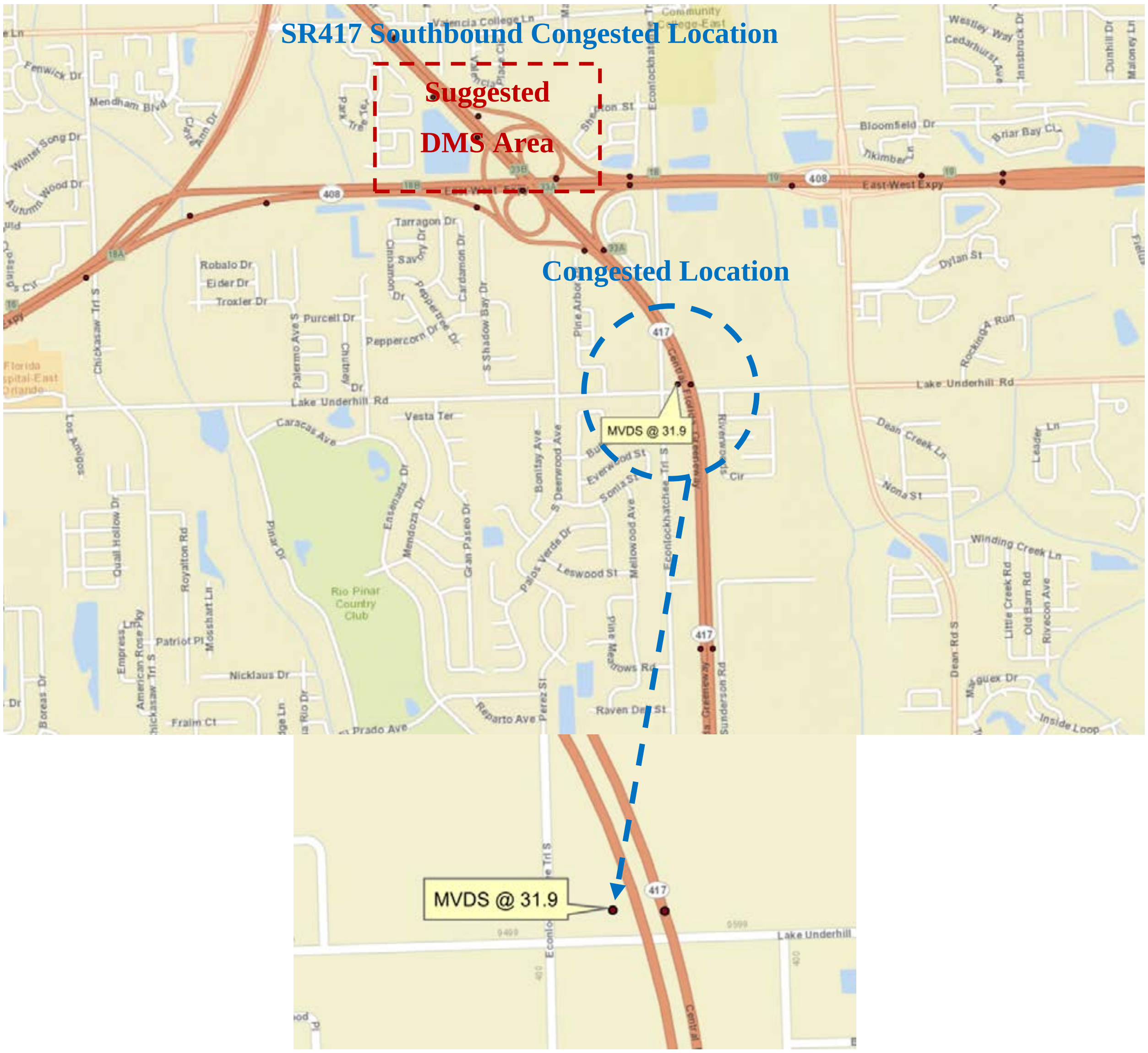


Figure Q-4 SR 417 Southbound Congested Location and Suggested DMS Area

Table Q-4 SR 528 Eastbound Congestion Area

Hour	17										18		
Minute	10	15	20	25	30	35	40	45	50	55	0	5	10
Beginning of Queue	9.5	9.5	9	9	9	9	9	9	9	9	9.5	9.5	9.5
End of Queue	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8

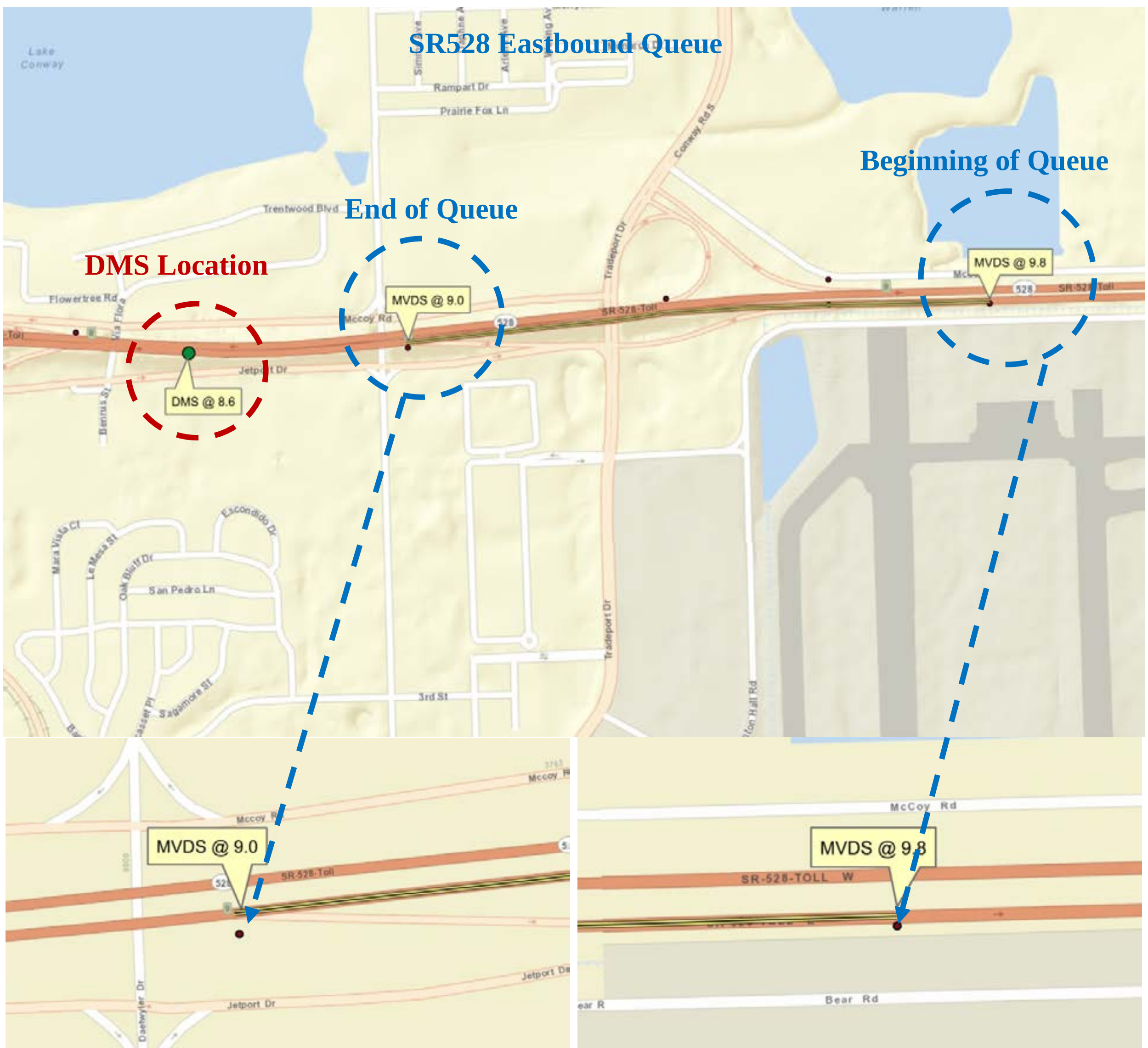


Figure Q-5 **SR 528 Eastbound Congested Segment and DMS Location**

Table Q-5 SR 528 Westbound Congestion Area

Hour	7			8			
Minute	45	50	55	0	5	45	50
Beginning of Queue	10.9	11	11	10.9	10.9	10.9	10.9
End of Queue	10.5	10.3	10.5	10.5	10.5	10.5	10.5

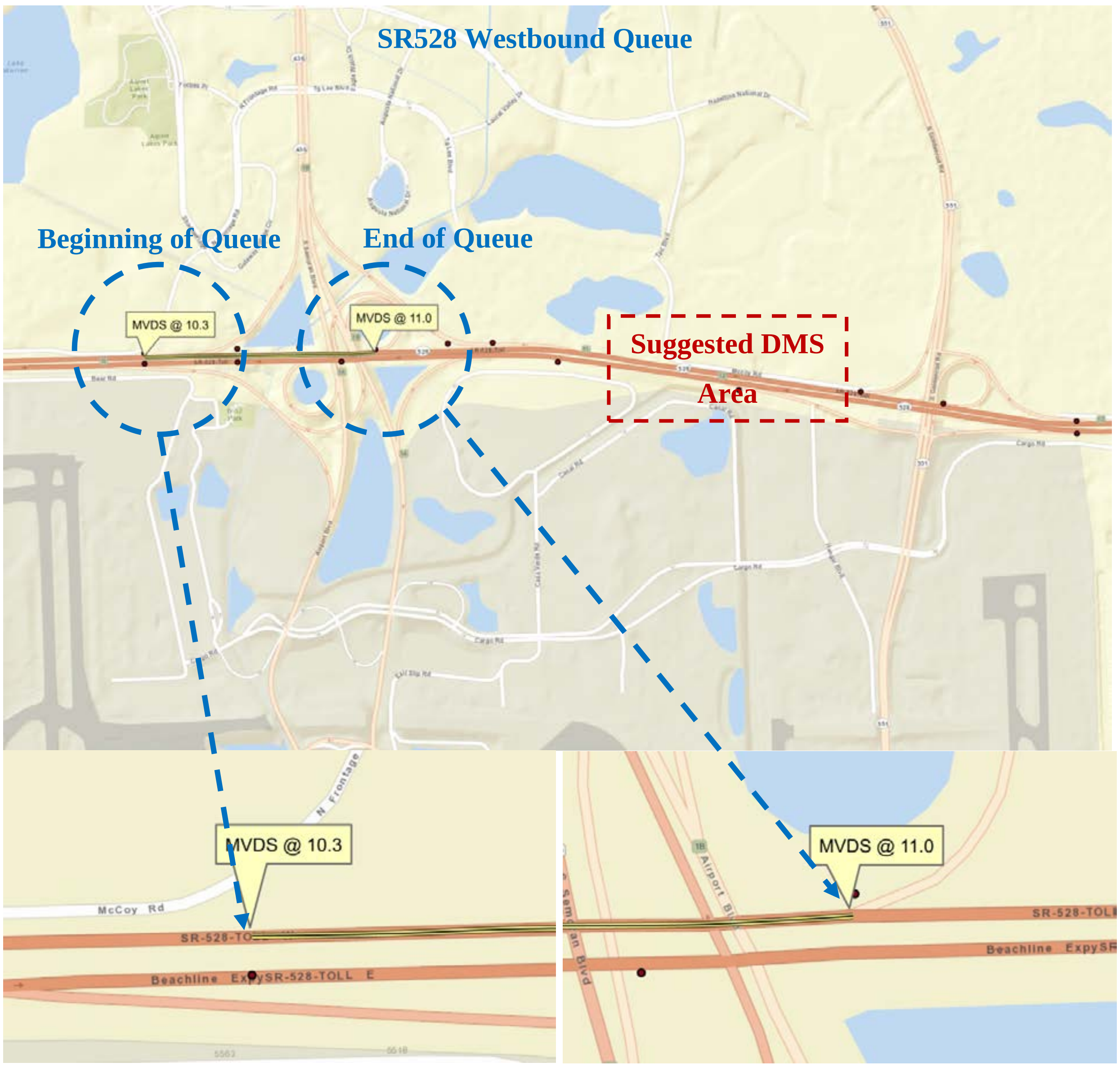
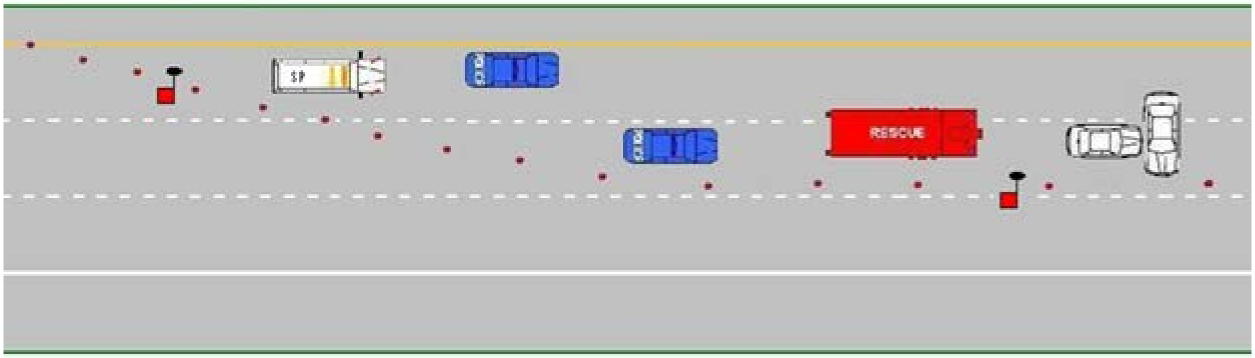


