RC-1631
July 31, 2015

Michigan Department of Transportation

Costs and Benefits of MDOT Intelligent Transportation System Deployments

FINAL REPORT

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Transportation Research Center for Livable Communities
Western Michigan University

Technical Report
Documentation Page

1. Report No.
RC-1631

2. Government Accession No.
N/A

3. MDOT Project Manager
Collin Castle

4. Title and Subtitle
Costs and Benefits of MDOT Intelligent Transportation System Deployments

5. Report Date
July 31, 2015

6. Performing Organization Code
N/A

7. Author(s)
Jun-Seok Oh, Valerian Kwigizile, Zhanbo Sun, Matthew L. Clark, Aous Hammad Kurdi, Matthew J. Wiersma

8. Performing Org. Report No.
N/A

9. Performing Organization Name and Address
Western Michigan University
1903 West Michigan Avenue
Kalamazoo, MI 49008

10. Work Unit No. (TRAIS)
N/A

11. Contract No.
2013-0069

11(a). Authorization No.
5

12. Sponsoring Agency Name and Address
Michigan Department of Transportation
Research Administration
8885 Ricks Rd.
P.O. Box 30049
Lansing MI 48909

13. Type of Report & Period Covered
Final Report
6/3/2013 - 7/31/2015

14. Sponsoring Agency Code
N/A

15. Supplementary Notes

16. Abstract
This report analyses costs and benefits of Intelligent Transportation Systems (ITS) deployed by the Michigan Department of Transportation (MDOT). MDOT ITS focuses on traffic incident management and also provide Freeway Courtesy Patrol services. According to a survey in this study, radio, television and Mi Drive are the most frequently used travel information sources and 93 percent of motorists are at least somewhat trusting general dynamic message sign (DMS) information. The survey also revealed that the motorists assisted by the freeway courtesy patrol (FCP) are willing to wait at least 15 minutes longer than actual wait times and over 90 percent are satisfied with the quality and response time of the service. MDOT ITS reduced significant incident duration and delays. Thanks to the delay reduction, the benefit-cost ratio of statewide ITS deployment was estimated at 3.16. Among ITS devices in Michigan, CCTV and DMS were found to be very cost-effective. Accordingly, future investments should focus on DMS and CCTV installation, while deployment of MVDS needs further studies in conjunction with the coming wake of Connected Vehicle technology. ITS deployments were more cost-effective on locations with higher incidents and higher traffic volumes. This study identified highway segments with highest potential for positive ITS benefit.

17. Key Words
Intelligent Transportation System; Cost and Benefit Analysis; Traffic Incident Management

18. Distribution Statement
No restrictions. This document is available to the public through the Michigan Department of Transportation.

19. Security Classification - report	20. Security Classification - page	21. No. of Pages	22. Price
Unclassified	Unclassified	189	N/A

Disclaimer

Acknowledgments

We would like to thank Mr. Collin Castle, the project manager, and Mr. Andre Clover, the research manager, for their continued support and technical guidance during this project. We also would like to thank the Research Advisory Panel members for their comments and suggestions.

Mr. Matt Smith, Michigan Department of Transportation
Mr. Mark Geib, Michigan Department of Transportation
Ms. Jennifer Foley, Michigan Department of Transportation
Ms. Elise Kapphahn, Michigan Department of Transportation

Their comments and suggestions greatly helped the research team in improving the final product of this research. This report is based upon work supported by the Michigan Department of Transportation under the contract number 2013-0069.

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Executive Summary

The Michigan Department of Transportation (MDOT)'s strategic plan for Intelligent Transportation Systems (ITS) revolves around attaining key mobility, safety, productivity, energy and environment, and customer satisfaction objectives. The integrated ITS regiment must provide these benefits to Michigan motorists at a reasonable and sustainable level of investment. As of 2013, MDOT operates and maintains over 800 ITS devices with coverage on over 500 miles of Michigan highways. Recently, major Michigan ITS construction projects have introduced a bevy of new applications and devices to the statewide highway system. The research team was tasked with performing a cost-benefit evaluation to determine the return on investment of these projects.

Many tasks were performed to complete a comprehensive and rigorous statewide cost-benefit analysis. These steps included development of a detailed spatiotemporal ArcGIS ITS database, a questionnaire survey regarding motorists' perception of and behavior towards ATIS, compilation and analysis of monthly TOC performance reports, and cross-sectional statistical analysis of incident duration reduction as a result of ITS. Other tasks included traffic microsimulation on choice study corridors using field-data focused models, statistical modeling on accident reduction due to ITS devices such as DMS, and ultimately, a tiered cost-benefit analysis considering all measurable and quantifiable costs and benefits of MDOT ITS deployments.

MDOT ITS Deployment

The total number of ITS devices installed during 2006 – 2013 was 765 including 397 in SEMTOC, 197 in WMTOC, and 171 in STOC. The total cost spent for these devices was $103,480,043 excluding the cost for major supporting infrastructure such as communication towers. The construction cost by device type and TOC coverage area is summarized in Table E-1. The maintenance and operations costs consist of maintenance contract cost, operations contract cost, utility costs, and MDOT staff costs. The annual average operations and maintenance (O&M) cost per device during 2006 – 2013 was $11,338 as shown in Table E-2, but the annual O&M cost tends to decrease with more devices. The annual average O&M cost has reduced from

$14,160 in 2007 to $8,983 in 2013. In addition, SEMTOC and STOC have been operating freeway courtesy patrol (FCP) programs which cost $2.3 million annually. Table E-3 summarizes the annual O&M cost including FCP costs.

Table E-1: Summary of ITS Construction Costs (2006-2013)

		TOC Coverage Area			Overall
		SEMTOC	WMTOC	STOC	
New CCTV Quantity		124	57	56	237
New MVDS Quantity		222	120	65	407
New DMS Quantity		50	20	45	115
New TTS Quantity		1	0	5	6
Total		**397**	**197**	**171**	**765**
ITS Construction Cost		$45,728,333	$15,423,533	$20,506,649	$81,658,515
Estimated Design Cost		$8,424,541	$2,359,045	$2,973,464	$13,757,050
Estimated System Manager Cost		$4,938,524	$1,382,888	$1,743,065	$8,064,478
Total Construction Cost		**$59,091,399**	**$19,165,466**	**$25,223,178**	**$103,480,043**
Average Construction Cost per Device	Overall	$148,845	$97,287	$147,504	$135,268
	CCTV	$161,404	$97,906	$141,945	$141,535
	MVDS	$105,945	$76,064	$45,853	$87,538
	DMS	$308,848	$222,860	$307,037	$293,185
	TTS	$115,187	N/A	$95,422	$98,717

Note) Costs for major supporting infrastructure (communication towers) were excluded.

Table E-2: Total Operations and Maintenance Costs (2006 – 2013)

	SEMTOC	WMTOC	STOC	Total
Total CCTV Quantity	1162	301	115	1578
Total MVDS Quantity	1096	486	151	1733
Total DMS Quantity	541	134	115	790
Total TTS Quantity	1	0	8	9
Total Devices (Device-Year)	**2,800**	**921**	**389**	**4,110**
Maintenance Contract Cost	$12,006,309	$1,135,537	$1,064,344	$14,206,190
TOC Operations Cost	$13,137,988	$2,953,545	$2,220,658	$18,312,191
Utility Cost (power)	$2,255,840	$597,636	$304,964	$3,158,440
Utility Cost (communication)	$2,202,764	$641,047	$258,283	$3,102,093
MDOT Staff Cost	$4,500,000	$1,800,000	$1,518,750	$7,818,750
Total O&M Cost	**$34,102,901**	**$7,127,765**	**$5,366,998**	**$46,597,664**
Annual Average O&M Cost per Device	**$12,180**	**$7,739**	**$13,797**	**$11,338**

Note) Total ITS device quantity is the sum of devices active each year during 2006 – 2013.

Table E-3: Summary of Annual Operations and Maintenance Cost (2013)

	TOC Coverage Area			Overall
	SEMTOC	WMTOC	STOC	
Total number of devices	589	214	171	974
Annual Operations and Maintenance Costs	$5,426,092	$1,303,177	$2,020,119	$8,749,387
Annual O&M Cost per Device	$9,212	$6,090	$11,814	$8,983
Annual Freeway Courtesy Patrol Cost	$1,933,333	NA	$366,667	$2,300,000

User Perception Survey

This research also conducted a web-based user perception survey to identify how Michigan travelers perceive the benefits attributed to ITS. The questionnaire consisted of five primary categories: 1) exposure information and demographics, 2) travel behavior, 3) ITS device familiarity, 4) travel information use, and 5) suggestion for better ITS services. In total, 1,261 surveys were completed during a six month period from December 2013 to June 2014.

With regard to ITS device familiarity, DMS and Mi Drive were the most well recognized applications with 98.4 and 91.1 percent of respondents having at least some knowledge of their existence, respectively. Radio and television were the most frequently used sources of advanced traveler information systems (ATIS) on a daily basis at 46.2 and 35.7 percent, respectively. The most common trip changes resulting from travel information were changes in departure time (94.2 percent at least sometimes change) as well as route (95.9 percent at least sometimes change). Almost all of these proportions are significantly higher than similar studies performed in Michigan, which is likely explained by the nature of the population almost wholly representing active consumers of travel information.

The impact of the various types of travel information provided by MDOT ATIS was investigated to better understand how respondents' primary concerns affect ITS device familiarity, ATIS usage frequency and trip changes. Among the respondents surveyed, those who placed any degree of importance in freeway camera imagery were more likely to be familiar with all ITS deployments except TTS. Likewise, importance placed in freeway camera imagery had a significant positive effect on usage frequency of all sources of travel information. These results mimic a common sentiment in the open response portion of the survey, where a large number of respondents voiced requests for extended publically available CCTV coverage as well as improved image quality. Regarding pre-departure travel behaviors, the degree of importance placed in various types of information, including camera images, crash/accident, planned special events and road weather, primarily affected the decision to change route more than any other trip change. This observation indicates that travel information proves more impactful in route decision than scheduling or mode choices.

According to the survey results, radio, television and Mi Drive are the most frequently used ATIS sources and 93 percent of motorists are at least somewhat trusting general DMS information. The survey also revealed that FCP assisted motorists are willing to wait at least 15 minutes longer than actual wait times and over 90 percent are satisfied with the quality and response time of the service.

Performance of MDOT ITS

The three MDOT TOCs collect performance data to define benefits (or measures of effectiveness) by each ITS system or devices, and collect necessary data to analyze benefits of ITS systems. Table E-4 summarizes MDOT ITS performance by TOC.

Table E-4: Summary of MDOT ITS performance

TOC	Content	2009	2010	2011	2012	2013
SEMTOC	MVDS	108	125	192	241	274
	CCTV	140	147	169	186	216
	DMS	62	69	81	87	98
	Number of Calls	64,468	71,807	69,113	72,877	71,880
	MiDrive Hits	3,131,612	2,127,418	2,071,801	NA	NA
	Construction Messages	1,121	815	1,259	1,025	NA
	Number of Incidents	5,006	5,836	5,395	6,882	8,056
	High Impact Incidents	670	819	870	1,006	1,241
	FCP services	51,384	48,143	37,957	38,344	48,613
	Average response time	12.8	13.9	16.3	15.6	17.1
	Average Clearance time	8.9	8.8	9.9	9.3	11.2

TOC	Content	2009	2010	2011	2012	2013
WMTOC	MVDS	42	42	120	120	120
	CCTV	23	26	67	67	67
	DMS	11	12	27	27	27
	Number of Calls	1059	2712	2703	3492	3789
	Construction Messages	451	504	641	491	NA
	Number of Incidents	606	1192	1015	1373	1477
	Incident Clearance time	54	75	81	69	68
	Roadway Clearance time	NA	NA	NA	23	24
STOC	MVDS	0	0	31	55	65
	CCTV	0	0	19	40	56
	DMS	2	6	22	36	45
	Number of Calls	NA	NA	NA	3690	NA
	Construction Messages	NA	NA	NA	236	184
	Number of Incidents	NA	NA	NA	2452	7458
	Incident Response time	NA	NA	NA	NA	13.1
	Incident Clearance time	NA	NA	NA	NA	16.3

Table E-5: Estimated Incident Duration Reduction

	SEMTOC	WMTOC	STOC	TOTAL
Total Number of Incidents	56,425	1,477	7,458	65,360
LCAR Incidents	8,056	1,477	1,502	11,035
FCP Assisted	48,369	-	5,956	54,325
Average Duration	24.2	54.9	46.5	27.5
LCAR Incidents	47.1	54.9	117.2	57.7
FCP Assisted	20.4	-	28.7	21.3
Average Duration Reduced by ITS	24.5	23.9	32.3	25.38
LCAR Incidents	24.5	23.9[1)]	18.9[2)]	23.66
FCP Assisted	24.5	-	35.7	25.73

1) 24.5 minute reduction for incidents within the ITS dense area; 10 minute reduction for those outside
2) 44.9 minute reduction for incidents within the ITS dense area; 10 minute reduction for those outside

In an effort to determine incident reduction as a result of ITS, a descriptive statistical incident duration analysis was performed based on processed data provided by the TOCs. Finally, incident delay analysis as affected by ITS was performed. The most notable effect of ITS observed in reducing incident duration occurred in the STOC region, which saw a 35.7 minute assisted incident reduction as a result of ITS. For LCAR incidents, the reduction was more substantial at 44.9 minutes for all ITS and 57.7 minutes for CCTVs. Cross-sectional statistical analysis determined that ITS reduced incident durations between 18.9 and 24.5 minutes for high-impact incidents and between 24.5 and 35.7 minutes for FCP assisted events. A summary of estimated incident duration reduction is presented in Table E-5.

Modeling ITS Corridors

In this project, the research team selected a sample of representative corridors from each of the three MDOT TOCs. The Quadstone Paramics traffic microsimulation software package was utilized to quantify benefits from "with/without" ITS scenarios with regards to freeway incident management. MDOT's incident management programs strive to produce savings in congestion cost, reduce incident duration, reduce motorist delay, and improve safety by minimizing the probability of secondary crash occurrence. Seven major MDOT freeway corridors were selected for the simulation study. The corridor characteristics under consideration for site selection included AADT, ITS device density, economic impact and crash/incident history.

The simulation study provided valuable insight into the operational performance of ITS on the corridor level. Analysis determined that ITS was most beneficial in high duration, high reduction scenarios. Many factors governed the results according to each corridor, namely, traffic volume, network configuration and ITS device placement. Using microsimulation models was a cost-effective method in analyzing ITS corridors. It is suggested to adopt microsimulation models in developing deployment plans for ITS corridors.

Cost and Benefit Analysis

A cost-benefit analysis was performed at two levels: (1) by TOC and (2) by device. For purposes of cost-benefit analysis, the base year was assumed to be 2012. The analysis period extends for 20 years after base ITS deployment, while applying a 3 percent discount rate over the duration.

It was assumed that all devices were installed at the same time during the base year (2012) in order to avoid complexity in estimating benefits with partial ITS deployments. It was also assumed that the lifespan of ITS devices was 20 years. O&M costs were applied during the analysis period (2013 – 2032) and assumed to be the same for all years.

Table E-6: Summary of ITS Costs by TOC

Period		SEMTOC	WMTOC	STOC	Total
Number Devices		589	214	171	974
	DMS	98	27	45	170
	CCTV	216	67	56	339
	MVDS	274	120	65	459
	TTS	1	0	5	6
Construction Cost		86,519,413	30,765,154	27,788,750	145,073,317
	DMS	28,732,112	7,915,990	13,193,317	49,841,419
	CCTV	18,908,122	5,865,019	4,902,106	29,675,248
	MVDS	38,780,462	16,984,144	9,199,745	64,964,351
	TTS	98,717	-	493,583	592,299
Annual O&M Costs		5,426,092	1,303,177	2,020,119	8,749,387
Annual FCP Cost		1,933,333	-	366,667	2,300,000

The key focus of MDOT ITS is managing traffic incidents and providing recurrent and non-recurrent traffic information. In this study, ITS benefits were estimated from these activities. The benefits of ITS were comprised of travel time saving, secondary incident reduction, fuel consumption saving, emission cost saving, and crash reduction. Other benefits are using MiDrive to acquire travel information to potentially alter motorist travel decisions and user satisfaction from FCP services.

Incident delay was estimated by applying the queue concept. The reduced capacity by an incident is the main source of delay. The total delay includes the time to dissipate the queue after the incident is cleared. The total delay is reduced when the incident duration is reduced by ITS services. Based on the concept of queueing, a delay computation model was developed to quantify the ITS benefit. The benefit of ITS in reducing secondary incidents was included as a complimentary part of incident delay reduction. It was based on the likelihood of secondary incidents during an incident period. Emission and fuel consumption saving benefits were also estimated by applying unit monetary values. Crash reduction benefit was estimated by employing the negative binomial model that analyzed the impact of ITS devices on crashes. The model indicates that one DMS is likely to reduce 16.6 percent of crashes while one ITS devices other than DMS reduces 1.9 percent of crashes. The total amount of time spent for Mi Drive webpage and mobile app was regarded as an ITS benefit, because users willingly spend their time to acquire traffic information worth more than the time spent. The total benefit from the Mi Drive is estimated as $6.6 million from the total amount of 434,140 hours. In addition, FCP user satisfaction benefit is quantified by applying an average of $60.25 per assist.