Figure Q-6 SR 528 Westbound Congested Segment and Suggested DMS Area

APPENDIX R. THE QUESTIONNAIRE

1. **Which of the following tolling system does your agency operate for toll collection?**
   (1) Open tolling only
   (2) Combination of open tolling and plazas
   (3) Plazas only
2. **Are there any procedures and practices for closing on ramps in case of total shut-down of the main-line travel lanes?**
   (1) Yes
   (2) No
3. **If yes, what are these procedures/practices in case of the availability of a frontage road?**
   (1) Re-route vehicles to downstream ramps
   (2) Detour to other surface streets
   (3) Treat on a case by case basis
   (4) Other, please specify …………………………………………………………………
4. **If yes but there is no frontage road or alternative available?**
   (1) Re-route vehicles to downstream ramps
   (2) Detour to other surface streets
   (3) Treat on a case by case basis
   (4) Other, please specify …………………………………………………………………
5. **If there are no procedures or practices, do you provide any information to motorists?**
   (1) Yes
   (2) No
6. **How do you provide ramp-closure (detour) information to the drivers?**
   (1) Dynamic Message Sign (DMS)
   (2) Radio
   (3) Fixed Signs
   (4) Other, please specify …………………………………………………………………
7. **Do you provide advice based on the specific closure condition?**
   (1) Yes, please explain …………………………………………………………………
   (2) No

8. **Does this procedure change depending on factors such as speed limit, number of lanes, time of day, etc?**
    (1) Yes, how ……………………………………………………………………
    (2) No
9. **Do you have any on-ramp volume control strategy (like ramp metering)?**
    (1) Yes, how ……………………………………………………………………
    (2) No
10. **What ITS systems do you use on your roadways? Check all that apply**
    (1) Automatic Vehicle Identification (AVI)
    (2) Dynamic (Changeable or Variable) message signs
    (3) Remote Traffic Management Sensors (e.g., Wavetronix)
    (4) Active Traffic Management, e.g., queue warning, please specify ………………………….
    (5) Travel time estimation
    (6) Electronic Toll Collection (ETC)
    (7) Other, please specify ……………………………………………………………………
11. **What is the average spacing between ramps? ……………….. mile**
12. **In the space below, please provide any relevant information that you can share with us about safety and/or traffic management on your system.**
13. **(Added Question) Is there any knowledge of *how* you close the ramps in case of shut-down of the main line? Do you take proactive measures such as staging cones at strategic locations, installing fixed gates, staging other MOT signage, etc?**



* Photo provided by Florida's Turnpike

Figure R-1 Florida's Turnpike Rollover Scene (Lane Blocking) Cone Setup

* Photo provided by Attica Tollway Operations Authority, Greece

Figure R-2 Heavy Yellow/Black Chain and Free-standing Pole

* Photo provided by Attica Tollway Operations Authority, Greece

Figure R-3 Chain and Safety Barrier

* Photo provided by Attica Tollway Operations Authority, Greece

Figure R-4 "Entrance Closed" Sign

APPENDIX S. EXPRESSWAY CRASH BY TYPE OF LANE

Table S-1 Expressway Crash by Type of Lane in 2012

Expressway	Total	Mainline	Toll Plaza Cash	Ramp
SR 408	626	402	27	197
SR 414	25	6	0	19
SR 417	369	193	13	163
SR 429	78	43	4	31
SR 528	277	202	5	70

Table S-2 Expressway Crash by Type of Lane in 2013

Expressway	Total	Mainline	Toll Plaza Cash	Ramp
SR 408	700	492	32	176
SR 414	40	14	1	25
SR 417	365	152	11	192
SR 429	76	47	1	28
SR 528	313	242	5	66

Table S-3 Expressway Crash by Type of Lane in 2014 (Jan – Jun)

Expressway	Total	Mainline	Toll Plaza Cash	Ramp
SR 408	361	239	19	103
SR 414	35	14	1	20
SR 417	218	103	6	109
SR 429	67	49	0	18
SR 528	178	143	2	33

APPENDIX T. CRASH BY YEAR

Table T-1 SR 414 Annual Crash Count by Type of Lane

Lane Type	2011	2012	2013	2014 (Jan – Jun)
Total Crash	30	25	40	35
Mainline	10	6	14	14
Toll Plaza Cash Lane	0	0	1	1
Ramp	20	19	25	20

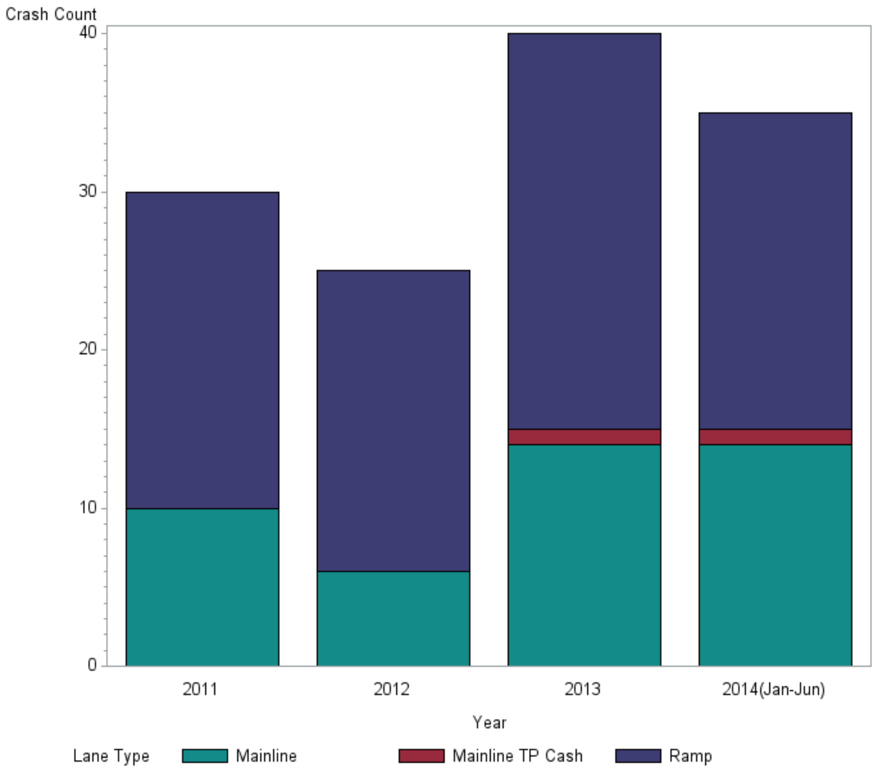


Figure T-1 SR 414 Crash Count by Year

Table T-2 SR 417 Annual Crash Count by Type of Lane

Lane Type	2011	2012	2013	2014 (Jan – Jun)
Total Crash	337	369	365	218
Mainline	204	193	152	103
Toll Plaza Cash Lane	15	13	11	6
Ramp	118	163	192	109

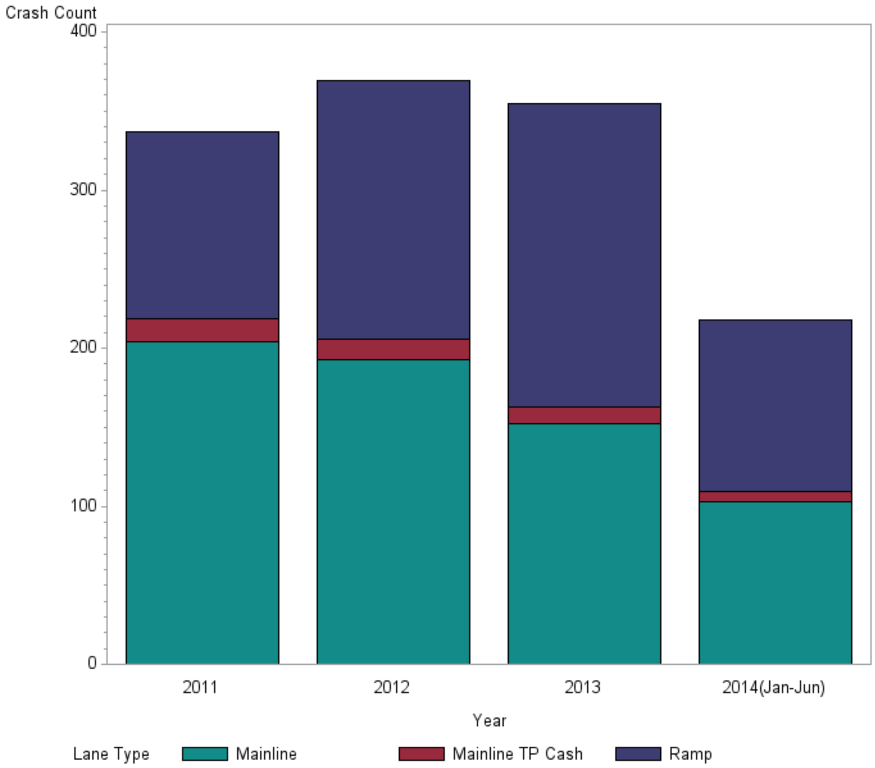


Figure T-2 SR 417 SR 414 Crash Count by Year

Table T-3 SR 429 Annual Crash Count by Type of Lane

Lane Type	2011	2012	2013	2014 (Jan – Jun)
Total Crash	83	78	76	67
Mainline	56	43	47	49
Toll Plaza Cash Lane	3	4	1	0
Ramp	24	31	28	18

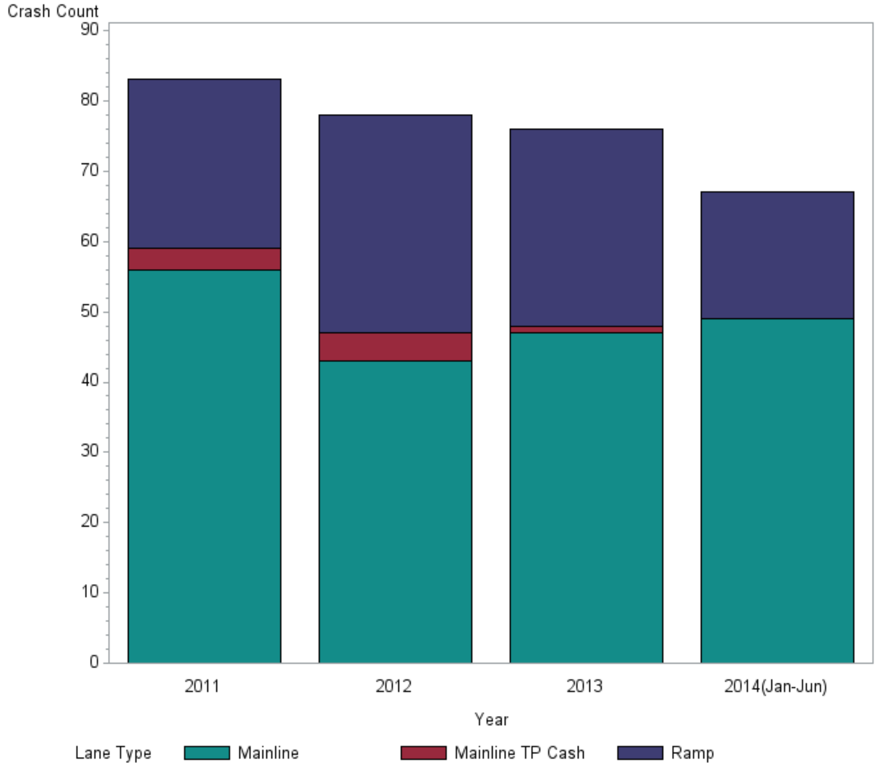


Figure T-3 SR 429 SR 414 Crash Count by Year

Table T-4 SR 528 Annual Crash Count by Type of Lane

Lane Type	2011	2012	2013	2014 (Jan -- Jun)
Total Crash	263	277	313	178
Mainline	208	202	242	143
Toll Plaza Cash Lane	13	5	5	2
Ramp	42	70	66	33

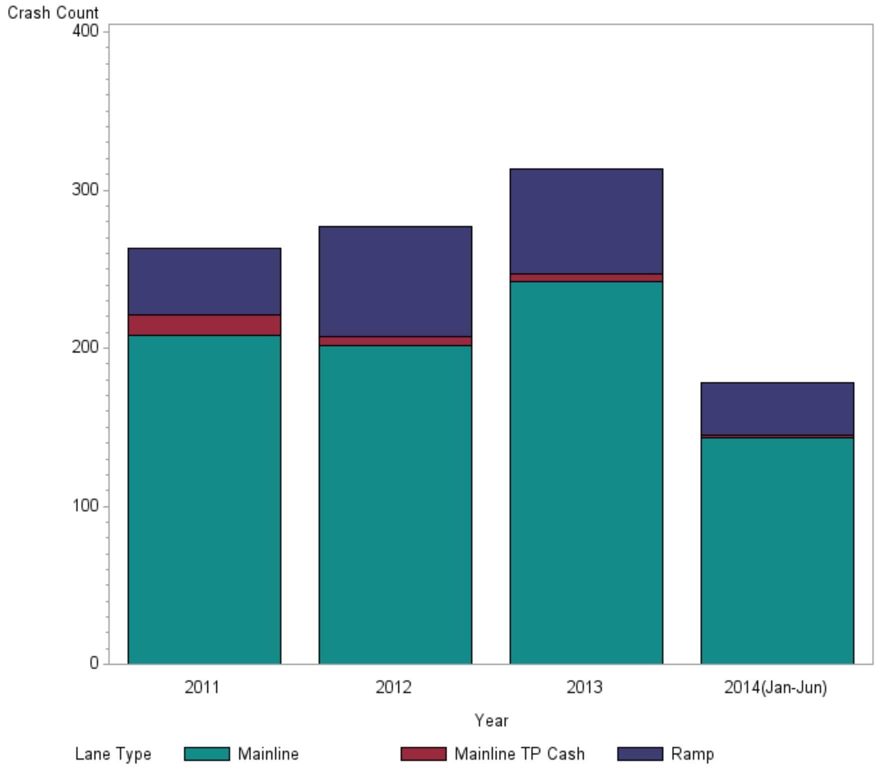


Figure T-4 SR 528 SR 414 Crash Count by Year

APPENDIX U. SPATIAL DISTRIBUTION OF TRAFFIC CRASHES

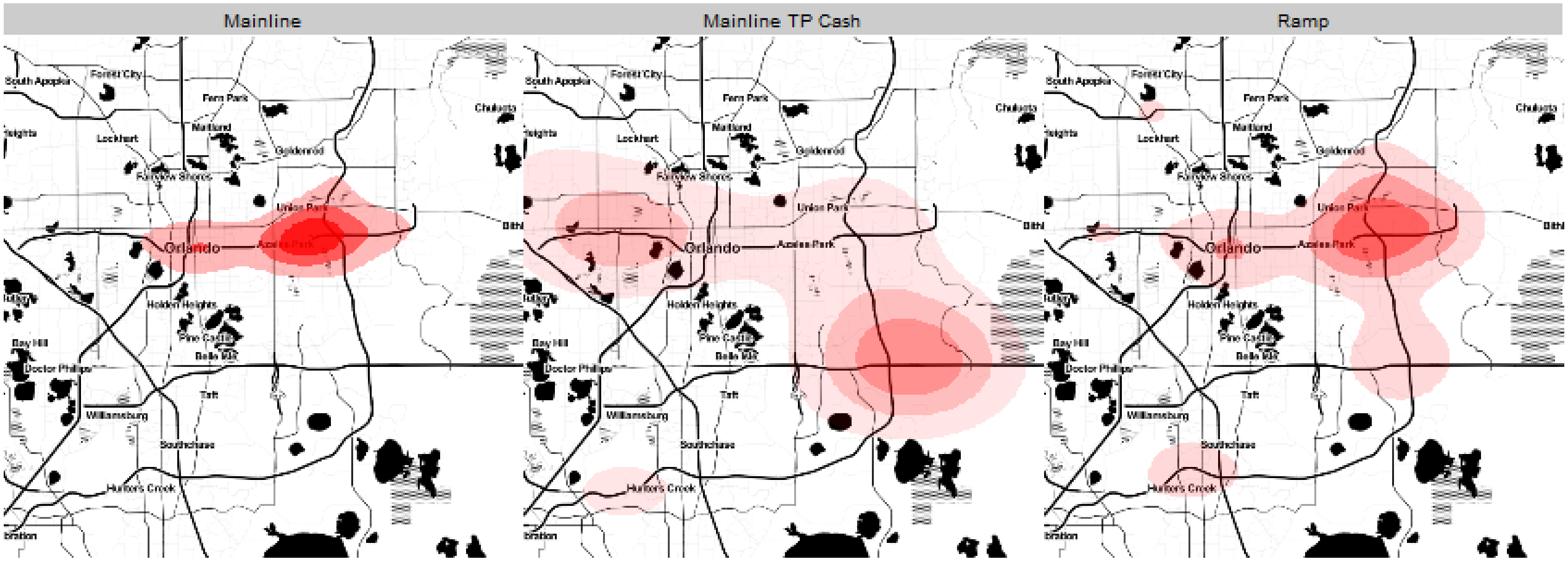


Figure U-1 Spatial Pattern of Traffic Crashes by Types of Lane in 2012

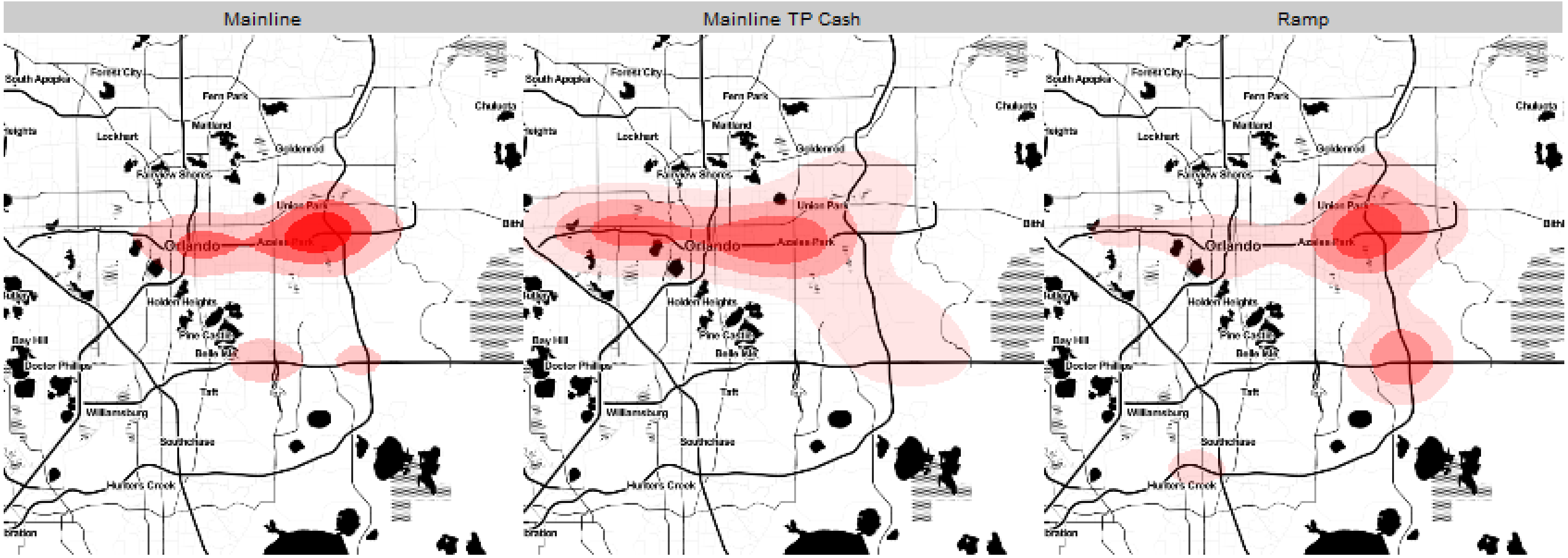


Figure U-2 Spatial Pattern of Traffic Crashes by Types of Lane in 2013

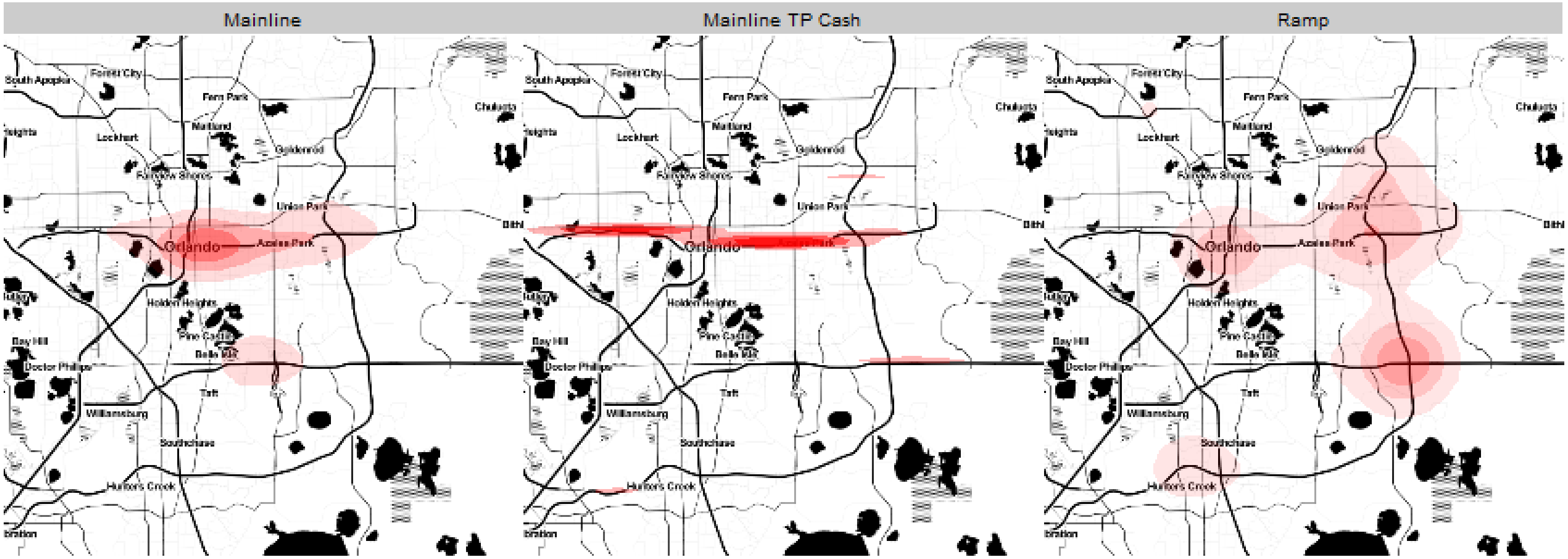


Figure U-3 Spatial Pattern of Traffic Crashes by Types of Lane in 2014 (Jan -- Jun)