Table E-7: Summary of Costs and Benefits

	SEMTOC	**WMTOC**	**STOC**	**TOTAL**
Construction Cost	$86,519,413	$30,765,154	$27,788,750	$145,073,317
Annual O&M Cost	$5,426,092	$1,303,177	$2,020,119	$8,749,387
Annual FCP Cost	$1,933,333	$0	$366,667	$2,300,000
Total Annual Benefit	**$46,764,939**	**$10,246,404**	**$8,675,271**	**$65,686,613**
LCAR Delay saving	$16,999,350	$2,916,013	$2,950,967	$22,866,331
FCP Delay Saving	$3,054,315	$0	$423,873	$3,478,188
Secondary Incident Delay Saving	$4,010,733	$583,203	$674,968	$5,268,904
Fuel Saving	$1,301,310	$187,994	$216,593	$1,705,897
Emission Saving	$1,315,257	$225,470	$263,126	$1,803,853
Crash Saving	$13,205,914	$4,924,239	$2,513,772	$20,643,926
MiDrive User Benefit	$3,963,827	$1,409,484	$1,273,122	$6,646,434
FCP Satisfaction Benefit	$2,914,232	$0	$358,849	$3,273,081

Benefit-cost ratios are presented at four different levels of benefits. As shown in Table E-8, benefit-cost ratios were all greater than 1.0, even at the base level, which includes delay, fuel consumption and emissions savings only. When including all benefits, the final statewide

BCR was estimated at $3.16 for every dollar spent. The BCR breakdown by TOC was 3.55 for SEMTOC; 3.04 for WMTOC; and 2.04 for STOC. Based on the estimated costs and benefits, it can be stated that MDOT's ITS investment was cost effective, even though its history was relatively short.

Table E-8: Summary of Benefit Cost Ratios

		SEMTOC	WMTOC	STOC	TOTAL
Sum of Present Value (Cost)		$196,009,067	$50,153,131	$63,298,098	$309,460,296
Sum of Present Value (Benefit)	A: Delay + Fuel + Emission	$396,945,383	$58,210,798	$67,387,927	$522,544,108
	BCR	2.03	1.16	1.06	1.69
	B: A + Crash	$593,416,042	$131,471,044	$104,786,514	$829,673,599
	BCR	3.03	2.62	1.66	2.68
	C: B + Mi Drive	$652,387,782	$152,440,611	$123,727,361	$928,555,754
	BCR	3.33	3.04	1.95	3.00
	D: C + FCP Satisfaction	$695,744,199	$152,440,611	$129,066,128	$977,250,938
	BCR	3.55	3.04	2.04	3.16

While it is difficult to separate ITS benefits by device, there might be differences in utilization of devices and their effectiveness. In order to identify the difference, the research team conducted phone interviews with TOC operators to understand the proportion each device type was utilized for daily operation activities. The overall consensus was that an operator spent 64%, 24% and 12% of their time for activities related with CCTV, DMS, and MVDS, respectively. Based on the operator's time split, cost-benefit ratios by device were estimated as shown in Table E-9. The benefit-cost ratio (BCR) of CCTV was the highest, while that of MVDS was the lowest. Both FCP and DMS also showed high BCR values. Even though MVDS are the backbone of ITS through providing basic traffic information, the analysis result showed a low BCR, due to relatively low utilization from the operators' perspective. However, it should be noted that TOC operators are using travel time information obtained from traffic sensors for their proactive operations decisions.

Table E-9: Summary of Benefit Cost Ratios by Device

	DMS	CCTV	MVDS	FCP
Construction Costs	$50,433,719	$29,675,248	$64,964,351	$0
Annual O&M Costs	$5,249,632	$2,624,816	$874,939	$2,300,000
Annual Benefits	$22,940,145	$28,596,776	$5,361,895	$8,787,797
Sum of PV Cost	$89,484,354	$107,776,519	$77,981,230	$34,218,192
Sum of PV Benefit	$341,291,433	$425,447,811	$79,771,465	$130,740,229
BCR	**3.81**	**3.95**	**1.02**	**3.82**
NPV	$251,807,079	$317,671,292	$1,790,235	$96,522,037

Conclusion and Recommendations

While positive and reinforcing, the final estimated statewide MDOT ITS deployment BCR of 3.16:1 is a conservative estimate compared to similar evaluations performed in other states. The research team proposes some important recommendations that were formulated during various stages of the study duration to improve the statewide ITS economic benefits.

1) The development and strict operation and maintenance of a consistent statewide incident database shared between all three MDOT TOCs will aid in communication between agencies and facilitate ease in cost and benefit estimation for future studies.
2) Deployment of an FCP program in the WMTOC region is expected to result in similar incident duration reductions as witnessed in the SEMTOC region (up to 24.5 minute duration reduction).
3) Future investments should focus on DMS and CCTV installation, while deployment of MVDS needs further studies in conjunction with the coming wake of Connected Vehicle technology.
4) TV and radio media outlets should focus on exposing safety-related travel information and operators should tailor Mi Drive information according to seasonal trends.

Chapter 1 Introduction

1.1 Research Problem

Traffic congestion has been a worldwide problem as a result of increased motorized traffic and urbanization. Congestion reduces the efficiency of transportation infrastructure and increases travel time, fuel consumption, and air pollution. In many regions in the United States, traffic jams can occur at any daylight hour, many nighttime hours and on weekends. The problems that travelers and shippers face include extra travel time, unreliable travel time and a system that is vulnerable to a variety of irregular congestion-producing incidents. According to the Urban Mobility Report (Schrank et al., 2012), congestion caused urban Americans to travel 5.5 billion hours more and to purchase an extra 2.9 billion gallons of fuel at a cost of $121 billion in 2011. Each auto-commuter paid $818 as a congestion cost.

Intelligent Transportation Systems (ITS) have been regarded as a cost-effective solution to help travelers in using existing transportation infrastructure by taking advantage of advanced communication technologies, such as advanced traveler information systems (ATIS), advanced traffic management systems (ATMS), advanced public transportation systems (APTS) and commercial vehicle operations (CVO). The concept of ITS has evolved and ITS applications have been expanded in various directions, including the Connected Vehicles (CV) technology that applies advanced vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-device (V2D) communications technologies. Typically, ITS application areas are classified into two parts: intelligent infrastructure and intelligent vehicles. While applications of intelligent vehicles include collision avoidance, collision notification, driver assistance, etc., those of intelligent infrastructure include various roadside traffic operations and management applications, such as freeway management systems, arterial management systems, crash prevention and safety systems, road weather information systems, traffic incident management, transit management, emergency management, traveler information systems, commercial vehicle operations, intermodal freight management, etc. Various ITS applications are invented and deployed to fulfill U.S. DOT's ITS goals, such as safety, mobility, efficiency, productivity, energy and environmental impacts, and customer satisfaction.

Michigan's ITS deployment efforts date back to 1995, when MDOT initiated the design and build of ITS infrastructure in southeast Michigan. The initiation was considered the largest ITS deployment of its kind in the world at that time. Since then, MDOT has deployed many ITS devices, mostly in the southeast region of Michigan. MDOT's rigorous efforts led to developing strategic goals and objectives. According to the MDOT's ITS strategic plan, the ITS mission is as follows:

"Develop and sustain a program at MDOT to improve safety, operational performance and integration of the transportation system utilizing Intelligent Transportation System technologies for economic benefit and improved quality of life."

The MDOT strategic plan is executed by regional ITS architectures and deployment plans. MDOT has also invested many advanced ITS technologies, such as Connected Vehicles, to maintain leadership in this area as a home state of automobile industry. While many new ITS technologies are being developed and tested worldwide, advanced traffic control and information systems have been deployed to help Michigan motorists and travelers. MDOT's ITS deployment plans include applications in freeway traffic management systems, arterial management system, advanced public transportation systems, freeway service patrols, smart work zone, road weather information systems, and emergency traffic management. MDOT has invested significantly in ITS deployments across the state over the last six years. Michigan's traffic safety and operations have been improved by deploying these ITS technologies.

As Peter Ferdinand Drucker, a social ecologist, stated that, "*You cannot manage what you cannot measure*", performance measures are very important. Likewise, the U.S. Department of Transportation (DOT) emphasizes the importance of performance-based planning in the latest authorization of transportation bill, Moving Ahead for Progress in the 21st Century Act (MAP-21). One of the key emphases in MAP-21 is performance measurement. Under MAP-21, performance management is emphasized as a means towards more efficient investment through performance-based planning and programming (FHWA, 2012). In fact, due to an increasingly competitive fiscal environment, transportation agencies around the country are being asked more than ever to justify their programs and expenditures. ITS investments are not an exception from this requirement. However, the benefits of Michigan ITS have not been fully quantified yet.

Accordingly, MDOT is lacking in response to inquiries from public and legislators on the costs and benefits of ITS deployments, despite its great benefits to Michigan travelers. Therefore, there are needs for reviewing and quantifying costs and benefits of MDOT's ITS investments.

1.2 Research Objectives

The main objective of this research is to review and summarize the benefits and costs of ITS deployed by the Michigan Department of Transportation. In order to achieve this main objective, this research includes the following sub-objectives:

1) developing a ITS database including all ITS devices deployed by region
2) reviewing costs associated with ITS deployment
3) collecting all performance measures reported by each Traffic Operation Center (TOC)
4) analyzing traffic incidents and clearance time
5) quantifying benefits from ITS deployed by MDOT

1.3 Research Scope and Overview

There are many types of ITS supported by MDOT, including Connected Vehicle Systems. However, this research does not include connected vehicle systems in its scope. The focus of this research is to analyze the costs and benefits associated with ITS devices deployed on Michigan highways. To accomplish the objectives of this research, the following tasks will be performed:

Task 1: Literature Review

Task 2: Reviewing MDOT's ITS Deployments

Task 3: User Perception Survey

Task 4: Collecting Performance Data

Task 5: Selection of Analysis Tool and Modeling ITS Corridors

Task 6: Cost and Benefit of ITS System

Task 7: Cost and Benefit of Individual ITS Devices

Task 8: Recommendations and Final Report

Figure 1-1 depicts the connectivity of the eight tasks and the overall flow of this research.

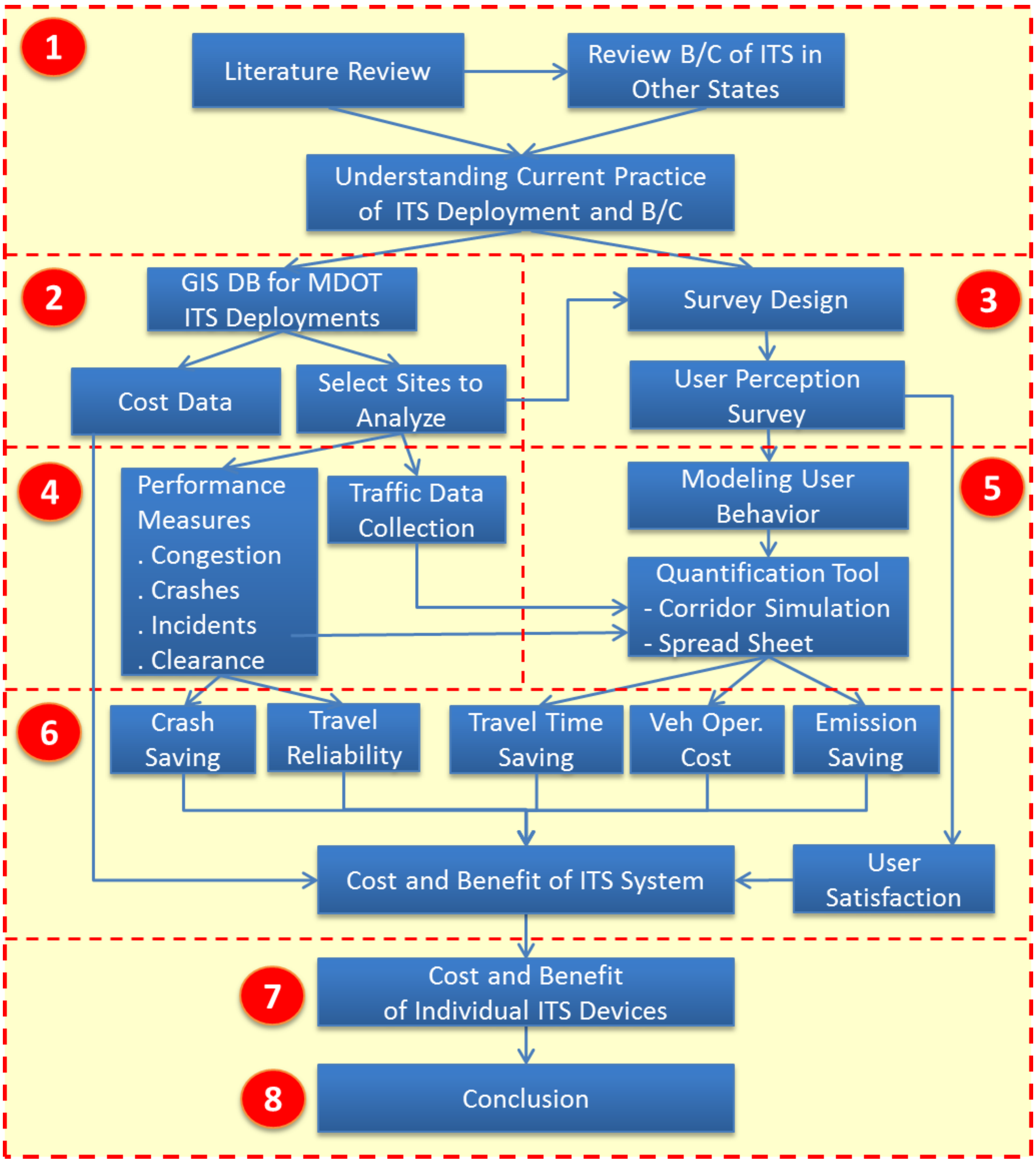


Figure 1-1: Overall Research Approach

Chapter 2 Literature Review

2.1 ITS Cost-Benefit Evaluation Methods

Various methods have been utilized in the past to evaluate ITS deployments, both pre- and post-implementation. Examples of these approaches include traditional cost-benefit analysis (CBA), multi-criteria analysis (MCA), sketch-planning, before-and-after studies, simulation studies, "willingness-to-pay" analyses and cased-based reasoning techniques. The discussion that follows will summarize past research which employed these methods.

2.1.1 Traditional Cost-Benefit Analysis

The traditional cost benefit analysis is the most utilized approach by researchers and transportation agencies in assessing the impact of ITS deployments on traffic operations performance. However, the method has stagnated and has not been refined or improved for several decades (Leviäkangas *et al.*, 2002). Regardless, some researchers continue to believe that CBA potentially represents the best method due to a lack of viable alternatives. Travel time savings are often the most important and relevant benefit gleaned by CBA. A key limitation of CBA is its inherent failure to analyze "risk-return tradeoff," which results in decision makers choosing against the alternative with acceptable Cost/Benefit (C/B) ratio if the probability for excessive cost is high (Yang *et al.*, 2007). Other limitations include the inability to quantify the value of ITS information dissemination to the user (or system) or the tendency of the user to alter travel behavior (Juan *et al.*, 2006).

2.1.2 Multi-Criteria Analysis

The MCA is also commonly referred to as the analytic hierarchy process (AHP). A key distinguishing factor of MCA compared to CBA is that priority is placed on investment efficiency rather than C/B ratio (Leviäkangas *et al.*, 2002). Some benefits of MCA include the allowance for analysis of criteria not easily quantified monetarily (Juan *et al.*, 2006), decision makers can evaluate ITS alternatives based on preferences, and criteria outside the range of CBA can be included. The disadvantages of AHP include the subjectivity of decision makers and it must be performed on case-by-case basis, thus stifling transferability (Leviäkangas *et al.*, 2002).

2.1.3 Sketch-Planning

Sketch-planning is a spreadsheet-based or GIS-based tool that produces order-of-magnitude estimates of transportation and land-use demand and impacts. It is touted for its low cost and reduced complexity. Typical applications include rural and suburban areas or fast-growing areas, as well as cities, counties, regional planning agencies and state agencies. Sketch-planning utilizes a framework of statistical relationships and rules that evaluate the ITS system on the basis of characteristics and measures of effectiveness (Berger et al., 2007). Recently, sketch-planning has been incorporated in a Florida DOT (FDOT) evaluation to determine environmental benefits as a result of ITS (Hadi *et al.*, 2008). For statewide ITS sketch-planning, two applications are typically utilized: SCReening for Intelligent Transportation Systems (SCRITIS) and the ITS Deployment Analysis System (IDAS). Of the two resources, SCRITIS requires less detail compared to IDAS (Peng *et al.*, 2000).

IDAS is a FHWA-developed software with a higher cost and complexity compared to most other sketch-planning tools (Peng *et al.*, 2000). It is designed to be a near-term ITS sketch-planning solution. IDAS can predict relative costs and benefits for more than 60 types of ITS investments. Input variables include travel time and speed, freeway throughput, number of accidents, emissions and fuel consumption, while output variables include travel time reliability, mobility, safety, emissions and fuel consumption. Output variables are calculated based on user-provided estimates of input variables. It can be used for alternatives analysis (He *et al.*, 2010). IDAS analyses often show a high degree of uncertainty in ITS benefits and costs (Yang *et al.*, 2007). Thus, it is not suitable for providing detailed and accurate estimates of ITS benefits.

2.1.4 Questionnaire Surveys

The most commonly utilized questionnaire design used by researchers to analyze motorist receptiveness to ITS is the stated preference approach. Stated preference questionnaires require the respondent to indicate how he/she would react to various scenarios or the degree of value placed in the topic of interest by offering a choice between limited, mutually exclusive alternatives. Stated preference surveys have been used by researchers to investigate the impact of ATIS on trip changes (Tay *et al.*, 2010; Richards *et al.*, 2007; Abdel-Aty *et al.*, 1997; Bifulco *et al.*, 2014; Razo *et al.*, 2013), in various non-recurrent traffic conditions (Muizelaar et al., 2007), on acceptance of transit (Abdel-Aty *et al.*, 2001) and in emergency situations (Robinson *et al.*, 2011). The primary limitation of stated preference surveys is the overstatement of travel behaviors (Richards *et al.*, 2007; Peng *et al.*, 2004).

2.1.5 Other Methods

Before-and-after studies represent another commonly used approach that attempts to comprehensively summarize ITS benefits in a practical sense (He et al., 2010). Such studies can evaluate the following changes as a result of ITS deployment: traffic capacity, human resources, reduction of traffic accidents and duration and frequency of congestion (He et al., 2010; Chen et al., 2010). Before-and-after studies require field measurement data from devices, such as vehicle detectors, before and after ITS device deployment.

Another frequently employed evaluation method is the simulation study. These studies are more suitable for urban roadways where traffic signals and congestion are more frequent (RITA, 2011). ITS evaluation using simulation has been used to evaluate ICM deployment, crash prevention and safety, work zone management, system impact of TMC, and the impact of traveler information.

"Willingness-to-Pay" studies have been conducted to evaluate the "Countdown" real-time information system on London transit. Juan *et al.* (2006) performed a real-time survey on transit vehicles to measure user willingness to pay an additional amount while riding the bus.

Case-based reasoning (CBR) is an artificial intelligence technique based on the premise that humans typically solve a new problem by adapting and revising a solution to a previous problem. The approach establishes a "case-base" of previous ITS deployments under different traffic conditions with which to compare against. Sadek et al used CBR in conjunction with a DTA model to evaluate the benefits of diverting traffic through the use of VMS (Sadek *et al.*, 2003).

2.2 ITS Costs and Benefits by Device

In September 2011, the US DOT Research and Innovative Technology Administration (RITA) released a report titled, "Intelligent Transportation Systems Benefits, Costs, Deployment, and Lessons Learned Desk Reference: 2011 Update". The report summarizes a collection of databases known as the "ITS Knowledge Resources", which track developments regarding evaluation of deployed ITS nationwide. The discussion that follows is a comprehensive synopsis of the report contents concerning freeway traffic management, arterial traffic management, advanced public transit, smart work zones, road weather information systems and regional parking management.

2.2.1 Freeway Traffic Management

Freeway traffic management ITS applications consist of surveillance, ramp control, lane management, special event transportation management, information dissemination, and enforcement. Surveillance systems use vehicle detectors and cameras in conjunction with other freeway management technologies. Closed circuit television cameras and other security applications can be used to monitor important transportation infrastructure. The unit cost for a CCTV ranges from $8,000 to $16,000 (RITA, 2011). Speed enforcement is conducted by detector-activated CCTV feed, which records vehicles breaking the speed limit. Dynamic message signs (DMS) and highway advisory radio (HAR) are used in freeway traffic management for information dissemination and lane management. DMS is used in 86 of the United States' largest metropolitan areas (populations exceeding 1 million). The unit cost for a DMS ranges $28,000 to $136,000, and $16,000 and $21,000 for a portable unit. In Grand Canyon National Park, DMS and HAR were estimated to reduce 66,000 to 99,000 vehicle-miles driven and save 2,600 to 28,000 gallons of fuel in 2008 (Briglia, 2009). HAR applications also provide info on 21 percent of freeway miles in the largest metro areas in the US. The unit cost for a HAR ranges from $15,000 to $36,000, and $4,000 to $8,000 for an HAR sign (RITA, 2011). The SR14 traveler information system in Washington employs the use of HAR, with a total system cost of $511,300 (Briglia, 2009). With respect to the stated ITS goals of safety, mobility, efficiency, productivity, energy/environment, and customer satisfaction, lane management has a positive impact on safety, while information dissemination has a positive impact on safety, mobility, and customer satisfaction. Some benefit-cost ratios related to freeway traffic management include 9.7:1 over 10 years for ICM deployment in San Diego, California and 14:1 to 39:1 for converting HOV lanes to HOT lanes in San Francisco, California (Cambridge Systematics, 2008; Alexiadis et al., 2009).

2.2.2 Arterial Traffic Management

Arterial traffic management ITS techniques include surveillance, traffic control, lane management, parking management, information dissemination, and enforcement. As seen, there is a considerable amount of overlap between ITS in freeway traffic management and arterial traffic management, with many of the same technologies in deployment in both applications. Surveillance of arterial streets can also be used to monitor security of critical infrastructure, as in freeway management. 48 percent of signalized intersections in the country's largest metro areas in 2010 are monitored by surveillance, representing a 100 percent increase since 2000 (Richards *et al.*, 2007). Surveillance is shown to positively impact customer satisfaction.

In Monroe County, NY, CCTV and other forms of surveillance have been shown to reduce incident validation times by 50-80 percent, for an estimated per incident time savings of between 5 and 12 minutes (Bergmann Associates, 2006). Some unit costs of common surveillance equipment used in ITS include $7.5K to $13.3K for inductive loops at intersections, $14K for a remote traffic microwave sensor at an intersection, and $8K-$16K for CCTVs (RITA 2011). Deployment of CCTV cameras on arterial streets is seeing a moderate growth rate. The cost to install and implement five CCTV cameras in Monroe County in 2005 was $55,860 per camera. A lesson learned by the New York State Police in coordination with the New York Department of Transportation was to use CCTV at signalized intersections for monitoring congestion and adjusting signal phases. CCTV can also be used as a roadside subsystem in lane management.

DMS are often used in arterial traffic management systems to share information collected with road users in an effort to smooth traffic flow during special events. DMS also has parking management applications in its ability to show parking space availability, as demonstrated by the smart parking system in deployment in San Francisco (Rodier, 2006). Similar to freeway traffic management, DMS is often used in information dissemination, with permanent DMS, portable DMS, and HAR being used on 2 percent of arterial street miles in the largest cities (RITA, 2011). DMS costs for arterial applications are the same as in freeway applications. HAR does not enjoy as high of a level of deployment in arterial ITS as compared to freeway ITS. With respect to the ITS goals outlined in the Freeway Traffic Management section, parking management has a positive impact on efficiency and a substantial positive impact on mobility and customer satisfaction. Information dissemination has a positive impact on mobility and a substantial positive impact on productivity. Some example B/C ratios of arterial ITS include 461.3:1 in Virginia and 57:1 in Pennsylvania (Park et al., 2010; Southwestern Pennsylvania Commission, 2011).

2.2.3 Advanced Public Transit

Despite the unfavorable economic condition of the past 10 years, the transit industry has grown by over 20% during this time-span (RITA, 2011). Accordingly, transit agencies continue to deploy ITS technology at a rapid rate. From 2000-2010 in the country's biggest cities, the percentage of fixed route buses equipped with AVL increased from 31 percent to 66 percent, the percentage of demand responsive vehicles with CAD increased from 28 percent to 88 percent, and the percentage of fixed route buses equipped with electronic real-time monitoring systems increased from 15 percent to 35 percent (RITA, 2011). ITS strives to increase passenger throughput by offering a safer and more reliable service due to systems that combine Automated Vehicle Location (AVL) and Computer Aided Dispatch (CAD), automatic passenger counters (APC), electronic payment and smart card systems, and real time information. AVL and CAD systems reduce passenger wait times by improving transit reliability. Vehicle-to-dispatch communication systems realize security and incident management benefits by facilitating quicker response times. Real time information on vehicle location and schedule allows agencies to provide transit signal priority, which improves trip and schedule reliability. Multi-Modal Trip Planning Systems (MMTPS) allow passengers to confirm schedule information, improve transfer coordination, and reduce wait times through their ability to provide public access to bus location data and schedule status information.

Two of the primary ITS programs from the mid-2000s are beginning to demonstrate positive impacts, namely the Mobility Service for All Americans (MSAA) and Integrated Corridor Management (ICM). With regard to the impact of advanced public transit ITS on the primary goals, operations and fleet management is shown to have a positive impact on mobility, productivity, and customer satisfaction, and a substantial positive impact on efficiency and energy/environment. Information dissemination has a positive impact on customer satisfaction. Transportation demand management has a positive impact on productivity and a substantial positive impact on customer satisfaction. Positive impacts have been demonstrated on the goals of safety, productivity, and customer satisfaction through the safety and security public transit ITS applications, such as the advanced software and communication technology used to enable data and voice to be transferred between TMCs (Transportation Management Centers) and transit vehicles.

Some costs associated with ITS in public transit include a capital cost of between $1K and $4K per mobile data terminal, with installation costs between $500 and $1,000. AVL/CAD systems have a unit cost of between $8K and $10K per vehicle (RITA, 2011). A few lessons were learned from deployment of ITS in public transit applications, including: a need to plan for the semi-annual evolution of communications technologies, foresee and prepare against the challenges of operating and maintaining a reliable TSP system (installation, calibration, and testing of TSP emitters), and improving general transit safety and security through video assessment (RITA, 2011).

2.2.4 Smart Work Zones

ITS is used in smart work zones (SWZ) as temporary traffic or incident management systems. These systems can be stand-alone or supplement existing systems during construction. ITS deployments in smart work zones govern travel speeds, disseminate information regarding lane configuration changes or travel times and delays, hasten incident detection and allocate pertinent incident management, and guide traffic flow during full road closures. Smart work zones improve driver behavior through dynamic lane merger systems. SWZs which include speed monitoring displays have been shown to reduce vehicle speeds by 4-6 MPH and reduce speeding likelihood by 25-78 percent (RITA, 2011). 39 percent of TMCs on freeways and 34 percent of TMCs on arterials are deploying SWZs, according to a 2010 survey. SWZs display positive impacts on efficiency, productivity, and customer satisfaction, and substantial positive impact on safety and mobility.

With respect to the mobility impact, a work zone simulation of four-to-two lane closure in Washington D.C. revealed that a VSL configuration resulted in mean savings of 267 vehicle-hours of delay (Fudala *et* al., 2010). While in Texas, work zone traffic management systems diverted an average of 10% of mainline traffic to alternate routes (Luttrell, 2008). With respect to the safety impact, in Kalamazoo, MI, activation of a Dynamic Lane Merger System in work zones reduced the number of forced mergers by seven times and the number of dangerous mergers by three times (Luttrell, 2008). With respect to the customer satisfaction impact, in Little Rock, Arkansas, a survey showed that 82% of drivers stated that an Automated Work Zone Information System enhanced their reaction to slow or stopped traffic (Krechmer, 2010). In the United States, a study of 17 states determined the cost of work zone ITS to range from $100K to $2.5 million, with the majority costing in the $150K-$500K range (RITA, 2011). A lesson learned about SWZ is the necessity to coordinate the schedules for ITS deployment and roadway construction through involvement of the construction contractor.

2.2.5 Road Weather Information

The estimated cost of weather-related crashes in the US ranges from $22-$55 billion annually, with 24% of all crashes occurring during poor weather conditions from 1995-2008 (RITA, 2011). Recognition of the importance in mitigating the impact of weather on transportation systems prompted the creation of the Road Weather Management Program (RWMP) at the Federal Level. The RWMP develops weather related ITS systems. Environmental Sensor Stations (ESS) represent the standard method to monitor road conditions in the Road Weather Information System (RWIS), and the recently developed *Clarus* web-interface collects and distributes ESS data across North America for all interested parties. The RWMP also developed the Maintenance Decision Support System (MDSS), a decision support tool that automatically integrates weather model information with a road model, rules of practice, and maintenance resource data.

Integration of weather information into agency TCMs is known as Weather-Responsive Traffic Management (WRTM). WRTM operates under three specific strategies: advisory, control, and treatment. Information dissemination falls under the “advisory” strategy, and includes fog warnings on DMS and indicating flooded routes. With respect to the “control” strategy, variable speed limits are used to reduce speed limits and ITS is used to modify traffic signal timing based on pavement conditions reported by ESS. The MDSS is commonly employed with regard to the “treatment” strategy. In addition, agencies install winter maintenance vehicles with AVL systems and mobile sensors to aid in determining pavement conditions and correct treatment application rates (RITA, 2011).

Within RWIS, surveillance, monitoring, and prediction systems have a positive impact on safety and mobility, and a substantial positive impact on customer satisfaction. Information dissemination (advisory strategy) positively impacts safety and has a substantial positive effect on customer satisfaction. Traffic control (control strategy) has a positive impact on safety. Response and Treatment (treatment strategy) has a positive impact on safety and productivity, and a substantial positive impact on energy/environment. Costs of RWIS vary widely, dependent on system scope, complexity, and the specific technology in use. In Michigan, RWIS demonstrated a region-dependent B/C ratio of 2.8:1 to 7:1 (Krechmer, 2010). Lessons learned about RWIS deployments include: investing in accurate road weather information to guarantee greater usage and lower costs, and usage of a self-evaluation guide and integration planning process to foster improved perception of the benefits of RWIS integration to enhance TMC performance (RITA, 2011).

2.2.6 Regional Parking Management

Regional parking management is typically deployed in urban areas or at airports and outlying transit stations. ITS is used to monitor open parking spaces and provide the information to drivers in an effort to reduce traveler frustration and congestion experienced while discovering a parking space. The proportion of agencies making use of parking management systems increased from 5% in 2000 to 8% in 2010 (RITA, 2011). An example of ITS technology used for parking management is electronic parking fee payment, which uses various forms of technology (magnetic cards, transponders, etc.) to simplify payment and lower congestion at entrances and exits. Regional parking management in the form of a Smart Parking system in San Francisco has shown to impart a positive impact on mobility (decrease average commute time by 5% for 50-minute commute and reduce total vehicle miles traveled by 9.7 miles per month) and customer satisfaction (30% of commuters would prefer an expansion of Automated Parking Information Systems), as well as a substantial positive impact on efficiency (Rodier, 2006). Some unit costs associated with a Parking Management System include $1K-$3K for entrance/exit ramp meters, $1K-$3K for tag readers, $10K-$15K for the billing/pricing database and software, and $16K-$35K for the parking monitoring system (RITA, 2011).

2.3 Similar Traffic Operation Centers in Other States

In an effort to compare MDOT's ITS deployments to other states, MDOT recommended a number of metropolitan areas to evaluate against the three state TOCs: SEMTOC, WMTOC and STOC. The recommended TMCs were judged to be most similar to MDOT TOCs on the basis of total miles of ITS coverage and percentage of ITS device coverage by device. With respect to SEMTOC, the cities included St. Louis, MO, Miami, FL, Kansas City, MO and Atlanta, GA. WMTOC was compared with the Collinsville, IL District 8 CommCenter, while the Lansing STOC was most similar to the Milwaukee, WI STOC. A discussion of literature review concerning ITS deployments in these similar locations by MDOT TOC follows.

2.3.1 SEMTOC

As mentioned previously, SEMTOC, located in Detroit, was determined to be most similar to the St. Louis, MO "Gateway Guide" TMC, the Miami, FL "SunGuide" TMC, the Kansas City, MO "KC Scout" TMC and the Atlanta, GA TMC. Among these four cities, analysis showed that the St. Louis Gateway Guide was most congruent with the Detroit SEMTOC, on the basis of total miles of ITS coverage as well as ITS device split, as shown in Table 2-1 on the following page. A short summary of some of the cost-benefit evaluation performed on the Gateway Guide ITS deployments follows.

VSL signs were installed on Interstate Loop I-270/I-255 to garner consistent speeds during congestion and lower the closing speeds of incoming traffic. This freeway management ITS deployment reduced the number of crashes by 4.5 to 8 percent (Bham, 2010). St Louis also has a traffic incident management and freeway service patrol system known as "St. Louis Motorist Assist", which covers all freeway segments in the metro area. Analysis revealed that St. Louis Motorist Assist reduced secondary crashes by 1,082 annually, with an estimated B/C ratio of 38.25:1 (Sun, 2010). Operating costs of St. Louis Motorist Assist were $2,015,378 in 2008 and $2,075,839 in 2009 (RITA, 2011). St. Louis has also deployed arterial service patrols, most notably during the "New I-64 Project", demonstrating a B/C ratio of 8.3:1 and reduction in yearly congestion costs of $1,034,000 (Ryan *et al.*, 2009).

Table 2-1: TOCs Similar to SEMTOC

Center	**SEMTOC**	**Gateway Guide**	**SunGuide TMC**	**KC Scout**	**Atlanta TMC**
Location	Detroit, MI	St Louis, MO	Miami, FL	Kansas City, MO	Atlanta, GA
Total Miles of ITS Coverage	200	200	215	150	230
Total ITS Devices	452	676	676	649	825
% Cameras	37.2%	44.4%	35.2%	39.6%	66.7%
% DMS	19.2%	18.5%	16.3%	9.2%	13.3%
% Vehicle Detectors	43.6%	29.6%	45.3%	43.6%	20.0%
% Ramp Meters	0.0%	0.1%	3.3%	4.5%	0.0%
% Dynamic Trailblazers	0.0%	0.0%	0.0%	0.0%	0.0%
% Travel Time Signs	0.0%	0.0%	0.0%	0.0%	0.0%
# of ITS Per Mile Coverage	2.3	3.4	3.1	4.3	3.6

Table 2-2: TOCs Similar to WMTOC

Center	**WMTOC**	**District 8 CommCenter**
Location	Grand Rapids, MI	Collinsville, IL
Total Miles of ITS Coverage	130	51
Total ITS Devices	213	127
% Cameras	31.5%	38.6%
% DMS	12.2%	6.3%
% Vehicle Detectors	56.3%	55.1%
% Ramp Meters	0.0%	0.0%
% Dynamic Trailblazers	0.0%	0.0%
% Travel Time Signs	0.0%	0.0%
# of ITS Per a Mile Coverage	1.6	2.5

2.3.2 WMTOC

The MDOT WMTOC is located in Grand Rapids, MI. The TOC manages 130 miles within the MDOT Grand Region with approximately 2.1 ITS devices per mile of coverage. The District 8 CommCenter in Collinsville, IL was found to be the most similar TMC to WMTOC, as shown in Table 2-2 on the following page. However, no previous research conducted on ITS deployment evaluation was found concerning the District 8 CommCenter in Collinsville.