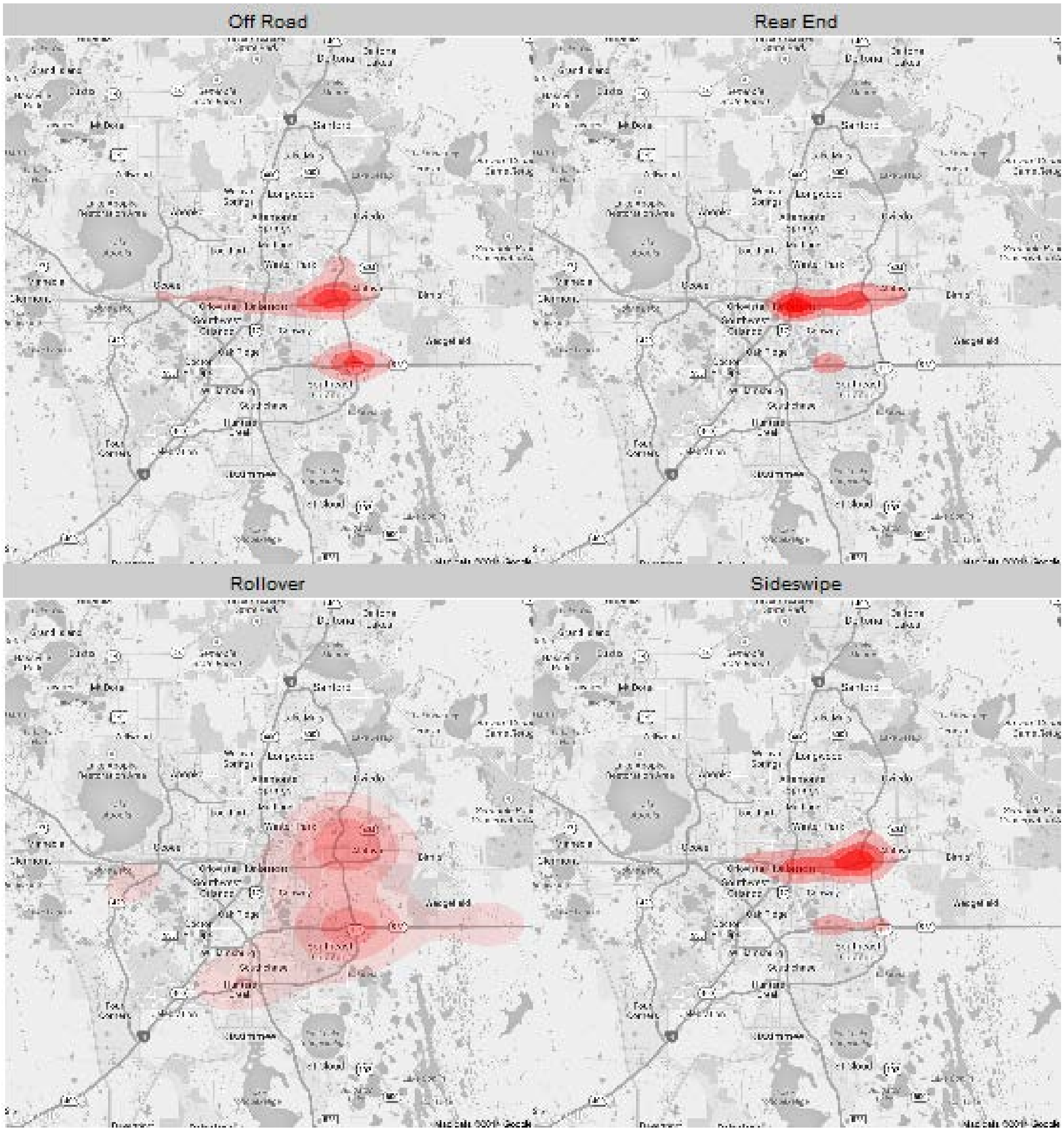


Figure U-4 Spatial Pattern of Traffic Crashes by Crash Type in 2012

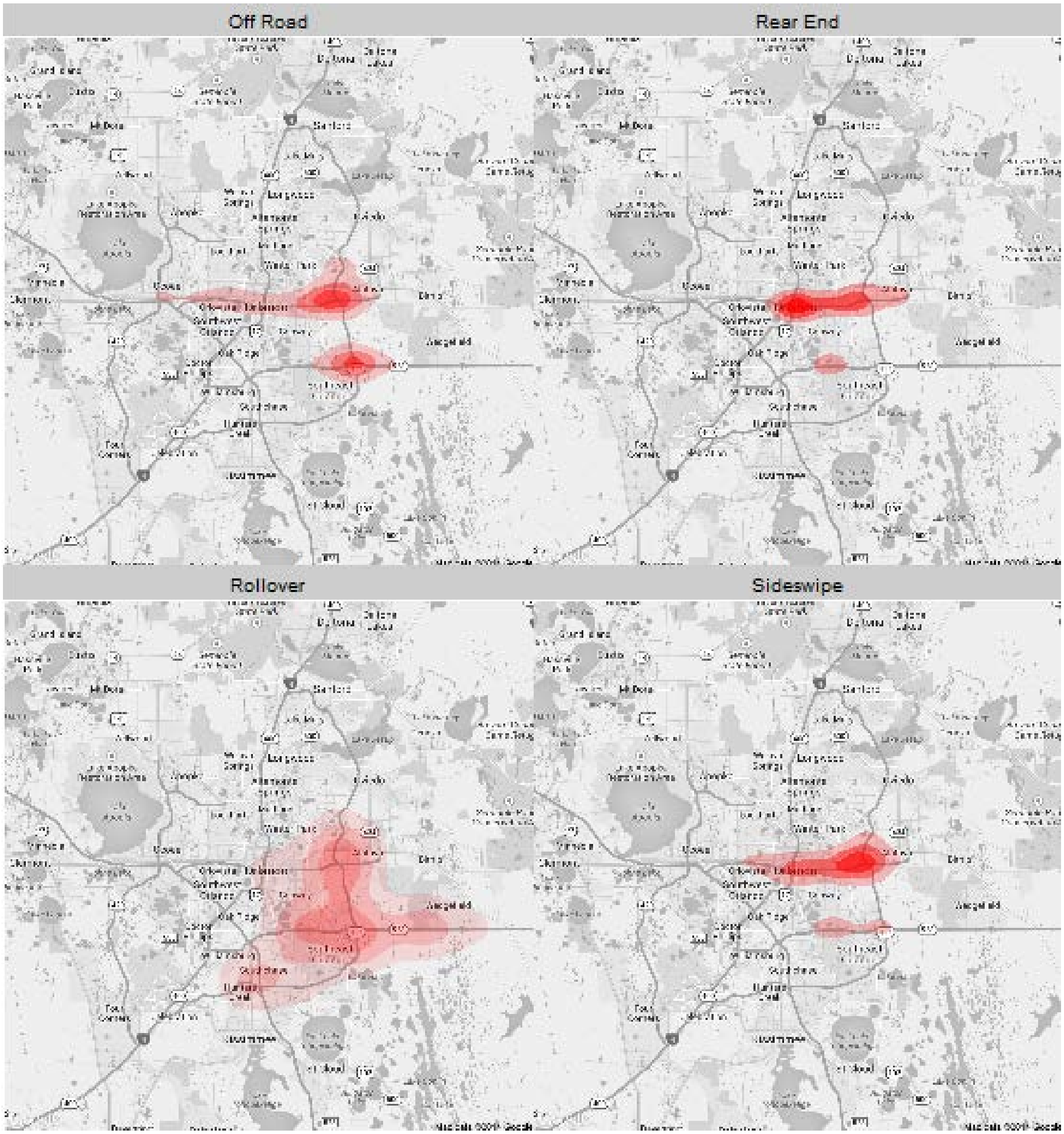


Figure U-5 Spatial Pattern of Traffic Crashes by Crash Type in 2013

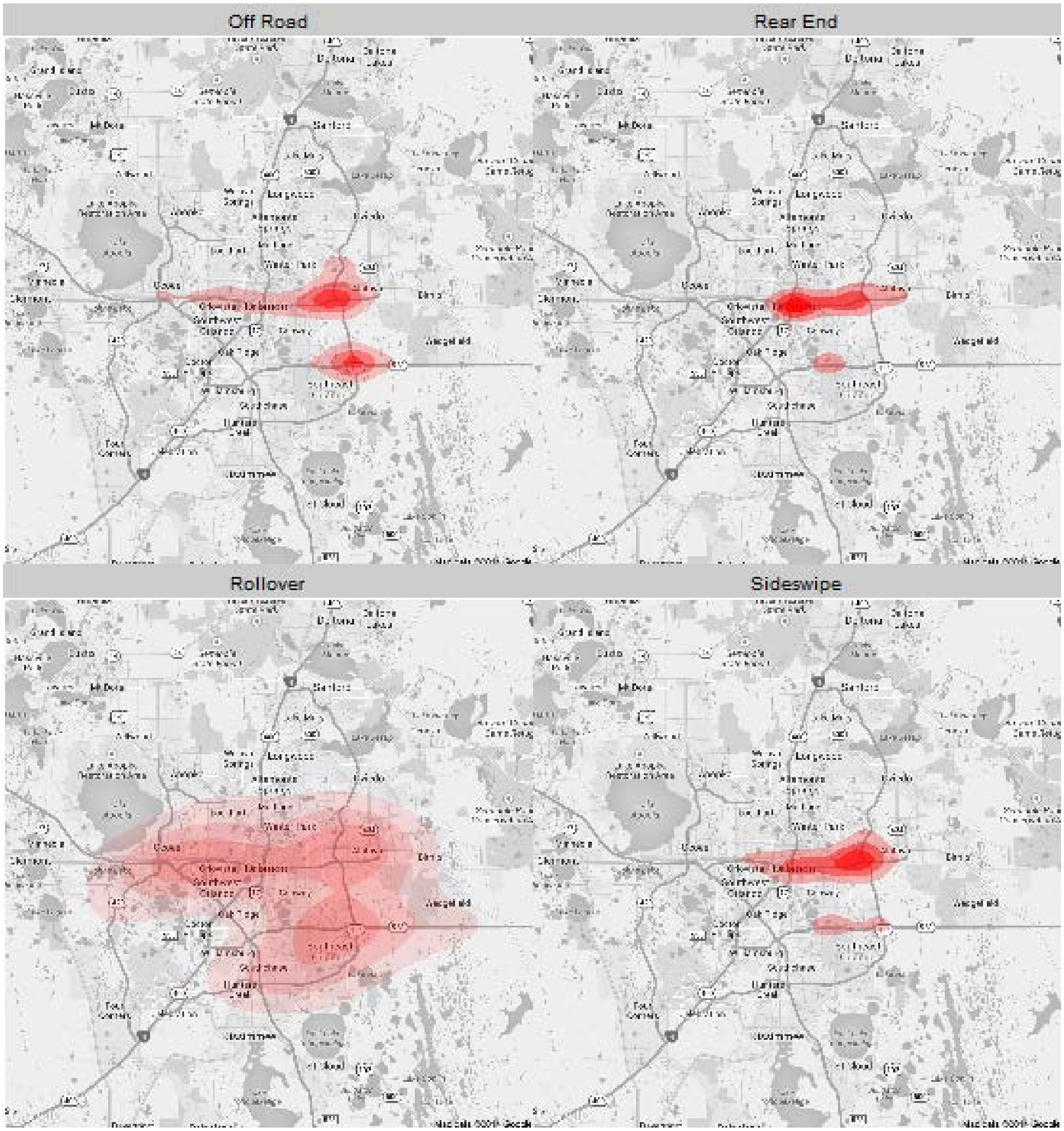


Figure U-6 Spatial Pattern of Traffic Crashes by Crash Type in 2014 (Jan – Jun)