2.3.3 STOC

The STOC, located in Lansing, MI, manages the rest of the 133 statewide ITS deployments outside of the Grand and Metro MDOT regions, with a primary focus on the University region. A comparative analysis determined that the STOC in Milwaukee, WI was most similar to the Lansing STOC on the basis of ITS device split, as shown in Table 2-3. In Milwaukee, automatic vehicle location (AVL) contributed to a 28 percent reduction in buses behind schedule by greater than one minute (RITA, 2011).

Table 2-3: TOCs Similar to STOC

Center	**STOC**	**STOC**
Location	Lansing, MI	Milwaukee, WI
Total Miles of ITS Coverage	N/A	N/A
Total ITS Devices	129	918
% Cameras	31.8%	33.6%
% DMS	28.7%	8.9%
% Vehicle Detectors	39.5%	41.2%
% Ramp Meters	0.0%	15.7%
% Dynamic Trailblazers	0.0%	0.7%
% Travel Time Signs	2.3%	0.0%
# of ITS Per a Mile Coverage	N/A	N/A

2.4 ITS Benefits

MDOT's strategic goals in ITS are to improve safety, mobility, efficiency, productivity, energy and environmental impacts, and customer satisfaction. ITS applications deployed to attain these goals include two components: intelligent infrastructure and intelligent vehicles. Intelligent vehicle systems consist of collision avoidance, collision notification and driver assistance. Intelligent infrastructure is primarily concerned with roadside traffic operations and management applications, such as freeway management systems, arterial management systems, crash prevention and safety systems, RWIS, traffic incident management, transit management, emergency management, traveler information systems, commercial vehicle operations, intermodal freight management, etc. A number of ITS evaluation studies have been conducted in Michigan, a few of which will be summarized below.

In Oakland County, signal retiming provided a 1.7-2.5 percent reduction in carbon monoxide emissions, 2.7-4.2 percent reduction in hydrocarbon emissions, and a 1.9-3.5 percent reduction in nitrogen oxide emissions (Halkias *et al.*, 2004). A pre-deployment CBA of RWIS performed by Krechmer *et al.* (2010) revealed a rural, region dependent B/C ratio ranging from 2.8:1 - 7.0:1, due to reduced travel times, crash reduction and lowered operating costs. A summary of the costs in the four regions under analysis is shown in the table below (includes 2007 annualized capital cost and annual O&M costs).

Table 2-4: Costs and Benefits of Michigan Road Weather Information Systems

Region	ESS Quantity	Capital	O&M	B/C Ratio
North	50	$4,020,000	$460,000	2.8
Bay	15	$2,060,000	$256,000	7
Grand	?	$2,272,000	$233,000	5.1
Superior	34	$3,463,000	$358,000	3.4

Source: Krechmer *et al.*, 2010

Luttrell et al. (2008) found that, in Kalamazoo, smart work zones reduced the frequency of forced merges and dangers merges by seven times and three times, respectively. The Flint Mass

Transportation Authority established a back-up emergency system at an estimated capital investment of $500,000, with $50,000 annual operations and maintenance costs (IBI Group, 2005). Sayer *et al.* (2011) performed a behavioral analysis on 108 volunteers who drove vehicles with crash warning systems installed, and found that eight of the volunteers stated that the system prevented a crash, with 72 percent of the drivers indicating a preference to have the system installed in their personal vehicles. A 1999 U.S. DOT report (1999) investigated adaptive cruise control in a Michigan field evaluation and reported a reduction of rear-end crashes by 8 to 23 percent. Gates *et al.* (2012) and Hedden *et al.* (2011) examined the utilization frequency of various travel information sources in Michigan (including DMS, radio, television, Mi Drive, other websites, etc.), and found very low user familiarity with Mi Drive: 22.5 and 19 percent, respectively.

Kimley Horn (2010), in association with Cambridge Systematics and HNTB, prepared the "I-75, US-127, I-94 Triangle ATIS Plan" in May 2010, evaluating traffic conditions and incident issues on these Michigan freeways. The report used the Michigan statewide travel demand model, in conjunction with IDAS, to evaluate ITS alternatives. ITS projects were evaluated in areas that include the North, Bay, Southwest, University and Metro regions. A "spectrum" approach was used to analyze the statewide ITS plan, using criteria that consisted of existing volumes, future volumes and crash rates. Finally, the report assigned a deployment plan based on the results of the spectrum to provide information on alternate routes in an effort to reduce congestion and incidents.

The Washington State DOT (WSDOT) published "The 2014 Corridor Capacity Report" in October 2014 (WSDOT, 2014). The report comprehensively summarizes a multimodal analysis of Washington's highway system performance, including a cost-benefit analysis of WSDOT's incident management program – "Incident Response" (IR). As of 2013, WSDOT operated 933 CCTVs, 279 DMSs, 109 RWISs and 767 traffic data stations. IR managed 43,088 incidents in 2013 with an average clearance time of 12.7 minutes. The report estimated $67.4 million in economic benefit as a result of IR in reducing incident-related congestion and secondary incident prevention, resulting in a 15:1 B/C ratio. The estimated savings due to incident-related congestion reduction and secondary crash prevention were $37.6 million and $29.8 million, respectively.

URS Corporation published "Task Order 5.2: Benefits Analysis for the Georgia Department of Transportation NaviGAtor Program" for the Georgia DOT in August 2006 (URS, 2006). The report summarized the methodology and findings of a sweeping cost-benefit analysis performed for the GDOT incident management program –"NaviGAtor". Benefits under consideration included mobility, environmental, safety and customer satisfaction. Similar to the WSDOT report, the mobility benefit provided by incident management was the total savings in incident-delay. Also like the WSDOT analysis, the safety benefit was wholly provided by the reduction in secondary crashes. In total, NaviGAtor provided an estimated $187,228,535.00 in estimated cost savings, resulting in an annual B/C ratio of 4.4:1.

Chou and Miller-Hooks (Chou, 2009) utilized a simulation-based analysis to conduct a B-C analysis of the New York state freeway service patrol – "Highway Emergency Local Patrol". Simulation scenarios were developed varying incident type by number of lanes (or shoulder) blocked, traffic volume, and incident duration reduction to determine the savings in travel delay, fuel consumption and emissions. On these measurements alone, the study computed a B/C ratio of 2.68:1, assuming a $40.00/truck-hour operating cost rate. Khattak and Rouphail (Khattak, 2004) assessed the benefits provided by Incident Management Assistance Patrols (IMAP) on North Carolina freeways. The research focused on creation of a decision-support tool for determining highest priority locations for IMAP dispatch based on incident/crash data and freeway traffic volume. However, in the process of developing the tool, Khattak and Rouphail estimated a 4.3:1 and 3.5:1 B/C ratio for deploying IMAP in Raleigh and Asheville, respectively. The benefits in this study were conservatively estimated on incident-delay reduction alone. Similarly, Moss (Moss, 2012) developed a benefit-cost model for incident management in Knoxville, TN using incident-delay savings provided by incident management based on traffic sensor travel time data and Tennessee DOT incident logs. Moss estimated a B-C ratio of 8.5:1. Ozbay et al (Ozbay, 2009) utilized the Rutgers Incident Management System (RMIS), a traffic simulation used to evaluate incident management performance, on the South Jersey highway network to estimate the benefits provided by DMS and FSP. The study found that the impact of DMS in diverting traffic resulted in a B/C ratio of 9.2:1, while the positive effect of FSP in reducing incident duration resulted in a B/C ratio of 3.9:1. Chowdhury et al (Chowdhury, 2007) at Clemson University published the "Benefit Cost Analysis of Accelerated Incident Clearance:

Final Report" in April 2007 for the South Carolina DOT. The study employed traffic simulation to conduct a benefit-cost analysis of the impact of various ITS applications on accelerated incident clearance for both motorists and the environment. Algorithms were developed for use in the Paramics microsimulation software to model various incident detection, response and clearance strategies. Ultimately, B-C ratios of 11:1, 12:1 and 7:1 were determined for FSP, traffic cameras and traffic sensors, respectively.

2.5 Findings from Literature Review

Various methods were described to perform benefit-cost evaluations. These include, but are not limited to, traditional B-C analysis, multi-criteria analysis, sketch-planning, questionnaire surveys, and others. The traditional CBA approach is most commonly utilized, but suffers from limitations such as inability to analyze risk-return tradeoff, the value of ITS information dissemination and tendency of the user to alter travel behaviors. The multi-criteria analysis accounts for risk-return tradeoff by placing priority on investment efficiency rather than raw B/C ratio, while questionnaire surveys can return missing information on user benefits obtained from information dissemination and alterations to travel behavior as a result of ITS.

With regards to freeway traffic management, ITS benefits include positive impacts on safety, mobility and customer satisfaction. Concerning arterial traffic management, ITS has a positive effect on efficiency, mobility, customer satisfaction and productivity. Advanced public transit benefits include safety, mobility, productivity, customer satisfaction, efficiency and energy/environment. Smart work zones display positive impacts on efficiency, productivity, customer satisfaction, safety and mobility. Road weather information systems have proven beneficial in customer satisfaction, safety, productivity, and energy/environment. While regional parking management improves mobility and customer satisfaction.

MDOT TOCs were compared against other nationwide TOCs on the basis of total miles of ITS coverage and percentage of ITS device coverage by device. SEMTOC was most similar to the St. Louis, MO "Gateway Guide" TOC, WMTOC was most similar to the Collinsville, IL "District 8 CommCenter" and STOC was most similar to the Milwaukee, WI "STOC". A summary of B/C ratios reported by other studies is included in Table 2-5 on the following page.

Table 2-5: Example B/C Ratios from Other Studies

ITS Application	Location	B/C Ratio	Source
Freeway Traffic Management	San Diego	9.7:1	Briglia, 2009
	San Francisco	14:01	Cambridge Systematics, 2008
	San Francisco	39:1	Alexiadis et al, 2009
Arterial Traffic Management	Virginia	461.3:1	Park et al, 2010
	Pennsylvania	57:1	Southwestern Pennsylvania Commission, 2011
Road Weather Information	Michigan	2.8:1 - 7:1	Krechmer, 2010
Incident Management	St. Louis	38.25:1	Sun, 2010
	St. Louis	8.3:1	Ryan et al, 2009
	Washington	15:01	WSDOT, 2014
	Georgia	4.4:1	URS, 2006
	New York	2.68:1	Chou et al, 2009
	North Carolina	4.3:1 - 3.5:1	Khattak et al, 2004
	Tennessee	8.5:1	Moss, 2012
	New Jersey	3.9:1	Ozbay et al, 2009
	South Carolina	11:1	Chowdhury et al, 2007
DMS-Specific	New Jersey	9.2:1	Ozbay et al, 2009
CCTV-Specific	South Carolina	12:1	Chowdhury et al, 2007
Sensor-Specific	South Carolina	7:1	Chowdhury et al, 2007

Chapter 3 MDOT ITS Deployments

3.1 MDOT ITS Deployments

3.1.1 Introduction

A GIS database was developed using ESRI ArcMAP 10 to spatiotemporally reference MDOT's past and current ITS inventory. Individual ITS device locations from 2006-2013 were aggregated and summarized by TOC region as well as on a corridor segment-by-segment level within the three TOC regions. The MDOT 2012 Sufficiency file was used as the basis for the corridor database. The 2012 Sufficiency file contains information regarding the level-of-service and related attributes of MDOT highway segments. In addition to the sufficiency information, data regarding the following were summarized according to each sufficiency database segment:

- ITS device presence from 2006-2013,
- Yearly AADT and CADT from 2006-2013,
- 2010-2012 NAVTEQ minute-by-minute travel time and delay information,
- 2008-2013 vehicle accident frequency according to UD10 police crash reports,
- 2011-2013 statewide LCAR incident frequency and duration,
- and 2007-2013 statewide TOC Call Log FCP assisted incidents.

The remaining portions of this chapter will summarize the 2006-2013 MDOT ITS deployment and associated cost information by TOC region.

3.1.2 2006-2013 Statewide ITS Deployments

Three TOCs are currently in operation in the state of Michigan. A figure representing the TOC coverage areas is shown on the following page. The Southeast Michigan Transportation Operations Center (SEMTOC) operates 87 DMSs, 168 CCTVs and 197 MVDSs on approximately 400 freeway miles in the Detroit "Metro" region, while the West Michigan Transportation Operations Center (WMTOC) governs 26 DMSs, 67 CCTVs and 120 MVDSs on roughly 45 freeway miles in the Grand Rapids "Grand" region. The Statewide Transportation Operations Center (STOC) provides ITS management in regions outside the Metro and Grand regions, overseeing 36 DMSs, 40 CCTVs and 50 MVDSs. Tables comparing ITS deployments by device and MDOT region are shown below.

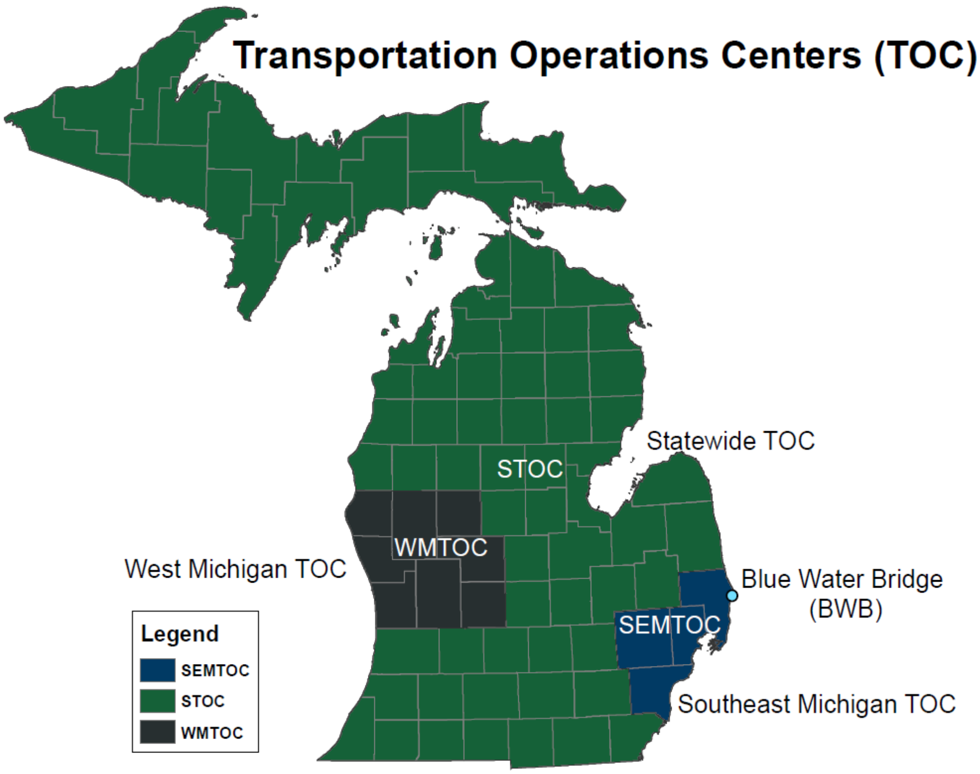


Figure 3-1: MDOT TOCs

Table 3-1: MDOT ITS Devices (2013)

Region	CCTV	DMS	MVDS	TTS
Metro Region /BWB	168	87	197	0
Grand Region	67	26	120	0
Bay Region	9	7	26	0
North Region	0	2	0	0
Southwest Region	10	4	5	0
Superior Region	0	8	0	0
University Region	21	15	19	3
Total	**275**	**149**	**367**	**3**

3.1.3 SEMTOC ITS Deployment

The SEMTOC has a rich history of ITS experience. The first ITS devices were installed in the mid-1990s in the Metro Detroit area. Figure 3-3 shows the cumulative total ITS deployment in SEMTOC from 2006 until 2013, by year of operation. As seen in Figure 3-3, between 2006 and 2008, no new ITS devices came into operation. Beginning in 2009, new devices came online, culminating in the 2013 total ITS device count. The number of MVDS in operation more than doubled between 2012 and 2013.

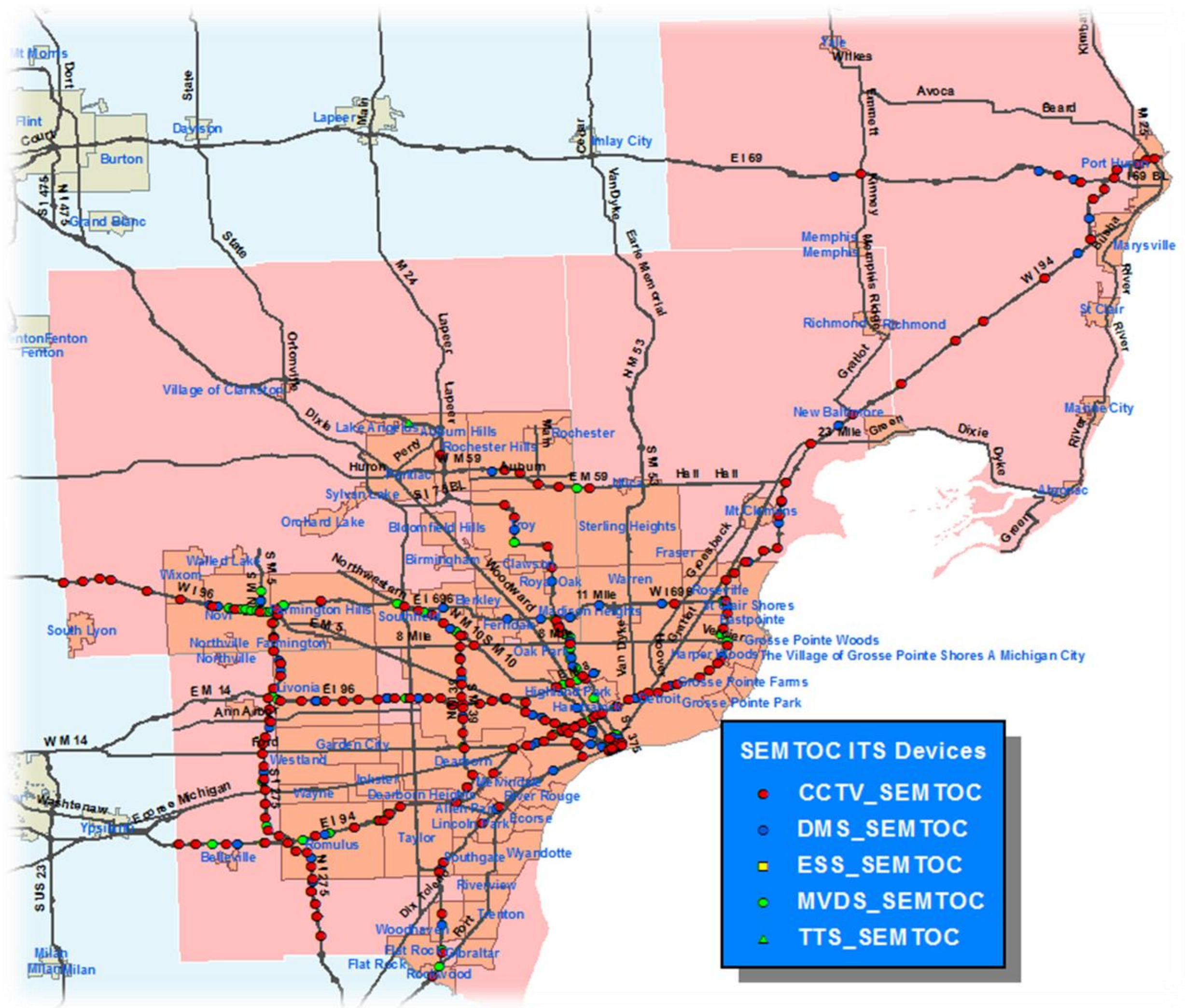


Figure 3-2: 2013 SEMTOC Device Locations

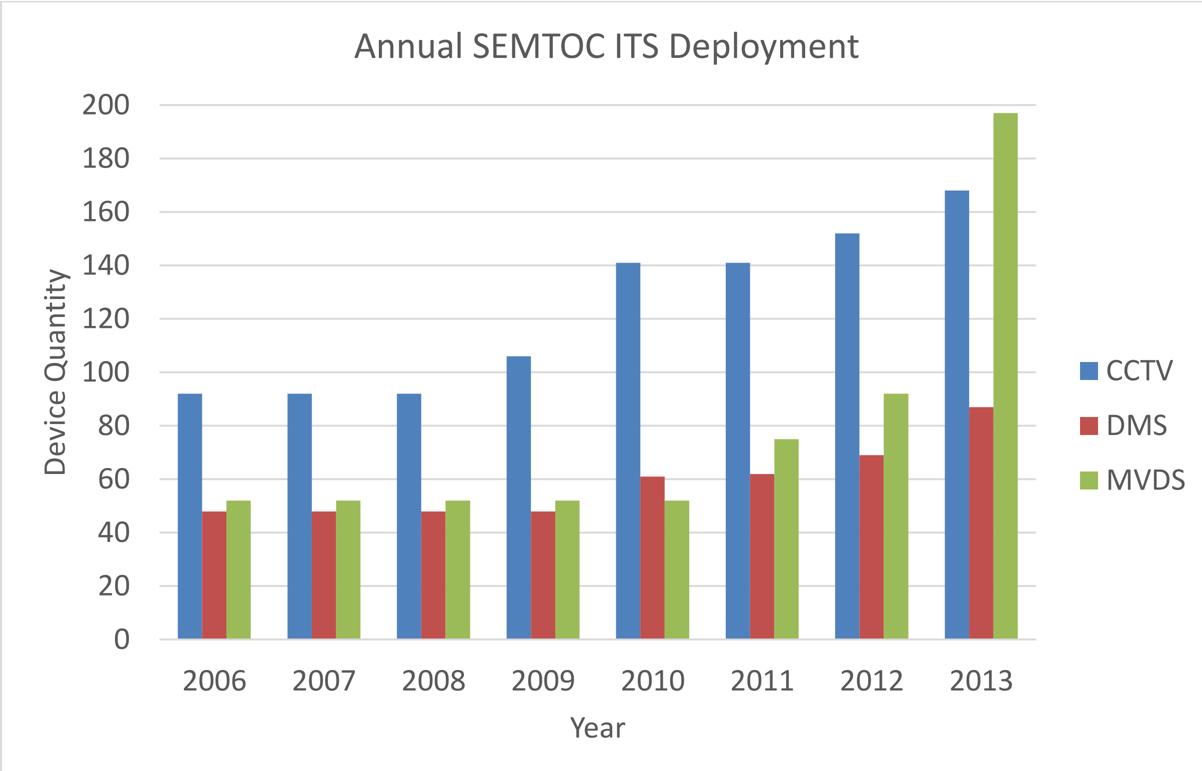


Figure 3-3: 2006-2013 SEMTOC ITS Deployment

Table 3-2: 2006-2013 SEMTOC ITS Devices by Operation Date

Year	CCTV	DMS	MVDS
2006	92	48	52
2007	92	48	52
2008	92	48	52
2009	106	48	52
2010	141	61	52
2011	141	62	75
2012	152	69	92
2013	168	87	197

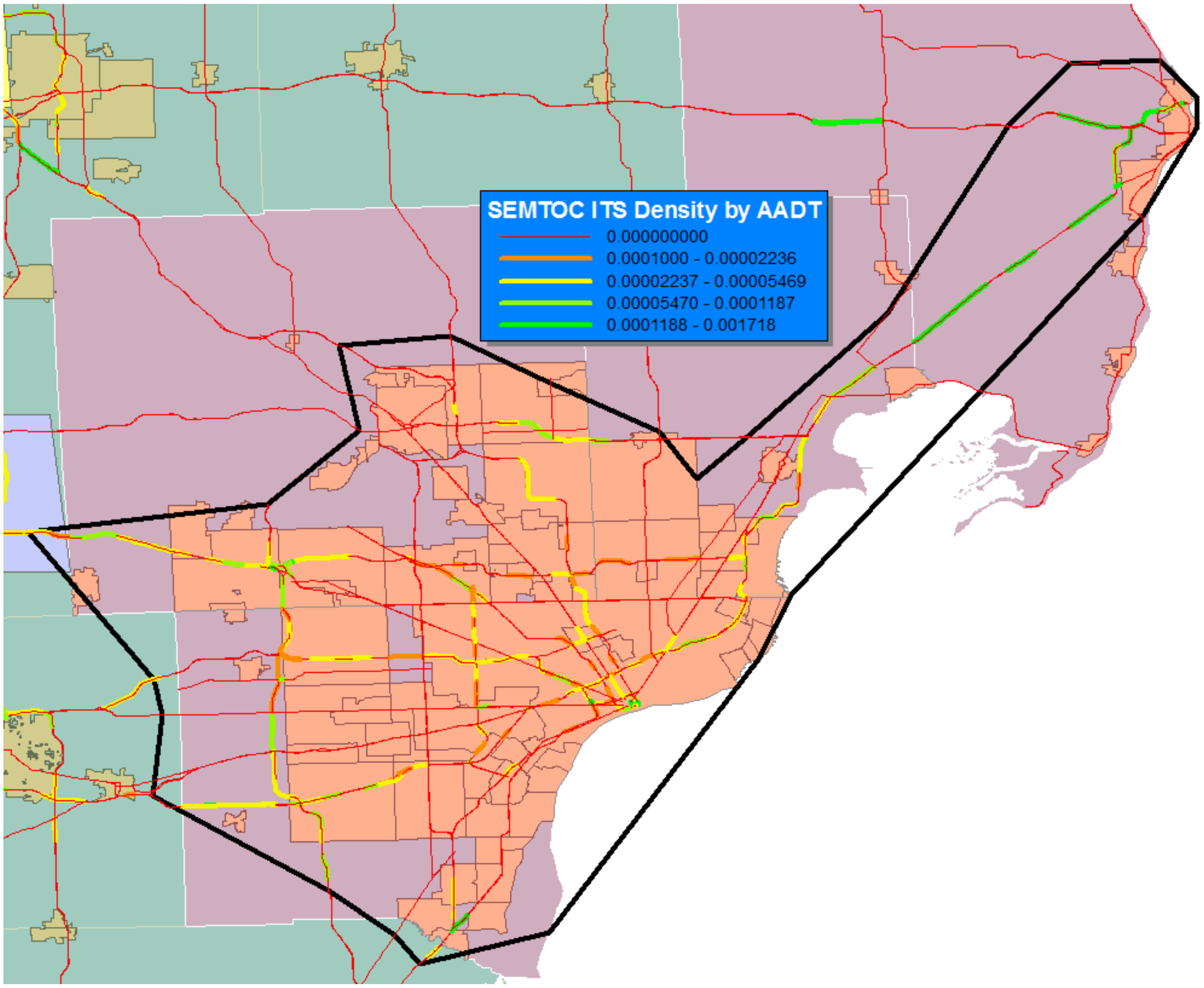


Figure 3-4: 2013 SEMTOC Segment ITS Density by 2013 AADT

The figure above shows 2013 ITS (summation of DMS, CCTV and MVDS in operation) density by 2013 AADT, according to 2012 MDOT Sufficiency database segments. A polygon region was defined as “Detroit” according to the region displaying the highest concentration of ITS devices in the SEMTOC region, as indicated by the black outline on

Figure 3-4. This region will be utilized in subsequent analysis when determining the impact of ITS on performance metrics such as crash count, incident count, incident duration and others. As seen, the “Detroit” region encompasses the majority of the entire SEMTOC region, with actual representation of 1,173 of 1,411 total miles (83 percent). Additionally, the majority of 2013 in-operation ITS devices (449 of 452, or 99 percent) reside within the "Detroit" ITS region.

Figure 3-5 shows the FCP routes (highlighted in green) in the SEMTOC region. As of 2013, the SEMTOC FCP patrols over 320 miles of freeway in Southeast Michigan.

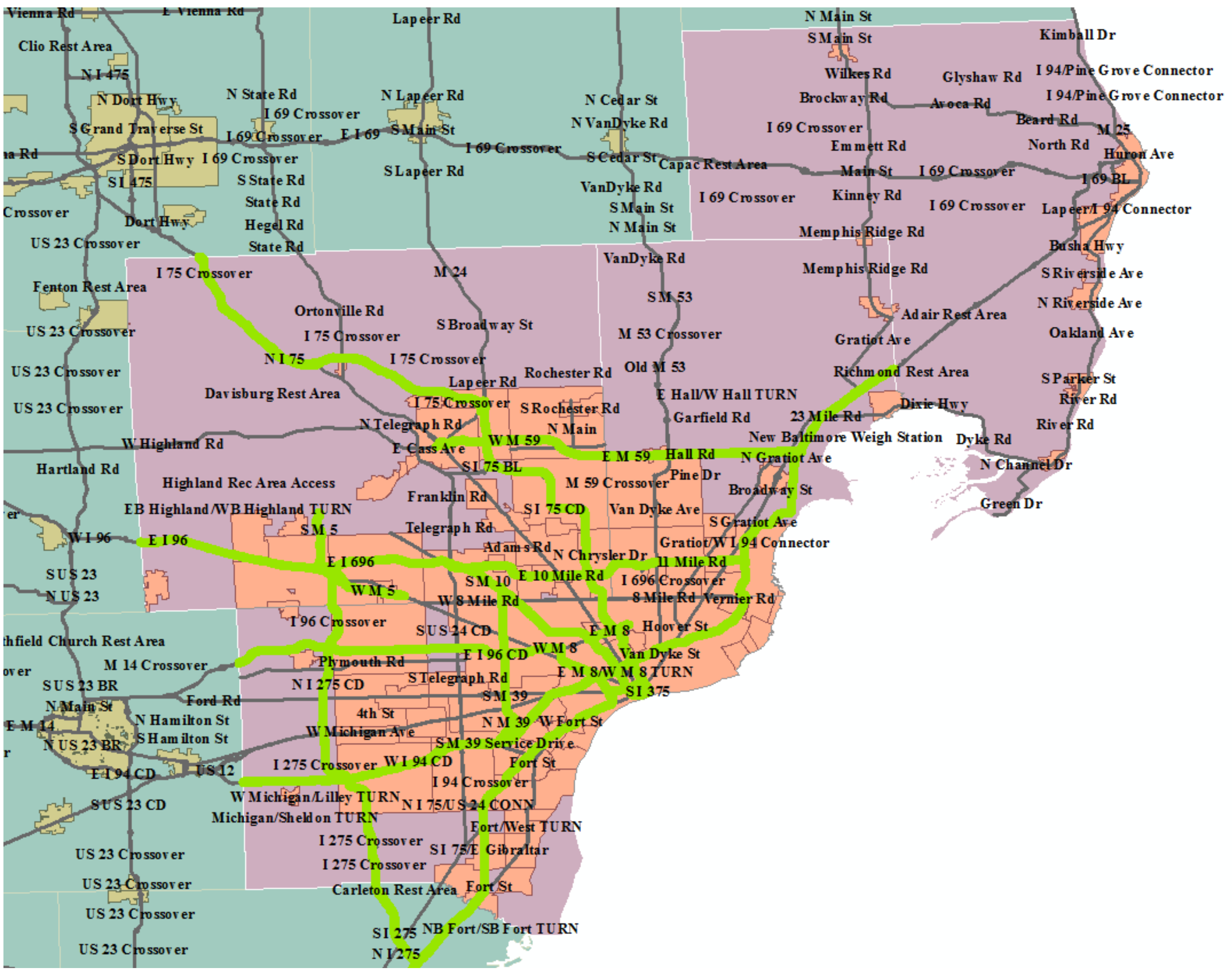


Figure 3-5: SEMTOC FCP Routes

3.1.4 WMTOC ITS Deployment

The WMTOC manages ITS deployment in the MDOT Grand Region, which consists of the city of Grand Rapids and outlying rural areas. Figure 3-6 shows the WMTOC ITS locations of those devices in operation during the year 2013 around and in the city of Grand Rapids. As shown in Figure 3-7, ITS deployment was relatively minor in the Grand region until the year 2010, which saw the introduction of 7 new CCTVs and 43 new MVDS into operation. Another significant boost to the quantity of operable ITS devices occurred between 2012 and 2013, where the total count of all ITS devices more than doubled.

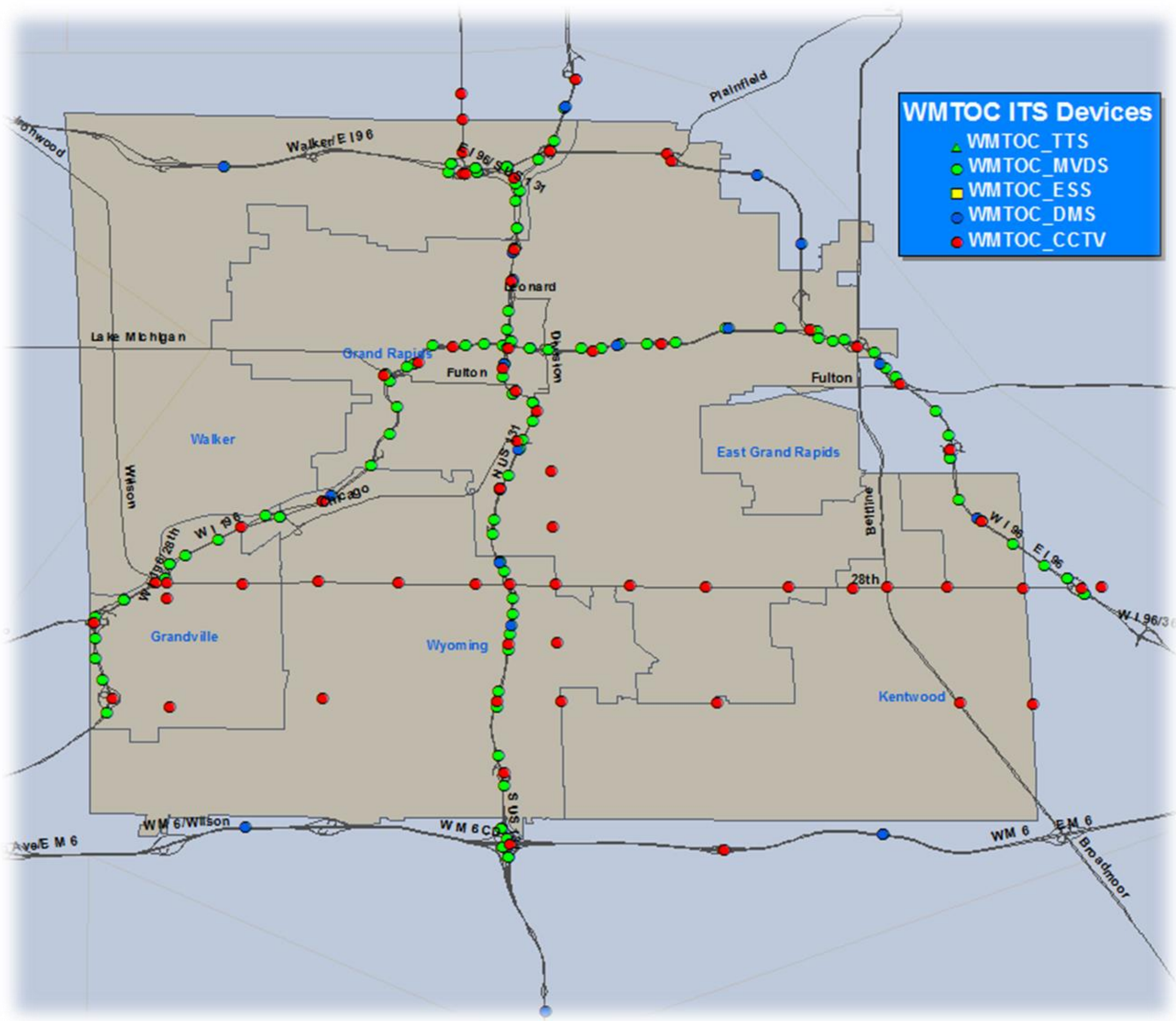


Figure 3-6: 2013 WMTOC Device Locations

Figure 3-8 shows the 2013 total in-operation ITS density by 2013 AADT according to 2012 MDOT Sufficiency database segments for the WMTOC region. The focus of the picture is around the Grand Rapids metropolitan region, as a scarce amount of ITS devices exist outside this area. Similar to the "Detroit" ITS polygon region defined for SEMTOC, a "Grand Rapids" ITS region was defined for WMTOC, indicating the space containing the highest concentration of ITS devices within the overall WMTOC region. However, unlike the SEMTOC case, the "Grand Rapids" ITS region covers a relatively smaller portion of total analysis roadway miles, only 264 miles of a total of 1285 WMTOC miles (20.5 percent). Similar to the SEMTOC "Detroit" ITS region, the "Grand Rapids" ITS region represents the overwhelming majority (208 of 213, or 98 percent) of the total ITS devices in operation in 2013 in the WMTOC region. WMTOC does not currently manage a FCP program, but plans to implement FCP on routes shown in Figure 3-9.