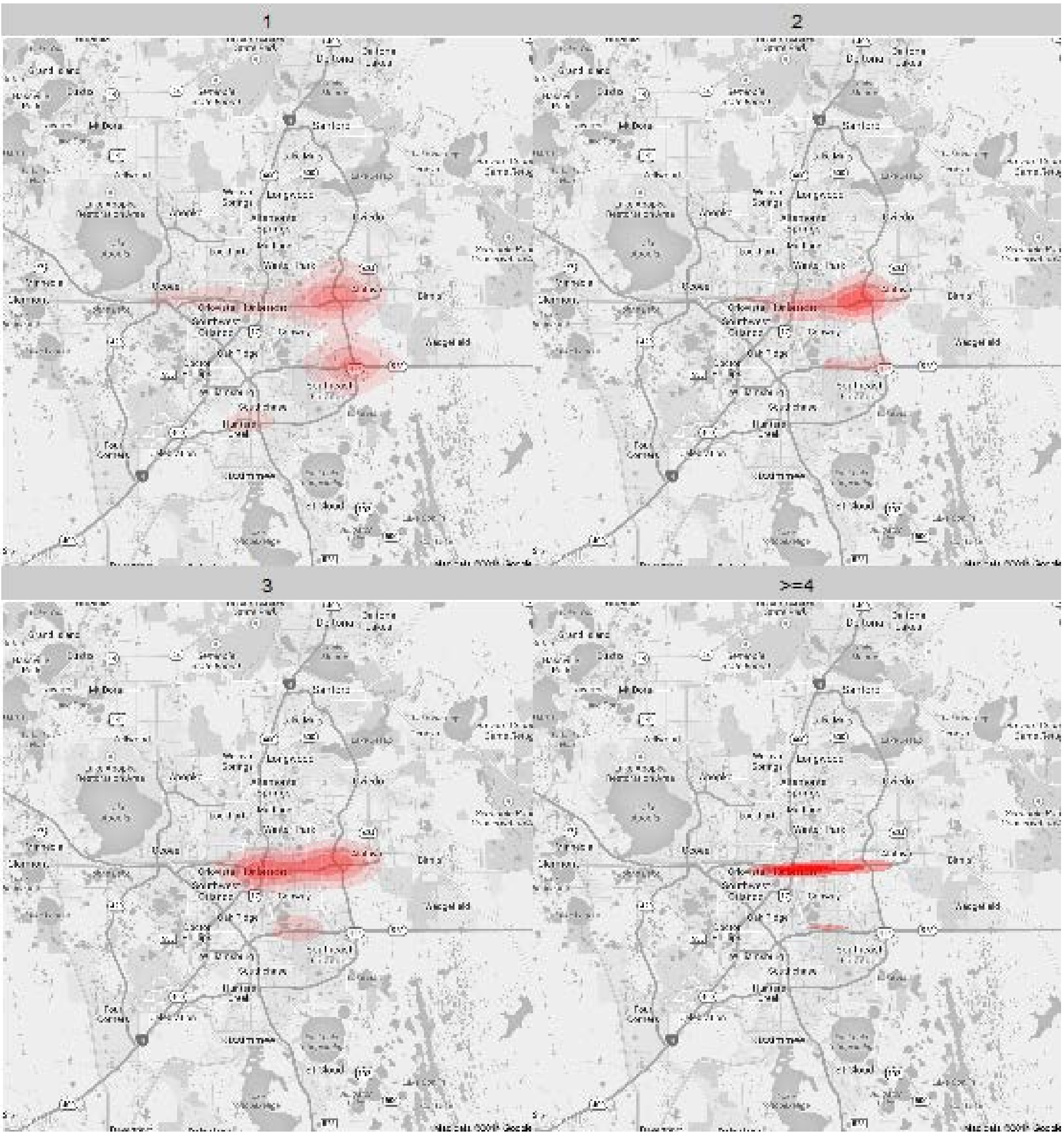


Figure U-7 Spatial Pattern of Traffic Crashes by Number of Vehicles in 2012

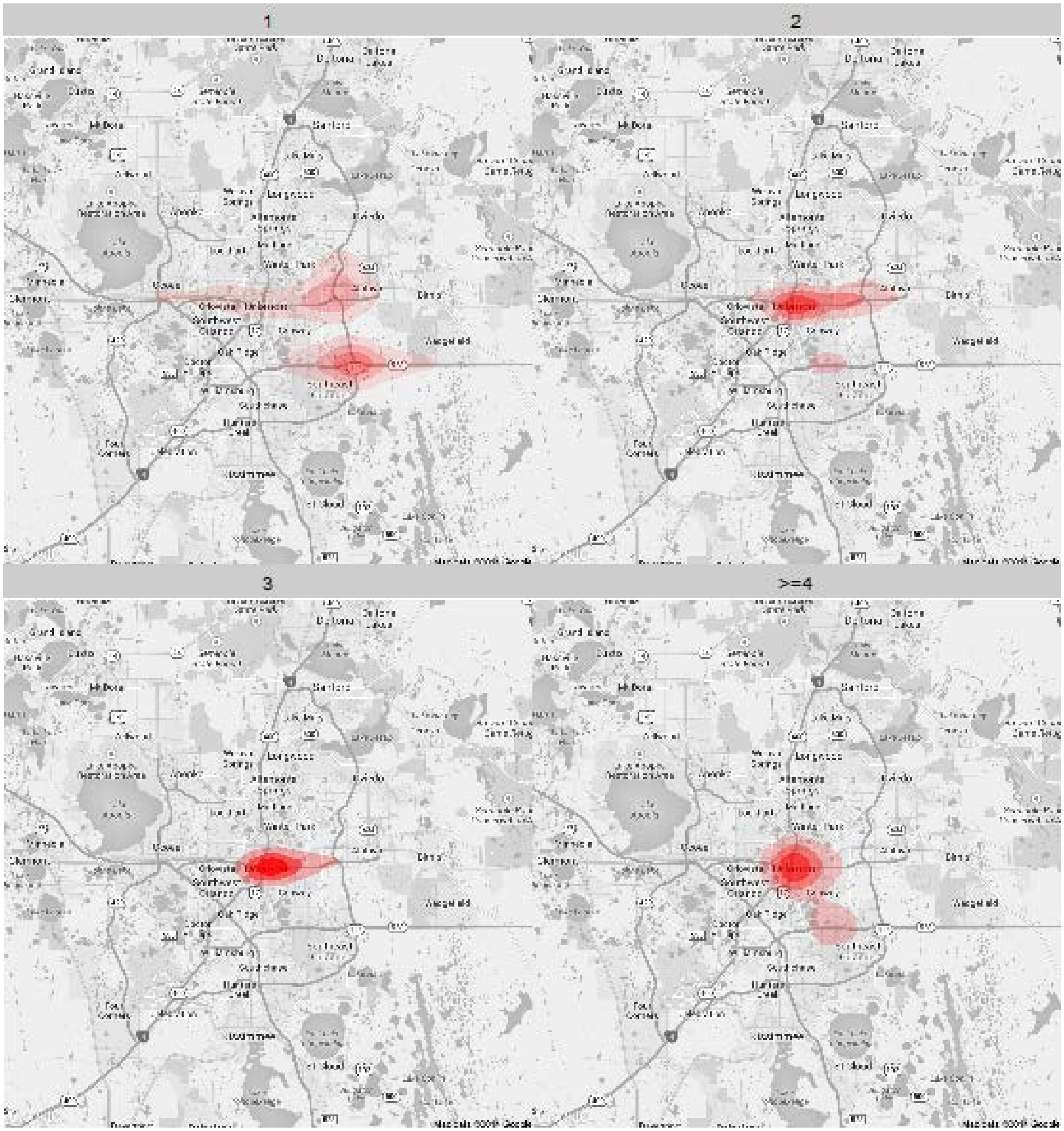


Figure U-8 Spatial Pattern of Traffic Crashes by Number of Vehicles in 2013

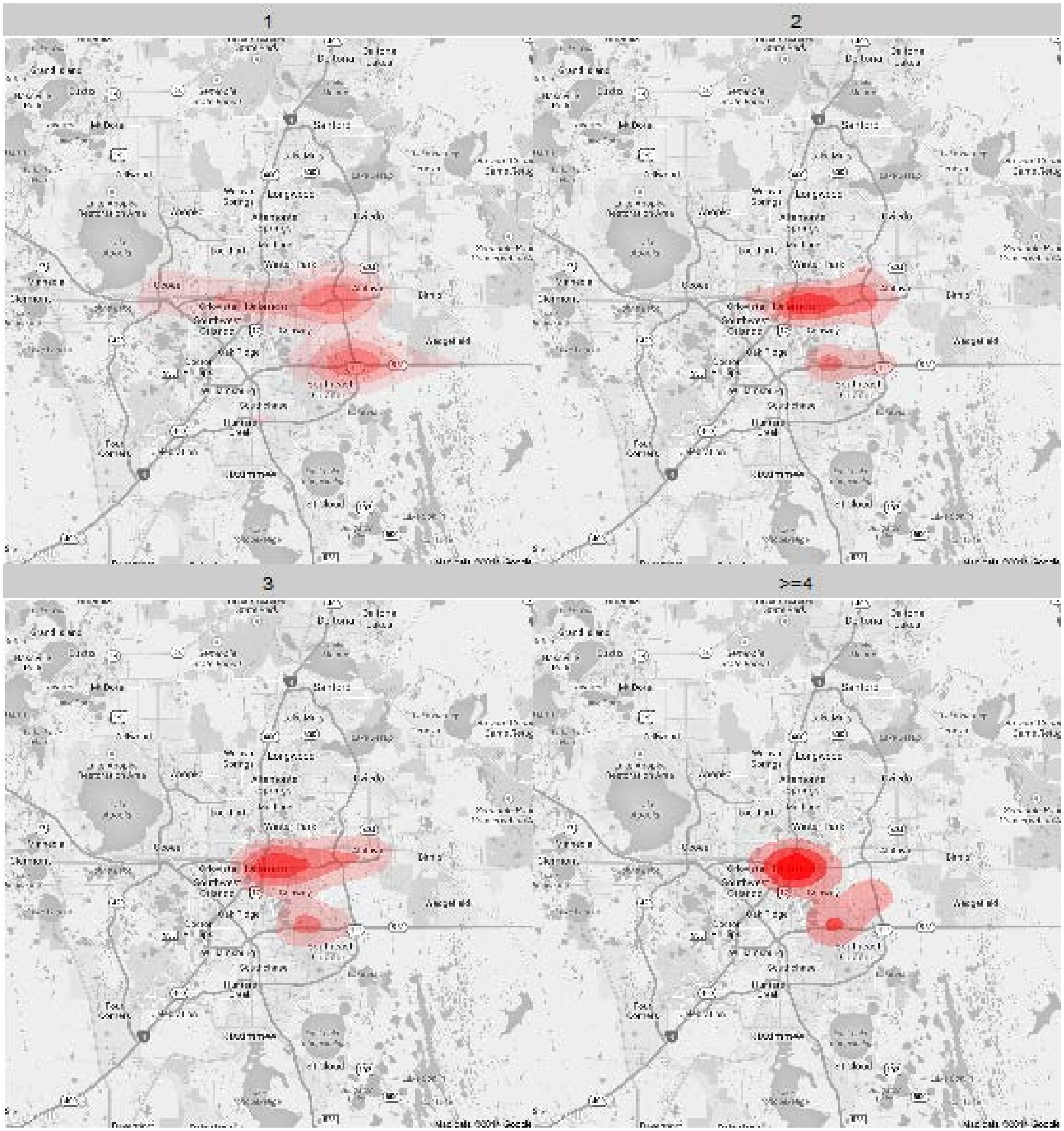


Figure U-9 Spatial Pattern of Traffic Crashes by Number of Vehicles in 2014 (Jan – Jun)

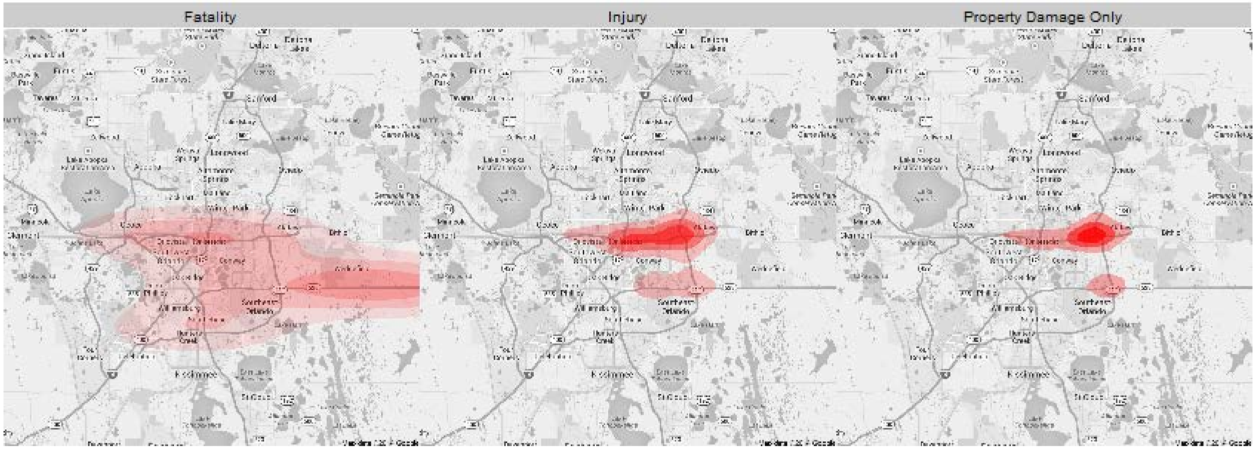


Figure U-10 Spatial Pattern of Traffic Crashes by Crash Severity in 2012

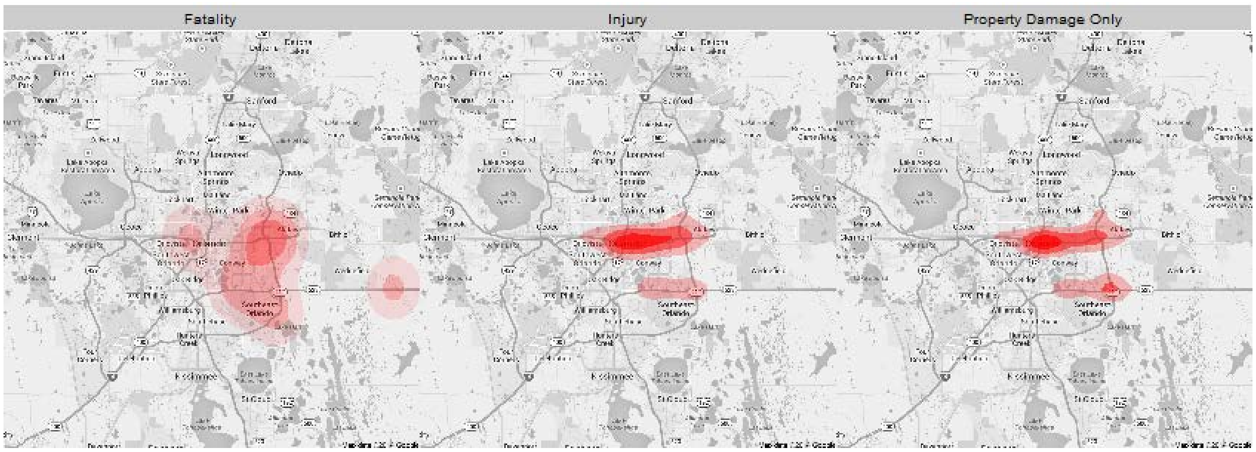


Figure U-11 Spatial Pattern of Traffic Crashes by Crash Severity in 2013

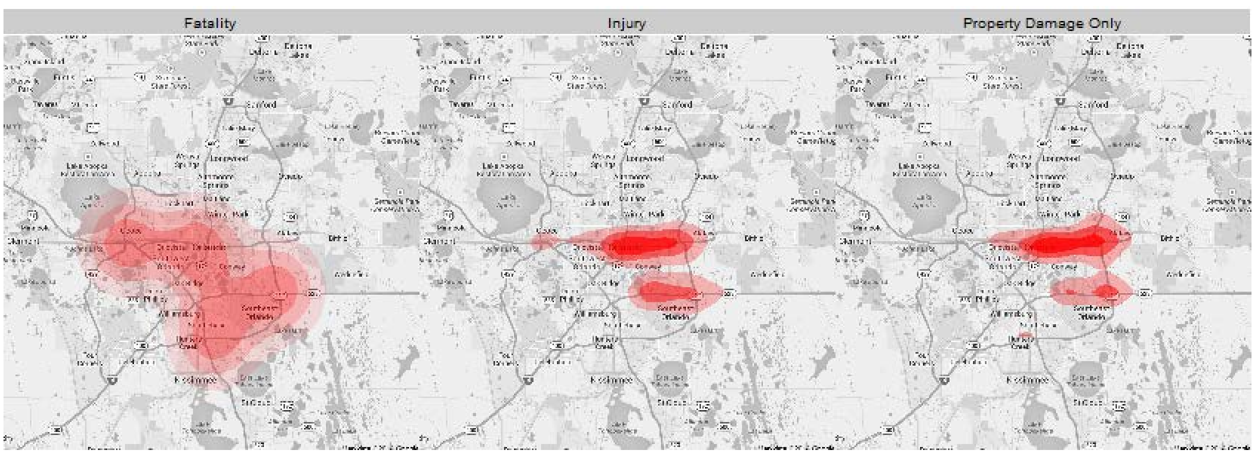


Figure U-12 Spatial Pattern of Traffic Crashes by Crash Severity in 2014 (Jan -- Jun)