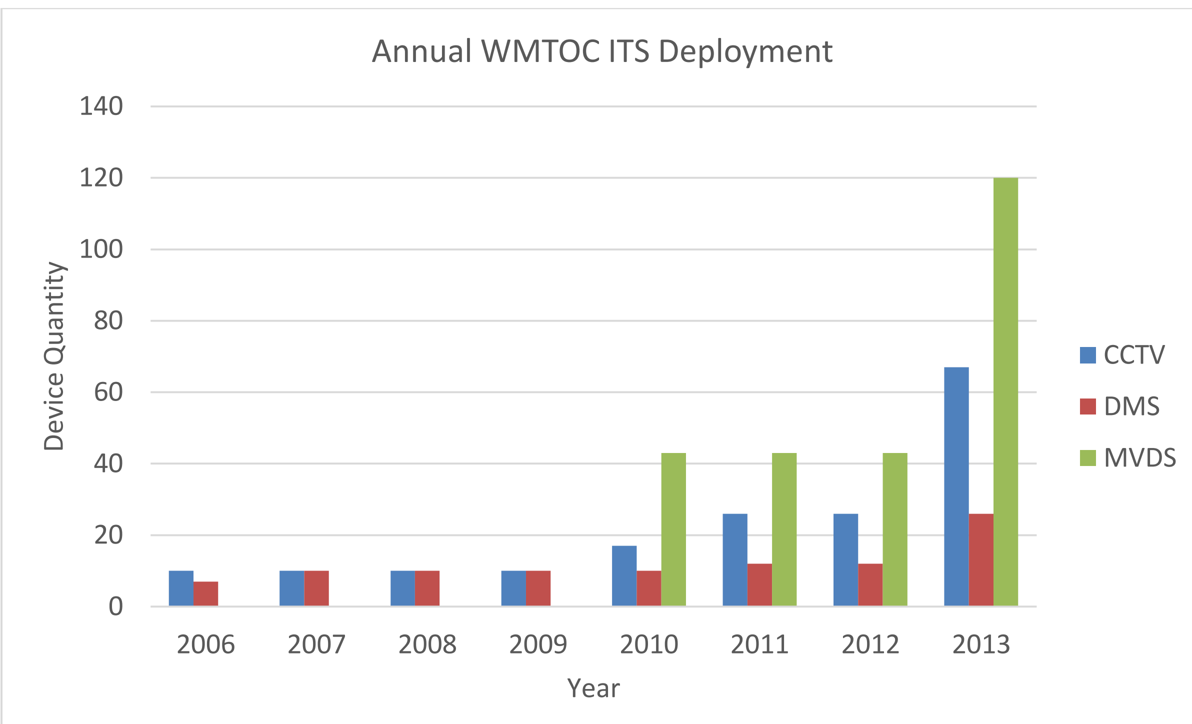


Figure 3-7: 2006-2013 WMTOC ITS Deployment

Table 3-3: 2006-2013 WMTOC ITS Devices by Operation Date

Year	CCTV	DMS	MVDS
2006	10	7	0
2007	10	10	0
2008	10	10	0
2009	10	10	0
2010	17	10	43
2011	26	12	43
2012	26	12	43
2013	67	26	120

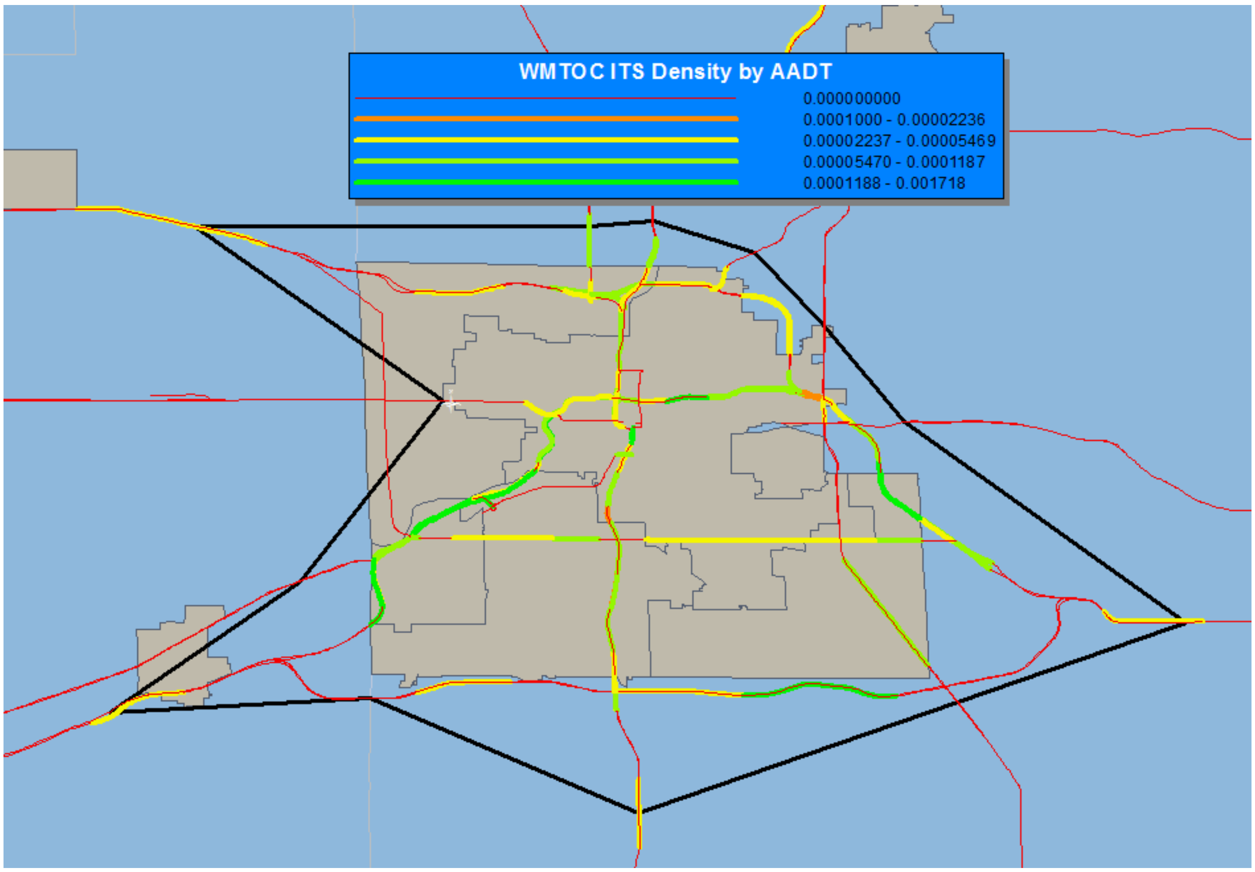


Figure 3-8: 2013 WMTOC Segment ITS Density by 2013 AADT

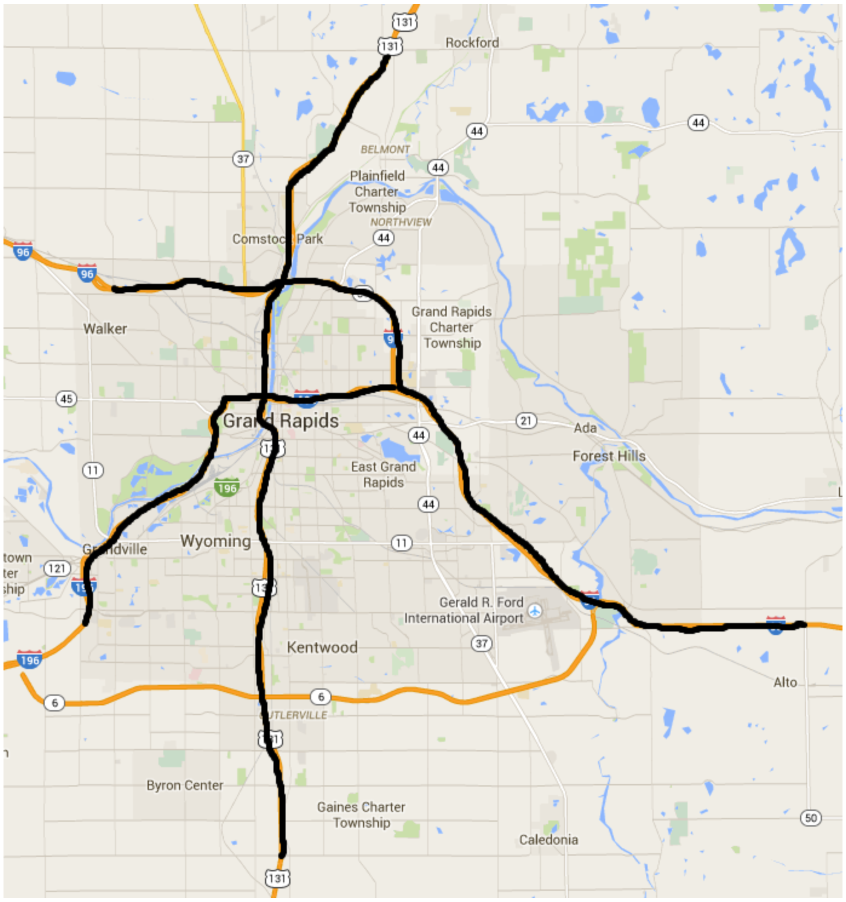


Figure 3-9: WMTOC FCP Routes (Planned)

3.1.5 STOC ITS Deployment

The STOC operates out of Lansing, MI and oversees all ITS related operation and maintenance outside of the Metro and Grand Regions, while also providing assistance and coordination with the other two TOCs, when required. Key focus MDOT regions for the STOC include the University, Bay and Southwest regions. Unlike the other two TOCs, STOC plays a key role in acquiring and disseminating road weather related information through their management of MDOT's ESSs, as indicated in Figure 3-10. As seen in Figure 3-11, the STOC experienced a rapid deployment of ITS functioning devices beginning in 2011. Also of note is the coming online of 40 CCTVs between 2012 and 2013. The STOC region consists of 9,304 total 2012 MDOT Sufficiency database segment miles.

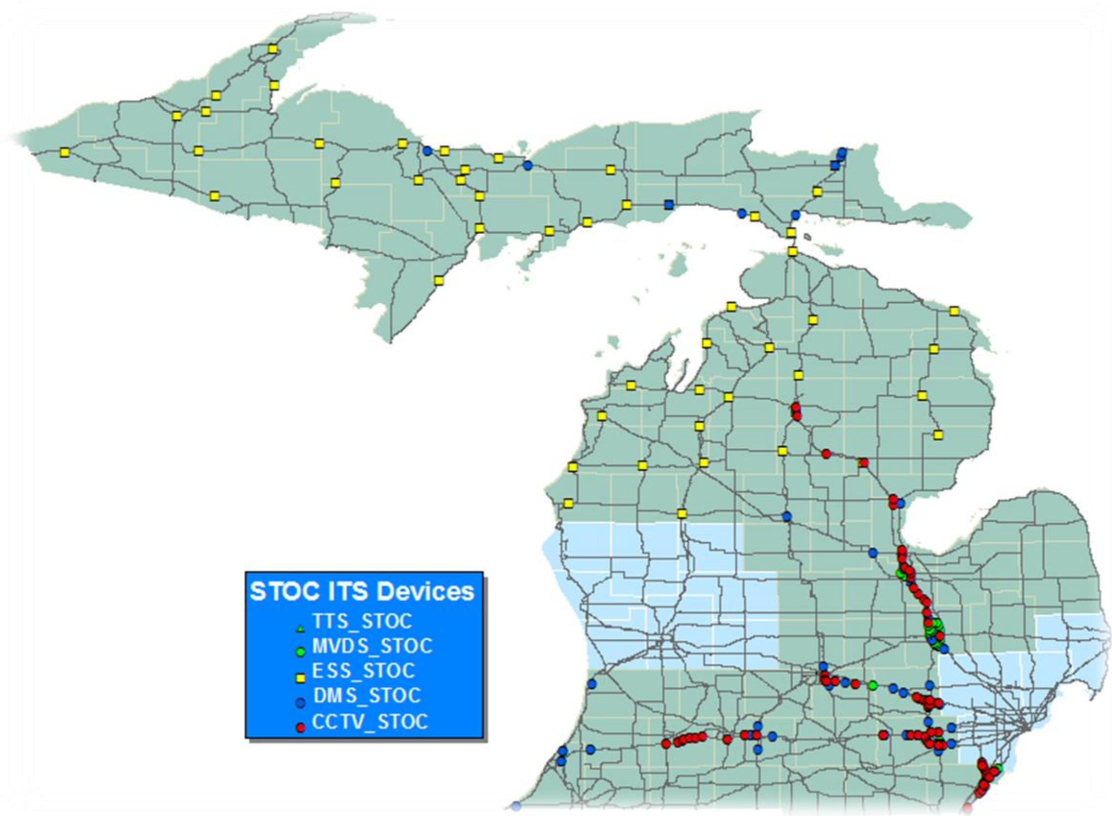


Figure 3-10: 2013 STOC Device Locations

In Figures 11-13, selected STOC ITS regions are indicated with associated 2013 segment ITS density. STOC Region 1, shown in Figure 3-12, is the stretch of I-94 between Kalamazoo and Battle Creek, for a total of 340 2012 MDOT Sufficiency database roadway miles. STOC Region 2, shown in Figure 3-13, covers a portion of I-96 between Howell and Brighton, for a total of 180 2012 MDOT Sufficiency database roadway miles. Finally, Figure 3-14 indicates STOC Region 3, which is a stretch of I-75 running from Flint to Bay City, for a total of 251 2012 MDOT Sufficiency database roadway miles. In total, the three STOC ITS regions hold 70 of the 129 ITS (CCTV, DMS, and MVDS) devices in operation in 2013 (54 percent), while only representing 771 of the 9,304 roadway miles (8 percent). Similar to SEMTOC, the STOC operates a FCP division, patrolling over 128 miles of freeway in the University Region (Figure 3-15) and plans to expand to the Lansing area (Figure 3-16) and the Southwest region (Figure 3-17).