Figure U-13 Spatial Pattern of Traffic Crashes by Lighting Condition in 2012

Figure U-14 Spatial Pattern of Traffic Crashes by Lighting Condition in 2013

Figure U-15 Spatial Pattern of Traffic Crashes by Lighting Condition in 2014 (Jan – Jun)

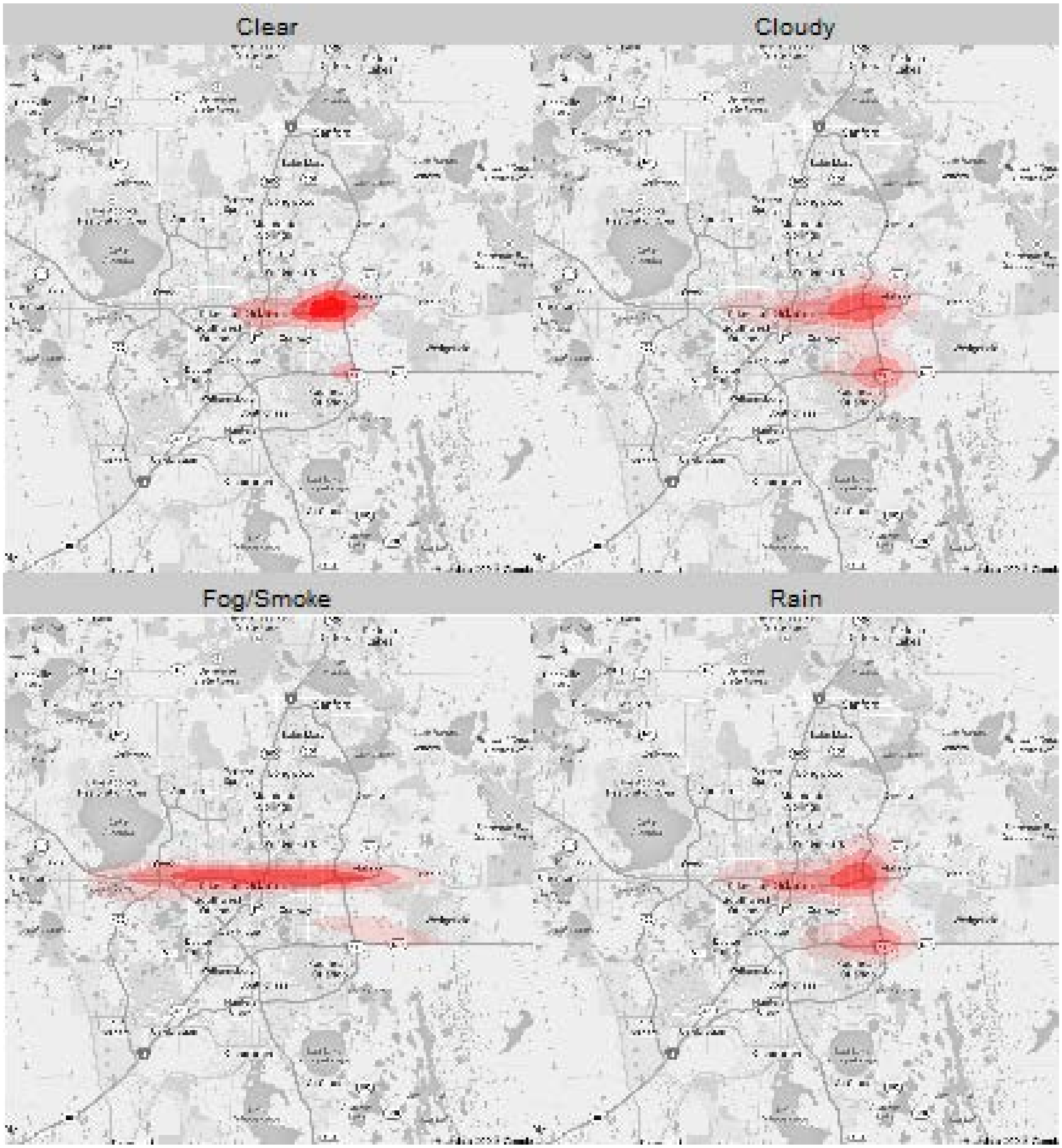


Figure U-16 Spatial Pattern of Traffic Crashes by Weather Condition in 2012

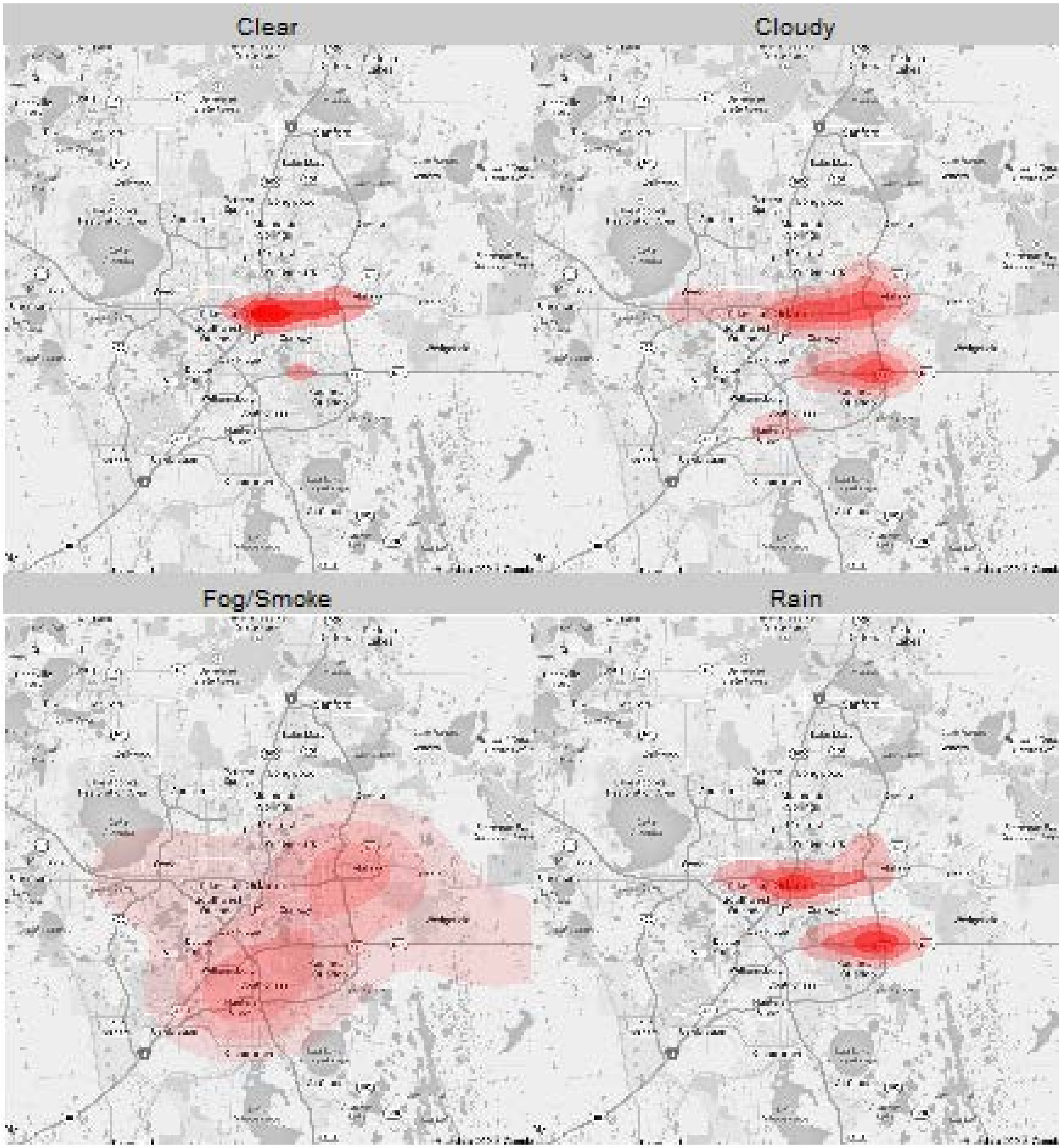


Figure U-17 Spatial Pattern of Traffic Crashes by Weather Condition in 2013

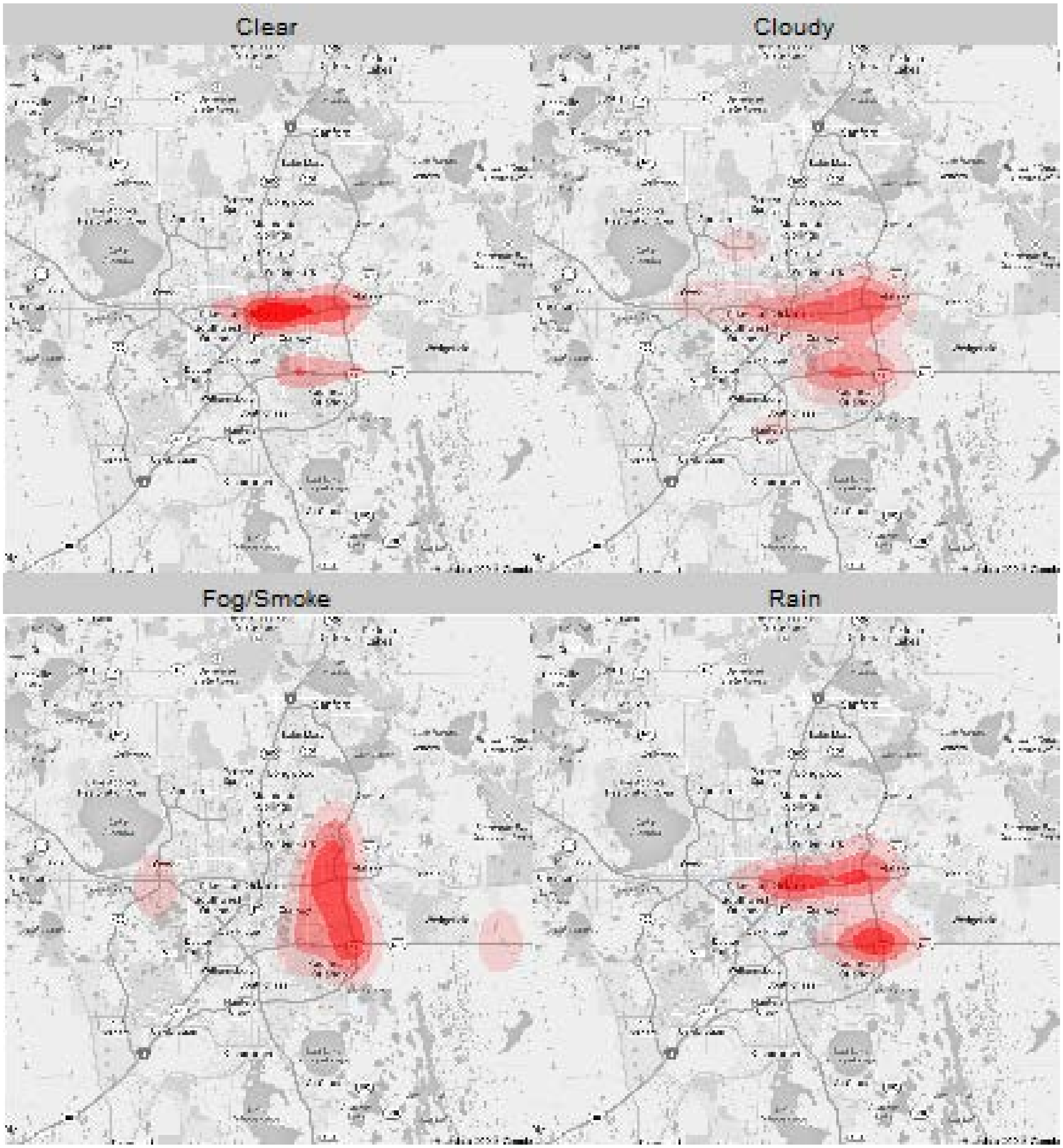


Figure U-18 Spatial Pattern of Traffic Crashes by Weather Condition in 2014 (Jan -- Jun)