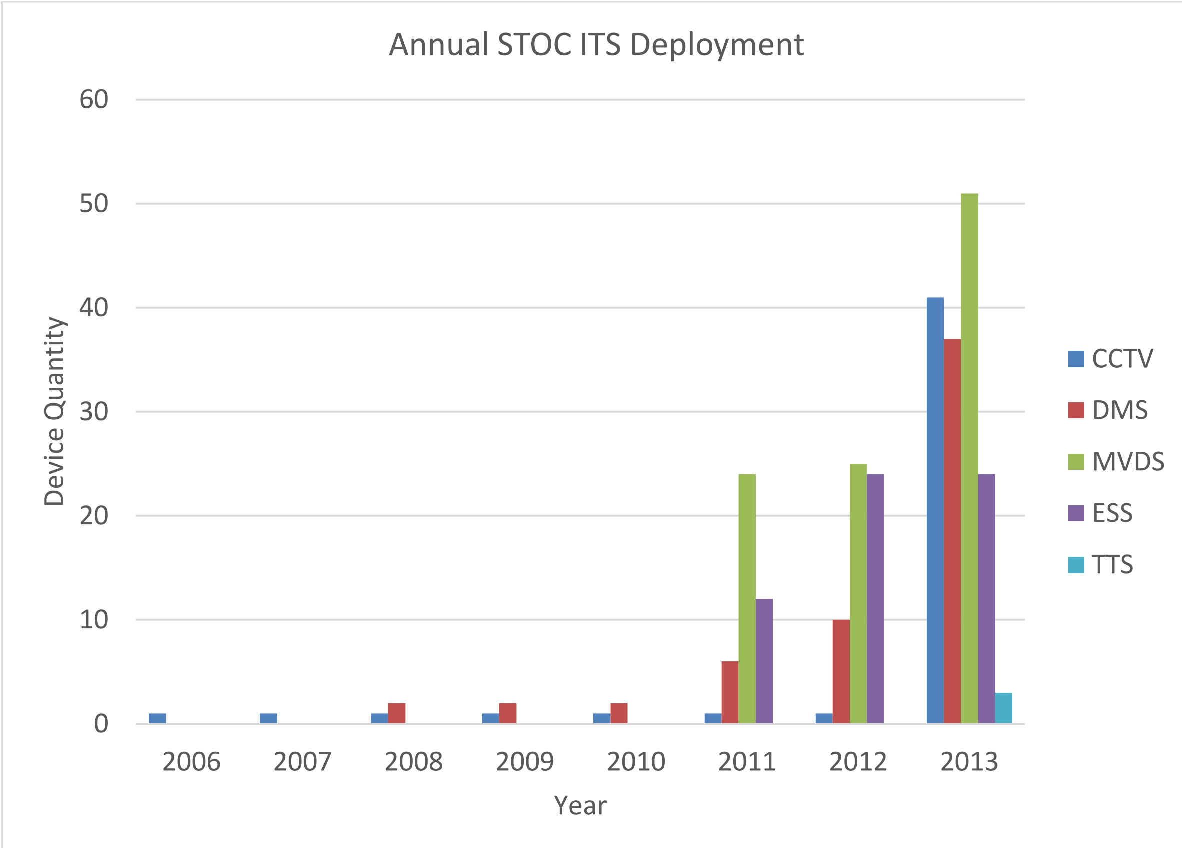


Figure 3-11: 2006-2013 STOC ITS Deployments

Table 3-4: 2006-2013 ITS Devices by Operation Date

Year	CCTV	DMS	MVDS	ESS	TTS
2006	1	0	0	0	0
2007	1	0	0	0	0
2008	1	2	0	0	0
2009	1	2	0	0	0
2010	1	2	0	0	0
2011	1	6	24	12	0
2012	1	10	25	24	0
2013	41	37	51	24	3

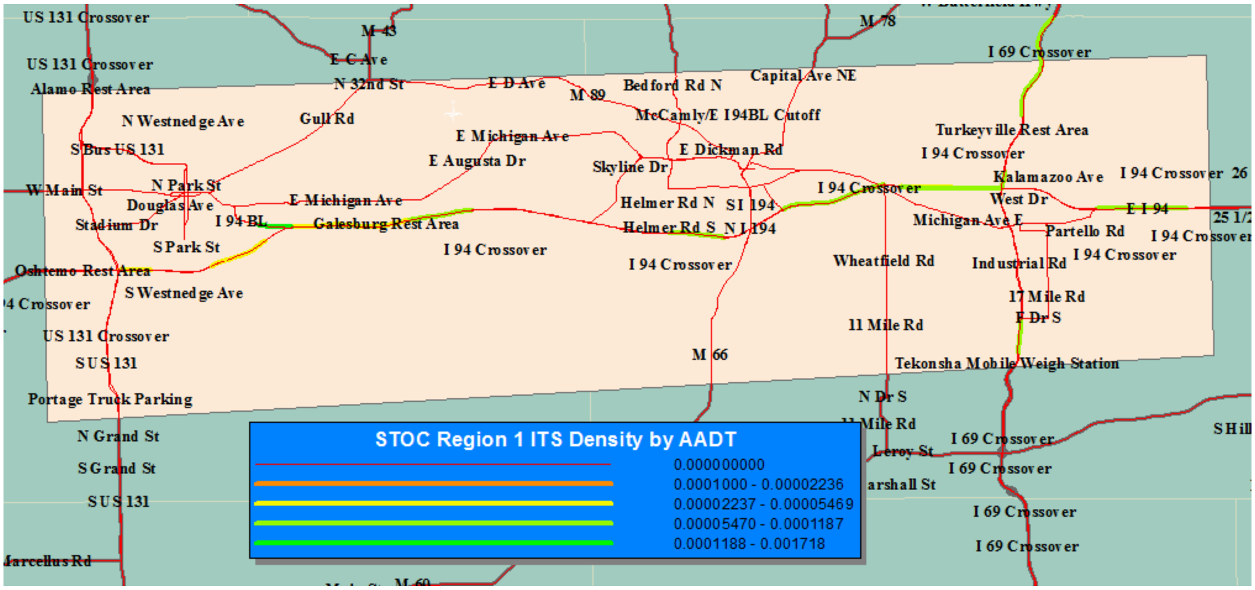


Figure 3-12: 2013 STOC Region 1 Segment ITS Density by 2013 AADT

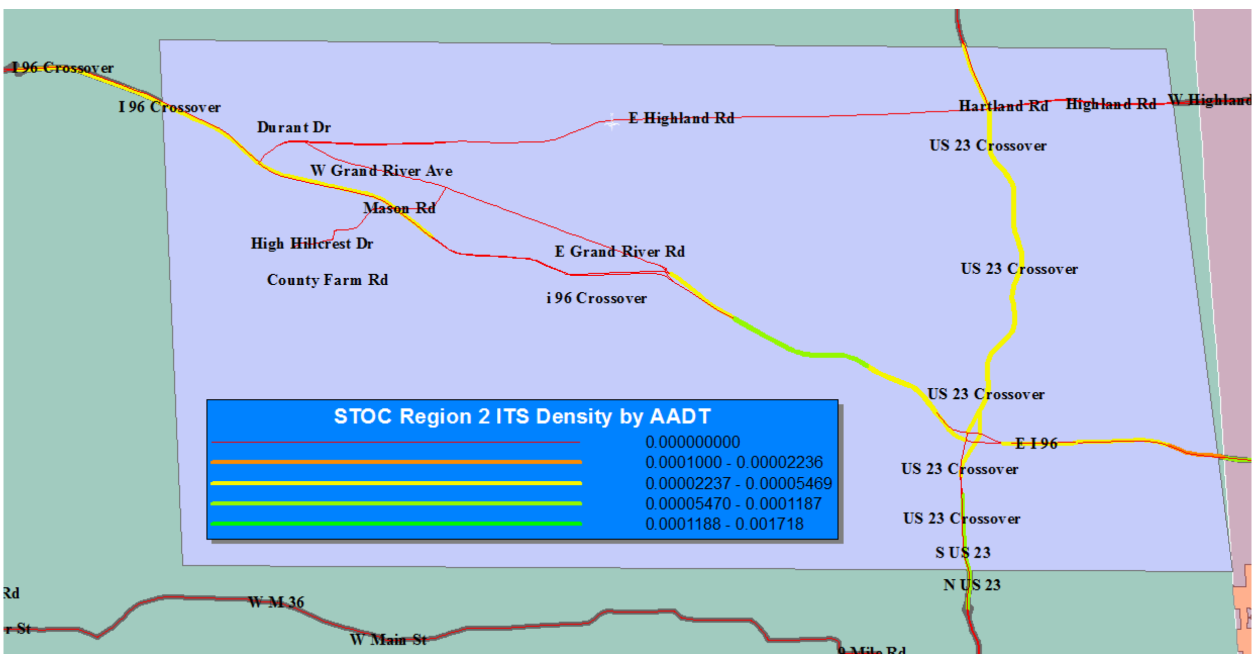


Figure 3-13: 2013 STOC Region 2 Segment ITS Density by 2013 AADT

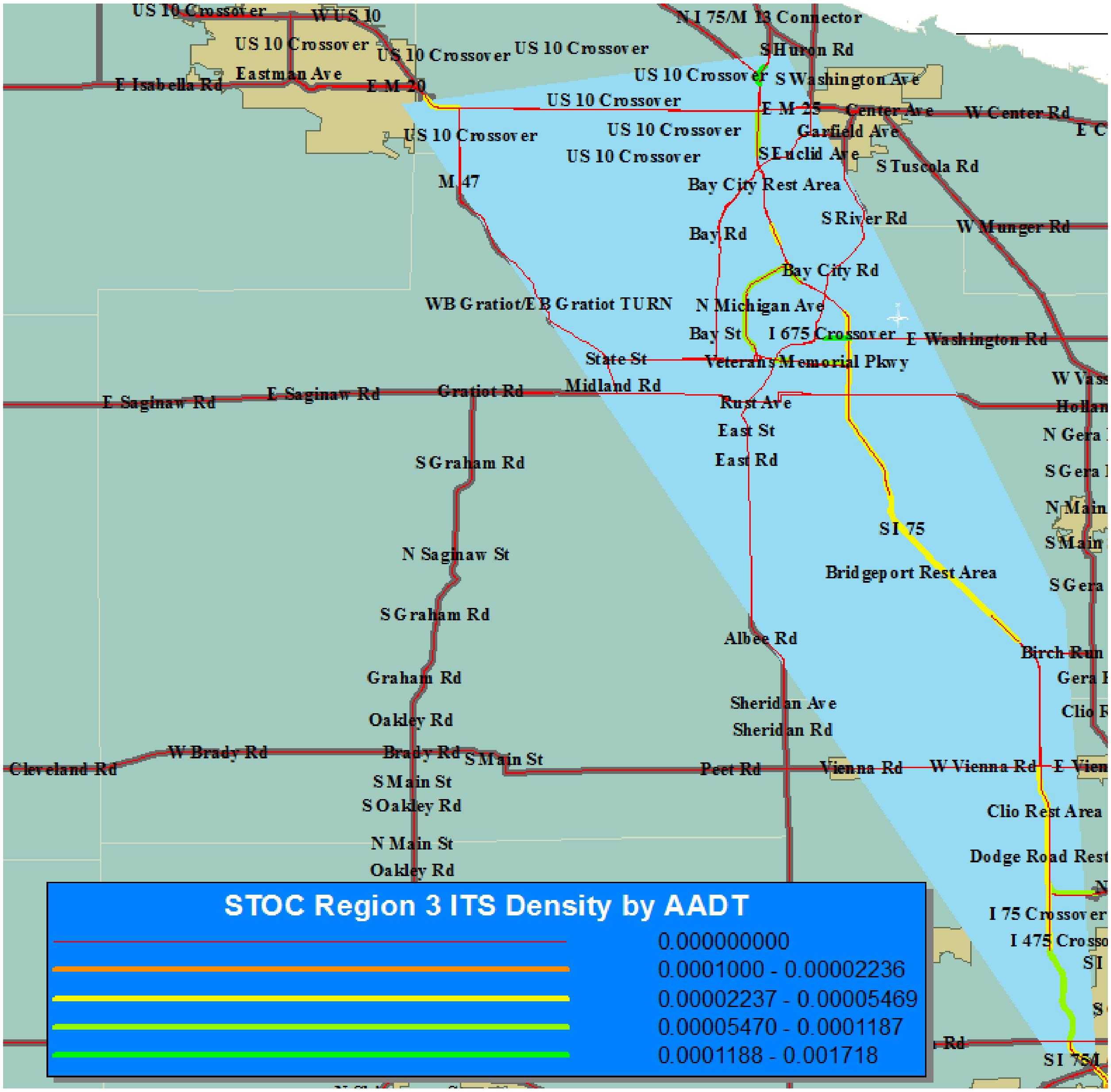


Figure 3-14: 2013 STOC Region 3 Segment ITS Density by 2013 AADT

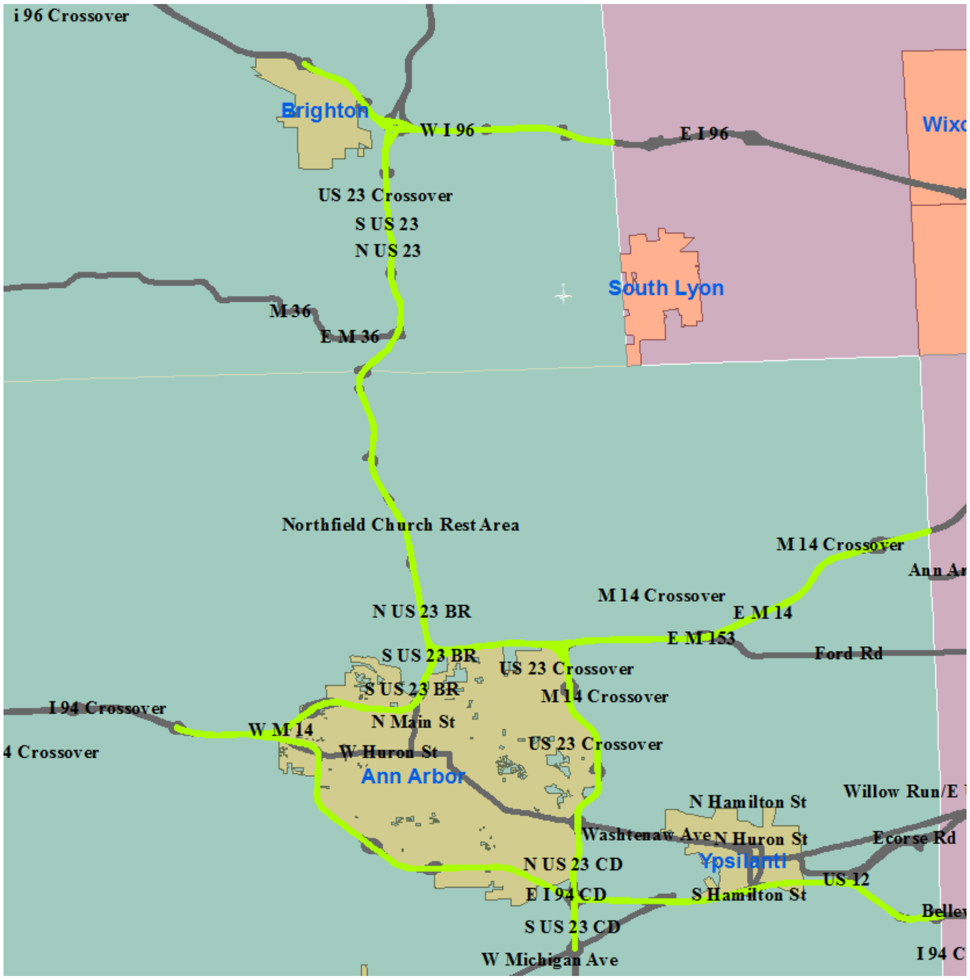


Figure 3-15: STOC University Region FCP Routes

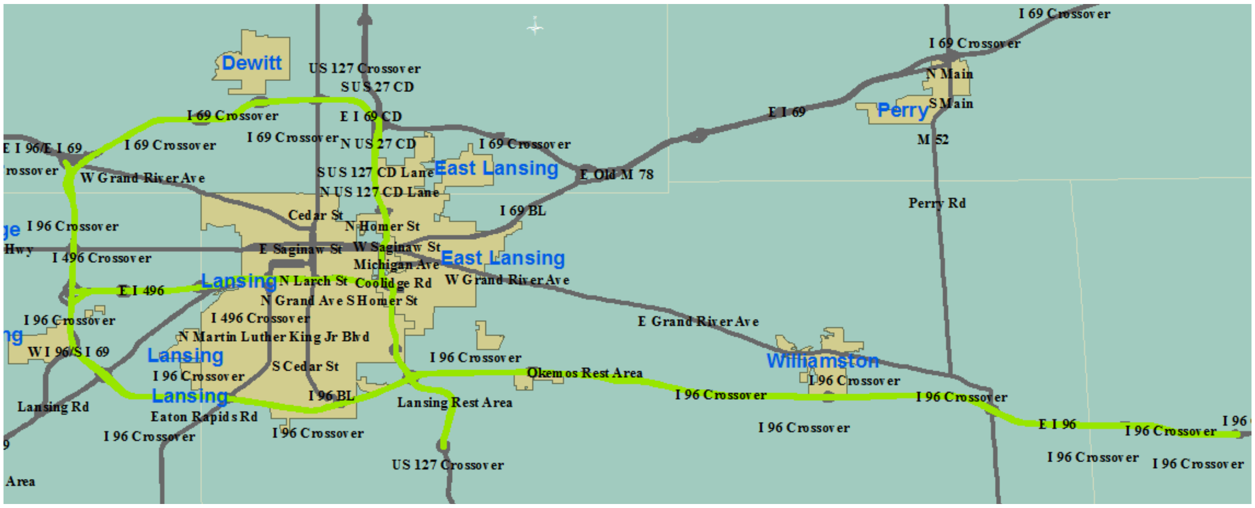


Figure 3-16: STOC Lansing FCP Routes (Planned)

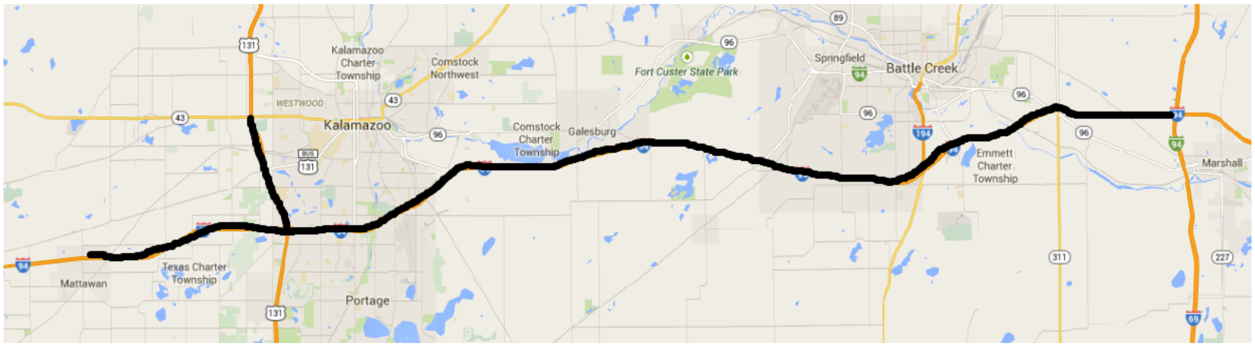


Figure 3-17: STOC Southwest Region FCP Routes (Planned)

3.2 Cost Analysis

A detailed cost analysis was conducted for this project. The majority of the task entailed a review of the contractor bid tabulation and final project closeout documentation for 50 individual Michigan Department of Transportation (MDOT) Intelligent Transportation Systems (ITS) projects between 2006 and 2013, and a summary of the construction cost information. Several road construction projects were also included in the analysis, because the projects included ITS pay items.