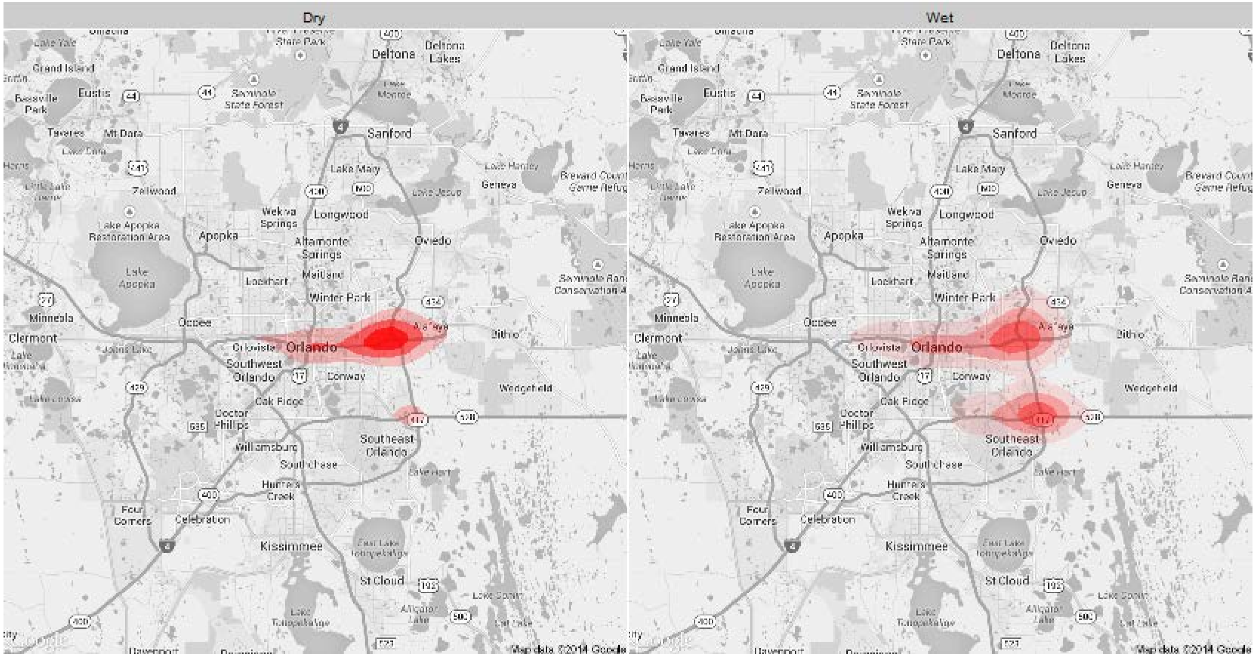


Figure U-19 Spatial Pattern of Traffic Crashes by Road Surface Condition in 2012

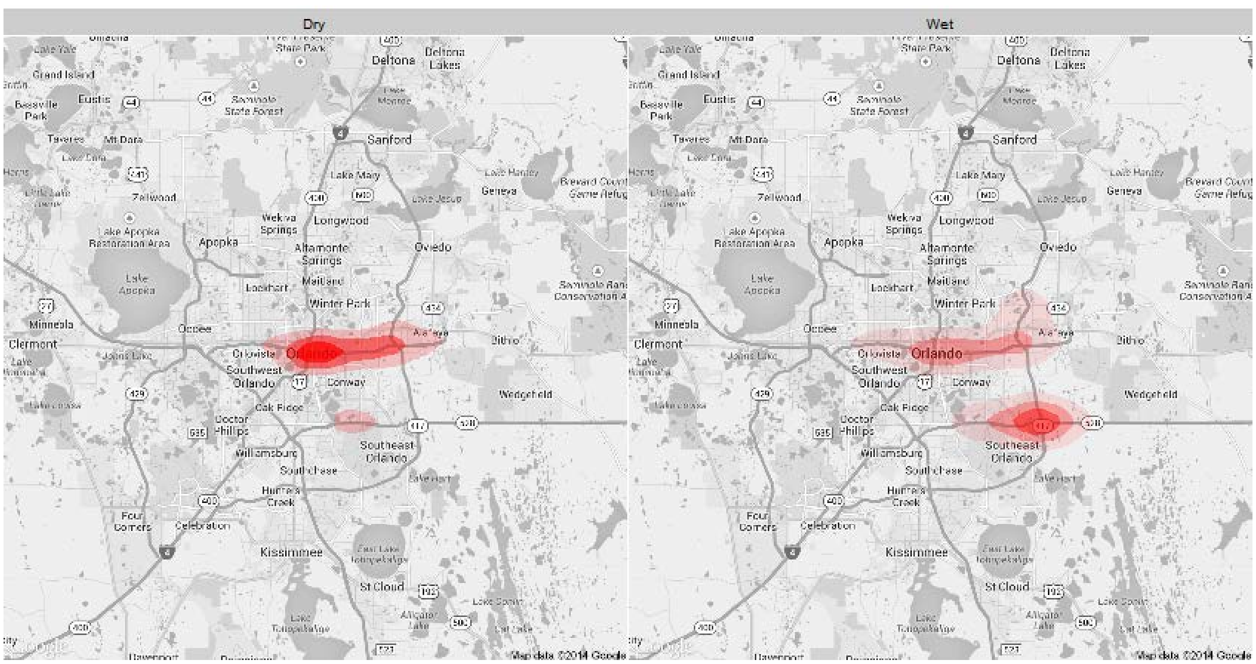


Figure U-20 Spatial Pattern of Traffic Crashes by Road Surface Condition in 2013

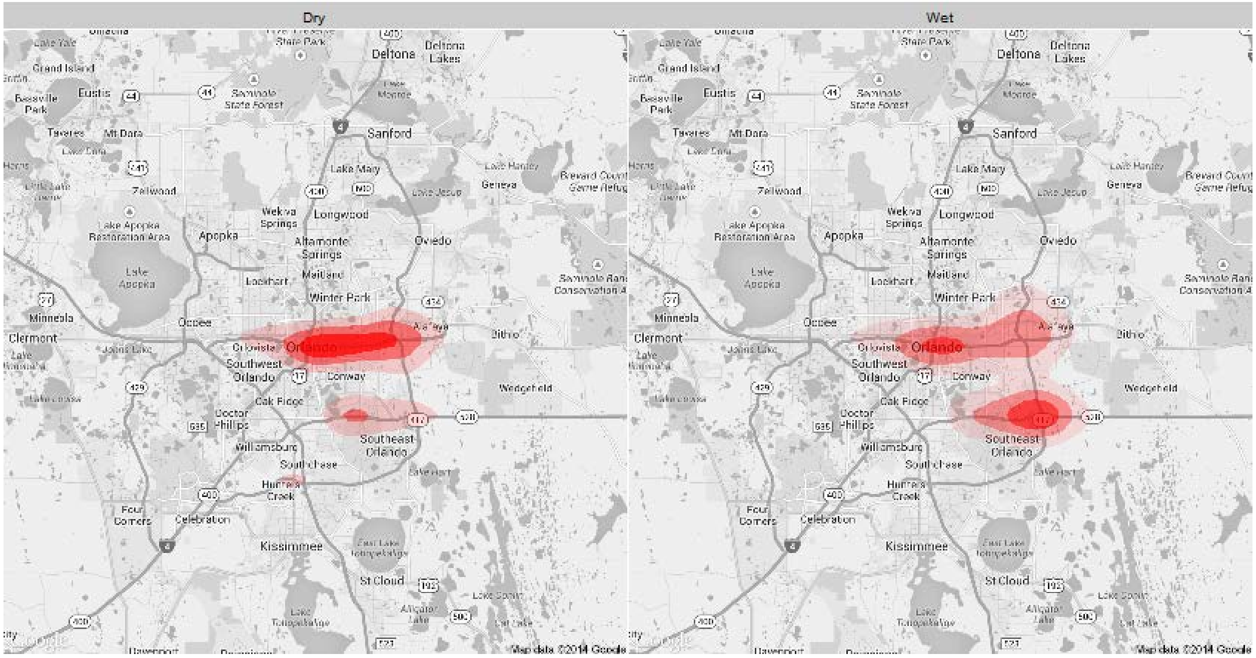


Figure U-21 Spatial Pattern of Traffic Crashes by Road Surface Condition in 2014 (Jan -- Jun)

APPENDIX V. TEMPORAL DISTRIBUTION OF CRASHES

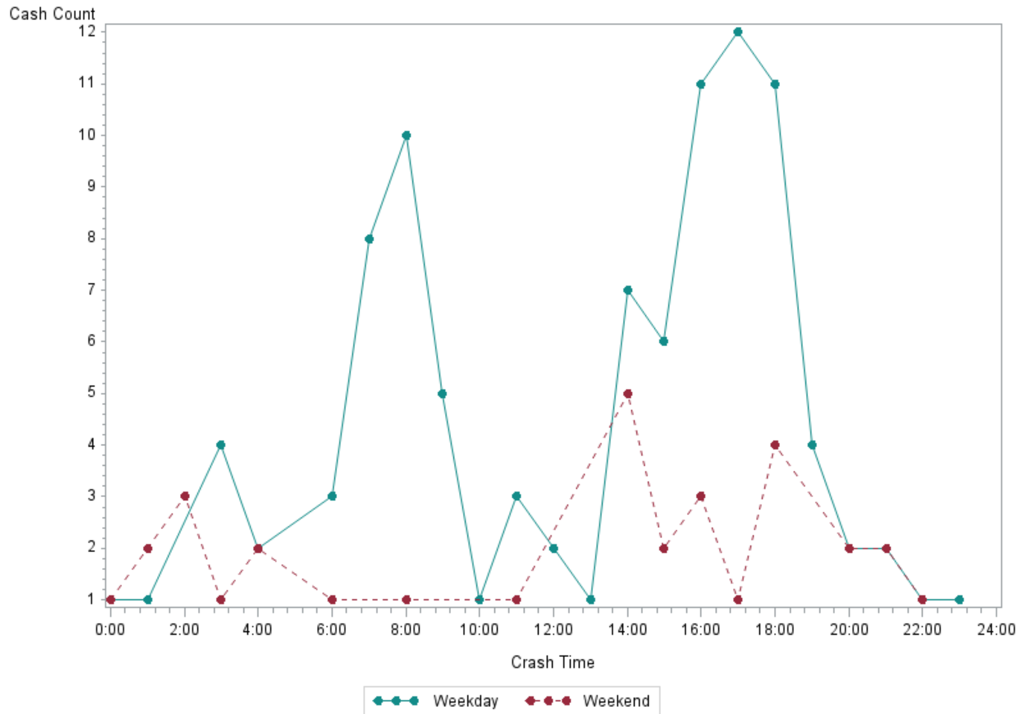


Figure V-1 Temporal Distribution of Traffic Safety on SR 414

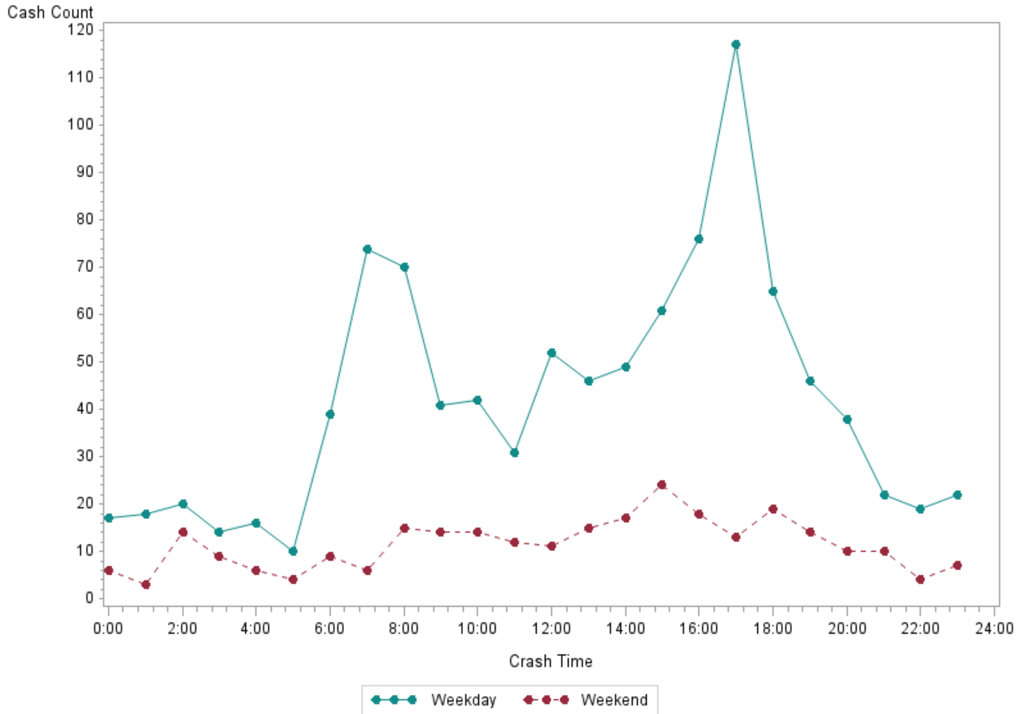


Figure V-2 Temporal Distribution of Traffic Safety on SR 417

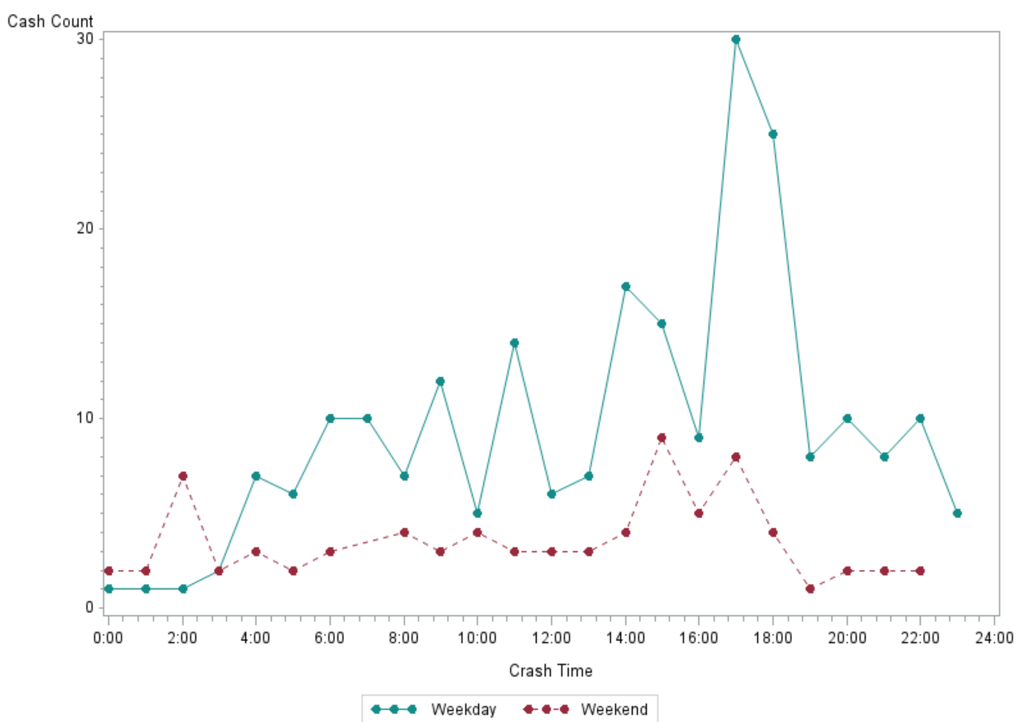


Figure V-3 Temporal Distribution of Traffic Safety on SR 429

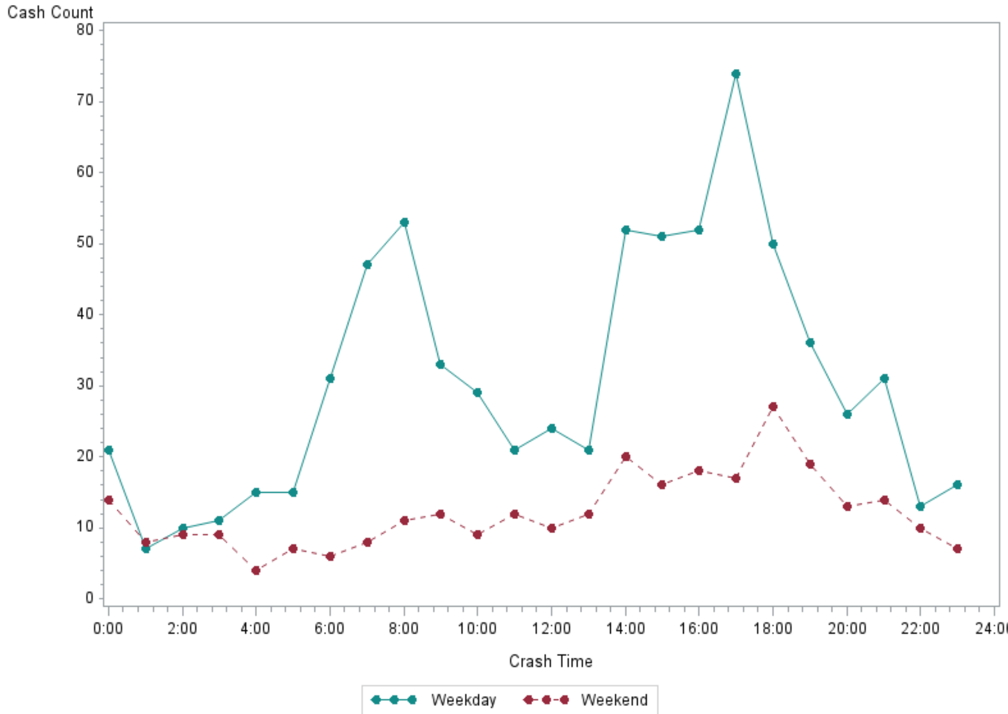


Figure V-4 Temporal Distribution of Traffic Safety on SR 528

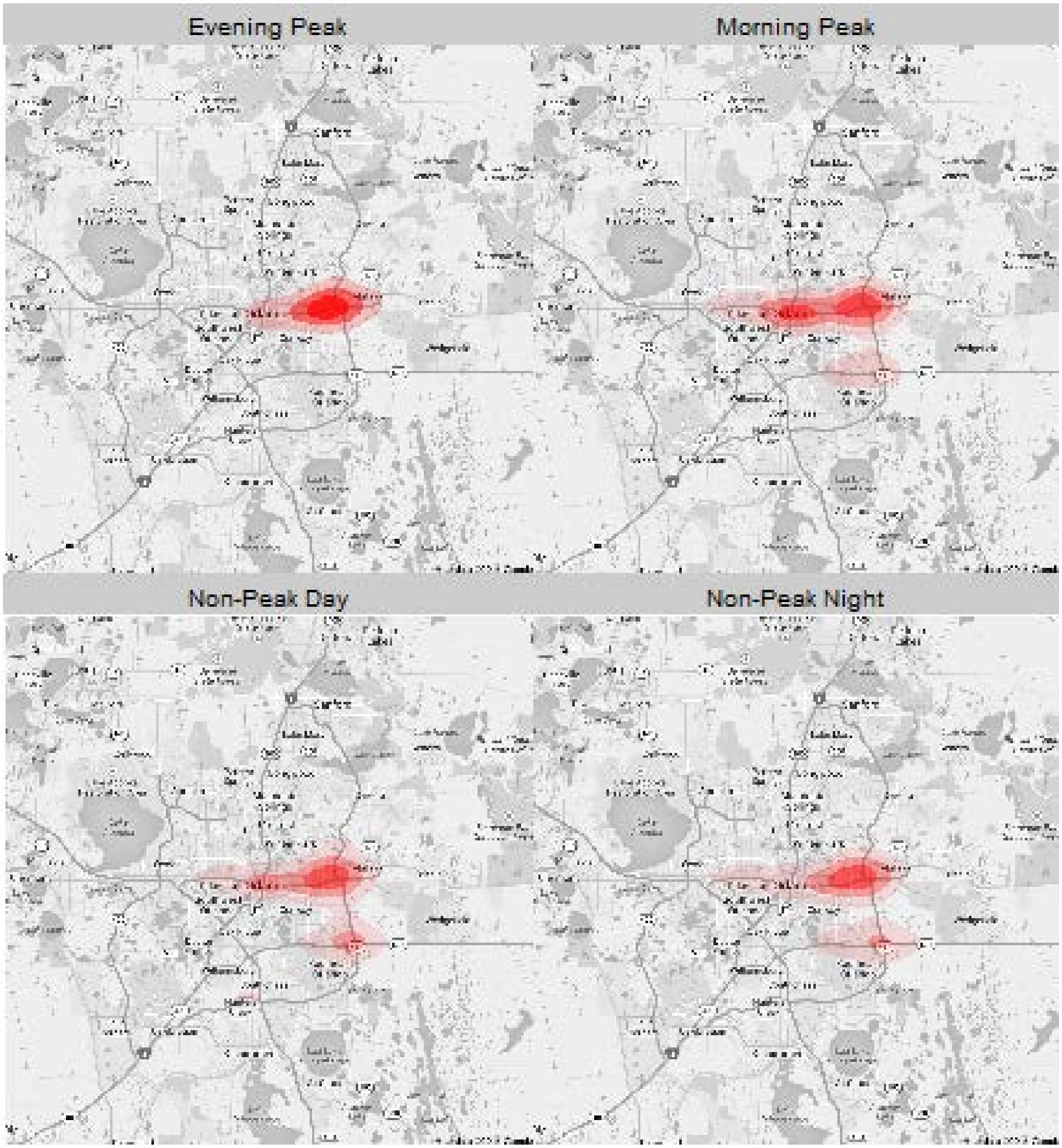


Figure V-5 Spatial-Temporal Distribution of Traffic Crashes in 2012

Figure V-6 Spatial-Temporal Distribution of Traffic Crashes in 2013

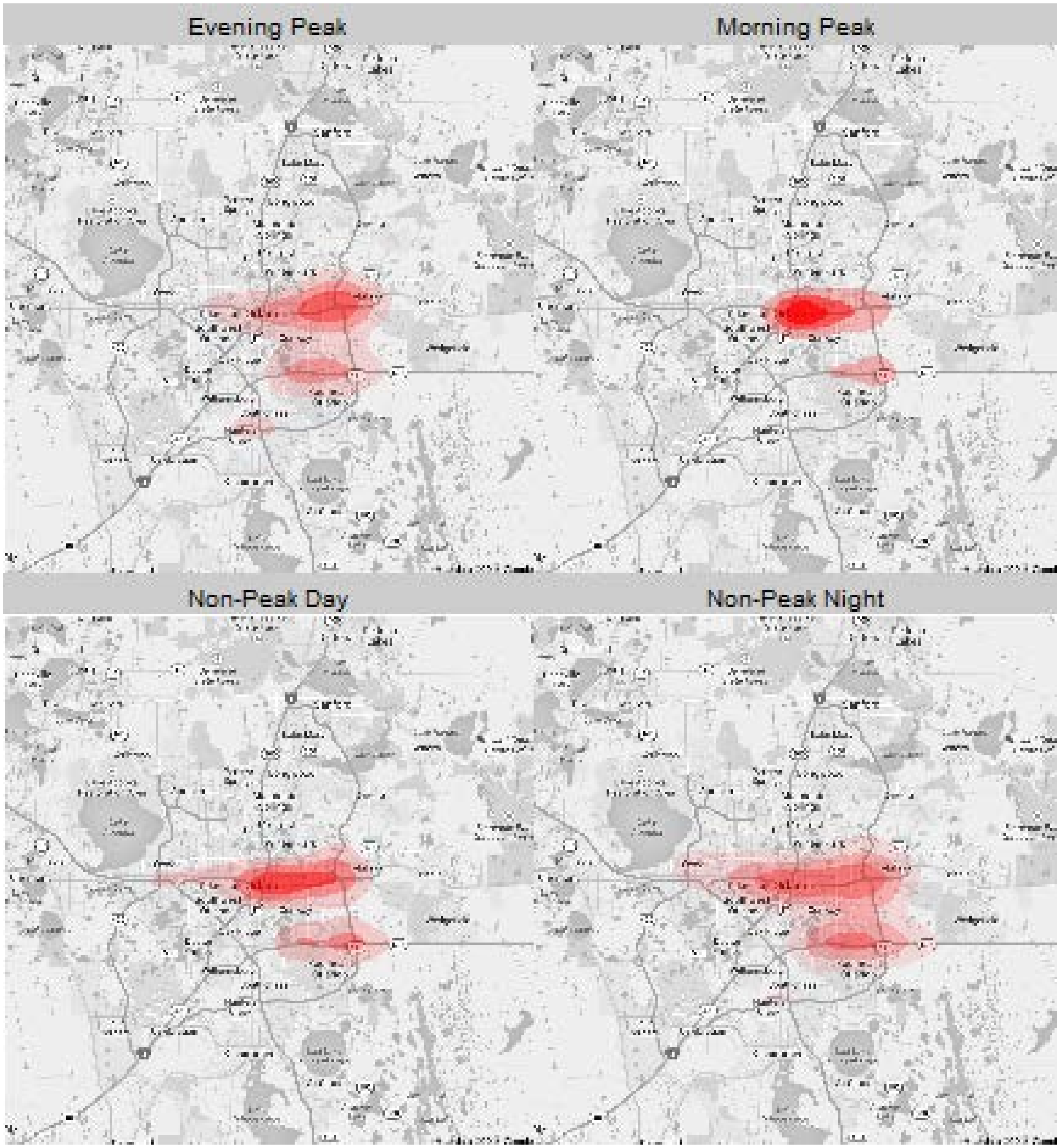


Figure V-7 Spatial-Temporal Distribution of Traffic Crashes in 2014 (Jan -- Jun)

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