In addition to the construction phase costs, costs associated with the maintenance and operation of the ITS network were collected and assembled into the year-by-year summary. The cost summary was further subdivided into three transportation operations center coverage areas representing the following operations:

- West Michigan Transportation Operations Center (WMTOC)
- Southeast Michigan Transportation Operations Center (SEMTOC)
- Statewide Transportation Operations Center (STOC)

3.2.1 ITS Construction-phase Costs

The construction-phase costs were subdivided into design, construction and system manager categories.

Design Contract Costs

Design costs are costs paid by MDOT to bring an ITS project from the planning phase to a biddable package of design plans and specifications. Generally, the costs are paid to an engineering consultant and the actual values of design contracts are not typically public knowledge. For the purposes of this analysis, it was agreed with MDOT that an average design cost for the ITS projects included in the analysis was approximately 15 percent of the project construction costs.

Construction Contract Costs

Construction costs are costs paid by MDOT to bring an ITS project from design plans through construction and into operation. The costs included in this category were determined from the official bid tabulation for each project, which can be found on the MDOT website (http://mdotcf.state.mi.us/public/bids/). For the road construction projects included in the analysis, it was necessary to tabulate only the pay items related to the ITS sites.

Between 2006 and 2013, MDOT constructed several projects that were limited to the communications infrastructure needed to support ITS devices, such as fiber optic cable installation or wireless communications towers. These projects were included as a separate item in the cost analysis.

Several projects were constructed under MDOT's statewide Dynamic Message Sign (DMS) procurement contract. For those projects, the cost of the DMS was tabulated separately since the costs were paid directly by MDOT and not included in the bid tabulations. Based on past guidance from MDOT, a cost of $53,000 per DMS was used for DMS purchased under the statewide procurement contract. These costs were included as a separate item in the cost analysis. Construction contract costs ranged between $63,000 and $6.952 million for the projects included in this analysis.

System Manager Contract Costs

System Manager costs are costs paid by MDOT to a consultant to act as an agent of MDOT and oversee the technical elements of the ITS construction project. Similar to the design contract costs, the actual system manager costs are not typically public information. Based on past projects, it was agreed with MDOT that an average system manager cost for the ITS projects included in the analysis was approximately 8.5 percent of the construction costs.

Construction Cost Summary

The cost analysis incorporated ITS projects that resulted in over 750 new ITS devices with a total construction cost of more than $100 million. In addition to tabulating the combined total cost of all devices for an average construction cost per device by TOC coverage area, the MDOT bid tabulations were reviewed in order to determine an average construction cost by device type (i.e.: DMS, CCTV, vehicle detector) and TOC coverage area. A summary of the construction costs by device, device type and TOC coverage area is shown in Table 3-5 and Table 3-6.

Table 3-5: ITS Construction Costs (2006-2013)

	SEMTOC	WMTOC	STOC	Total
New CCTV Quantity	124	57	56	237
New MVDS Quantity	222	120	65	407
New DMS Quantity	50	20	45	115
New TTS Quantity	1	0	5	6
Total	**397**	**197**	**171**	**765**
ITS Construction Cost	$45,728,333	$15,423,533	$20,506,649	$81,658,515
Estimated Design Cost	$8,424,541	$2,359,045	$2,973,464	$13,757,050
Estimated System Manager Cost	$4,938,524	$1,382,888	$1,743,065	$8,064,478
Total Construction Cost	**$59,091,399**	**$19,165,466**	**$25,223,178**	**$103,480,043**

Table 3-6: Average Construction Costs per ITS Device (2006-2013)

	TOC Coverage Area			Overall
	SEMTOC	WMTOC	STOC	
New Device Quantity	397	197	171	765
Total Construction Cost	$59,091,399	$19,165,466	$25,223,178	$103,480,043
Average Construction Cost per Device	$148,845	$97,287	$147,504	$135,268
Average Construction Cost per CCTV	$161,404	$97,906	$141,945	$141,535
Average Construction Cost per Vehicle Detector	$105,945	$76,064	$45,853	$87,538
Average Construction Cost per DMS	$308,848	$222,860	$307,037	$293,185
Average Construction Cost per TTS	$115,187	N/A	$95,422	$98,717

Note) Costs for major supporting infrastructure (communication towers) were excluded.

3.2.2 ITS Maintenance & Operations Costs

Maintenance and operation costs were subdivided into maintenance contract, Transportation Operations Center (TOC) contract, Freeway Courtesy Patrol (FCP) contract (SEMTOC and STOC coverage areas only), utility costs and MDOT staff cost categories.

Maintenance Contract Cost

MDOT contracts with a third party to provide ITS maintenance throughout the state, with the exception of the Grand Rapids metro area and the RWIS devices. The City of Grand Rapids provides ITS maintenance for MDOT ITS devices within the Grand Rapids metro area under a municipal agreement with MDOT. RWIS devices are maintained by a separate contractor and because RWIS were not included in this project, those costs were not analyzed.

The MDOT ITS Program Office (IPO) provided various data related to ITS maintenance contract costs for 2006-2013. The data from the MDOT IPO was compared to data provided by the MDOT Grand Region ITS staff in order to determine the estimated maintenance costs for devices outside of the SEMTOC and WMTOC coverage areas. Data for the annual maintenance contract cost for 2006 and 2007 was not readily available and was estimated to be $500,000 per year.

MDOT Grand Region ITS staff provided the annual ITS maintenance contract costs with the City of Grand Rapids for 2006-2013. In addition to the municipal agreement with the City of Grand Rapids for ITS device maintenance, MDOT contracted with an engineering consultant, beginning in 2013, to provide as-needed system manager services in the WMTOC coverage area, which supports the maintenance of the ITS communications network. The following ITS maintenance contract costs were used in the cost analysis:

- $45,000 - $365,000/year – WMTOC coverage area, 2006-2013
- $500,000 - $2.329 million/year – SEMTOC coverage area, 2006-2013
- $105,000 - $415,000/year – STOC coverage area, 2010-2013

Operations Contract Cost

MDOT contracts with an engineering consultant to provide ITS operations and engineering support at the WMTOC, STOC and SEMTOC. URS, the current ITS operations consultant at the three MDOT TOCs, provided ITS operations contract costs for 2006-2013. The following ITS operations contract costs were used in the cost analysis:

- $165,000 - $528,000/year – WMTOC coverage area, 2006-2013
- $1.200 million - $2.023 million/year – SEMTOC coverage area, 2006-2013
- $640,000 - $885,000/year – STOC coverage area, 2011-2013

Freeway Courtesy Patrol Contract Cost

MDOT contracts with a third party to provide Freeway Courtesy Patrol (FCP) services in the SEMTOC and STOC coverage areas. The SEMTOC coverage area has had FCP for the entire analysis period of 2006-2013, while the STOC coverage area has had FCP since 2013. The MDOT IPO provided the FCP contract cost information for the SEMTOC and STOC coverage areas. The following FCP contract costs were used in the cost analysis:

- $1.933 million/year – SEMTOC coverage area, 2006-2013
- $367,000/year – STOC coverage area, 2013

Utility Costs

Electrical power and communications utility costs for dynamic message signs (DMS) and closed-circuit television (CCTV) cameras were provided by MDOT and included co-located vehicle detectors. A separate electrical power cost was not used for vehicle detectors since stand-alone sites are not prevalent in Michigan, resulting in an assumed under-estimation of the electrical power costs. A limited number of travel time signs (TTS) were included in the cost analysis, and were assumed to have electrical power costs approximately one-tenth that of a DMS. The following average electrical utility costs were used in the cost analysis:

- $103.70/month for DMS (includes co-located vehicle detector)
- $105.34/month for CCTV (includes co-located vehicle detector)
- $8.64/month for TTS

Since a separate electrical power cost was not estimated for vehicle detectors, as noted above, a separate communications utility cost was estimated, resulting in an assumed over-estimation of the communication utility costs. The monthly communications utility cost for a

TTS was assumed to be comparable to a DMS. The following average communications utility costs were used in the cost analysis:

- $30/month for DMS
- $115.68/month for CCTV
- $30/month for vehicle detectors
- $30/month for TTS

Utility costs were included in the cost analysis based on the number of devices installed annually in the various TOC coverage areas. Utility costs for devices installed prior to the study period of 2006-2013 were also included in the cost analysis, as the utility costs are cumulative based on the number of devices in the MDOT ITS network.

MDOT Staff Costs

Several staff in each MDOT region are dedicated to supporting the MDOT ITS network. In lieu of requesting individual annual salary information for each individual, the following average salary was provided by MDOT for the purposes of the cost analysis:

- $62,500/year, plus an additional 20 percent ($12,500) for benefits

The following staffing levels were assumed to be associated with the MDOT ITS network during the cost analysis study period of 2006-2013. The staffing levels in the STOC coverage area apply to various portions of the study period based on when ITS devices were installed in the individual regions, as noted below.

- Grand Region (WMTOC coverage area) – 3 full-time staff, 2006-2013
- Metro Region (SEMTOC coverage area) – 7.5 full-time staff, 2006-2013
- North Region (STOC Coverage area) – 1 full-time staff, 2007-2013
- Superior Region (STOC Coverage area) – 2 full-time staff, 2010-2013
- Bay Region (STOC coverage area) – 2 full-time staff, 2011-2013
- Lansing Operations (STOC coverage area) – 4 equivalent full-time staff, 2011-2013
- Southwest Region (STOC coverage area) – 2 full-time staff, 2011-2013
- University Region (STOC coverage area) – 2 full-time staff, 2011-2013

The following annual MDOT staff costs were used in the cost analysis:

- $225,000/year – WMTOC coverage area, 2006-2013
- $565,000/year – SEMTOC coverage area, 2006-2013
- $20,000-$470,000/year – STOC coverage area, 2007-2013

Operations and Maintenance Cost Summary

The cost analysis incorporated more than 4,100 device-years and over $50 million in ITS operations and maintenance costs, plus an additional $15 million in FCP costs. A summary of the operations and maintenance costs by TOC coverage area is shown in Table 3-7 and Table 3-9. As shown in Table 3-8 and Figure 3-18, the average operations and maintenance costs decrease as the number of devices increases. The operations and maintenance cost per device is likely dependent on quantity of devices and density of device placement. In general, devices in the STOC coverage area have the greatest operations and maintenance costs per device and devices in the WMTOC coverage area have the least operations and maintenance costs per device. The statewide average cost has reduced from $14,160 in 2007 to $8,983 in 2013.

Table 3-7: Total Operations and Maintenance Costs (2006 – 2013)

	SEMTOC	WMTOC	STOC	Total
Total CCTV Quantity	1162	301	115	1578
Total MVDS Quantity	1096	486	151	1733
Total DMS Quantity	541	134	115	790
Total TTS Quantity	1	0	8	9
Total (Device-Year)	2800	921	389	4110
Maintenance Contract Cost	$12,006,309	$1,135,537	$1,064,344	$14,206,190
TOC Operations Cost	$13,137,988	$2,953,545	$2,220,658	$18,312,191
Utility Cost (power)	$2,255,840	$597,636	$304,964	$3,158,440
Utility Cost (communication)	$2,202,764	$641,047	$258,283	$3,102,093
MDOT Staff Cost	$4,500,000	$1,800,000	$1,518,750	$7,818,750
Total O&M Cost	$34,102,901	$7,127,765	$5,366,998	$46,597,664
Average O&M Cost per Device	$12,180	$7,739	$13,797	$11,338

Note) Total ITS device quantity is the sum of devices active each year during 2006 – 2013.

Table 3-8: Changes in Operations and Maintenance Cost

		2007	2009	2011	2013	Total (06-13)
SEMTOC	No. of Devices	206	310	442	589	2,800
	O&M	$2,641,795	$4,363,007	$5,358,605	$5,426,092	$34,102,901
	Cost/device	$12,824	$14,074	$12,124	$9,212	$12,180
WMTOC	No. of Devices	27	76	214	214	921
	O&M	$663,885	$794,561	$961,442	$1,303,177	$7,127,765
	Cost/device	$24,588	$10,455	$4,493	$6,090	$7,739
STOC	No. of Devices	2	2	72	171	389
	O&M	$21,959	$21,959	$1,427,456	$2,020,119	$5,366,998
	Cost/device	$10,979	$10,979	$19,826	$11,814	$13,797
Overall	No. of Devices	235	388	728	974	4,110
	O&M	$3,327,638	$5,179,527	$7,747,503	$8,749,387	$46,597,664
	Cost/device	$14,160	$13,349	$10,642	$8,983	$11,338

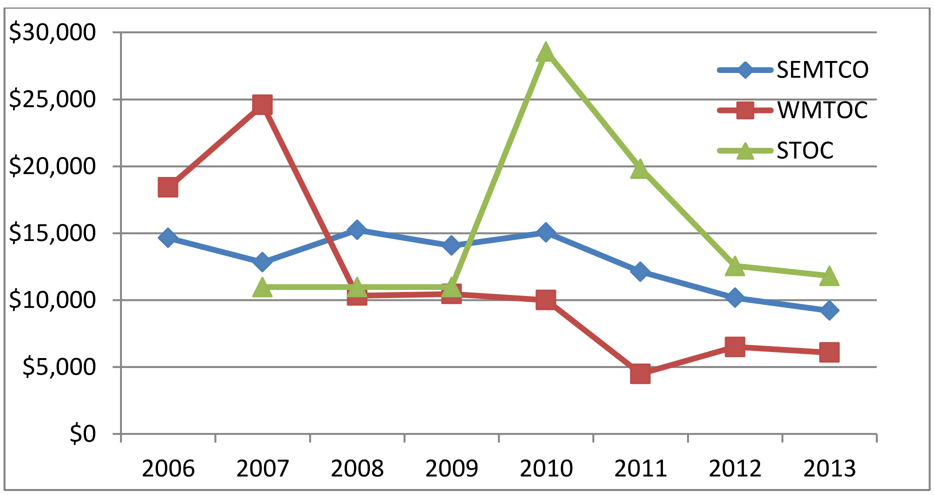


Figure 3-18: Changes in Annual Operations and Maintenance Costs

Table 3-9: Summary of Operations and Maintenance Cost

	TOC Coverage Area			Overall
	SEMTOC	WMTOC	STOC	
Total number of devices	589	214	171	974
Annual Operations and Maintenance Costs	$5,426,092	$1,303,177	$2,020,119	$8,749,387
O&M Cost per Device	$9,212	$6,090	$11,814	$8,983
Annual Freeway Courtesy Patrol Cost	$1,933,333	NA	$366,667	$2,300,000

Chapter 4 User Perception Survey

4.1 Introduction

Although many similar surveys have been conducted in the past, the overwhelming majority have focused on the performance of one particular device (such as Dynamic Message Signs (DMS)) at one particular area (Chicago, Shanghai, Sydney, etc.) conducted over a limited time range (typically a week or less). Accordingly, the present study distinguishes itself from the body of previous work by considering ITS deployments as a cohesive system (as well as individual devices) while gathering responses over an extended duration (six and a half months) across the entire state of Michigan. As addressed in the previous chapter, current MDOT ITS deployments under investigation include freeway management applications such as DMS, Travel Time Signs (TTS), Closed Circuit Television Cameras (CCTV), Road Weather Information Systems (RWIS), and Mi Drive.

Given that the survey was linked on MDOT's main web-based travel information portal, Mi Drive (http://michigan.gov/midrive/), the present survey is among the first to utilize an ITS service as the primary means of exposure (85 percent of respondents). Therefore, the main contributions of this study include the analysis of the entire range of Michigan ITS deployments individually and aggregated as a system, investigation of the effect of time/season on survey responses, and the audience consisting of primarily active ITS users on a statewide-scope, as opposed to the general public in a specific area.

4.2 Survey and Analysis Methodology

4.2.1 Survey Design and Data Collection

A mixed-preference questionnaire was prepared and pilot-tested by a group of university students before publically available at the link http://mdot.itssurvey.questionpro.com. The stated purpose of the survey was to identify how Michigan travelers perceive the benefits attributed to ITS. The questionnaire consisted of five primary categories, as summarized below:

- Category 1: Exposure Information & Demographics
    - "How did you find out about this survey?"

  - Age, Sex, Location (Zip Code), Date of Survey Completion
- Category 2: Travel Behaviors
  - “How many hours per day do you normally travel on freeways during the week and weekend?
  - “What is your major concern during your daily travel?
- Category 3: ITS Device Familiarity
  - Freeway Courtesy Patrol (FCP)
    - Waiting Time; Satisfaction; Willingness to Wait
  - Dynamic Message Signs (DMS)
    - Usefulness; Effects; Trustfulness
  - Travel Time Signs (TTS), Highway Advisory Radio (HAR), Closed Circuit Television Camera (CCTV), Road Weather Information Systems (RWIS), Mi Drive
- Category 4: Travel Information
  - Frequency; Importance; Trip changes
- Category 5: Suggestions for Better ITS Services
  - Open response

The survey opened on December 16, 2013, with responses collected through June 30, 2014, allowing for a six and a half month analysis window over two calendar seasons. A timeline of surveys completed is included in Figure 4-1 below. A copy of the survey questionnaire is provided in the Appendix 1.

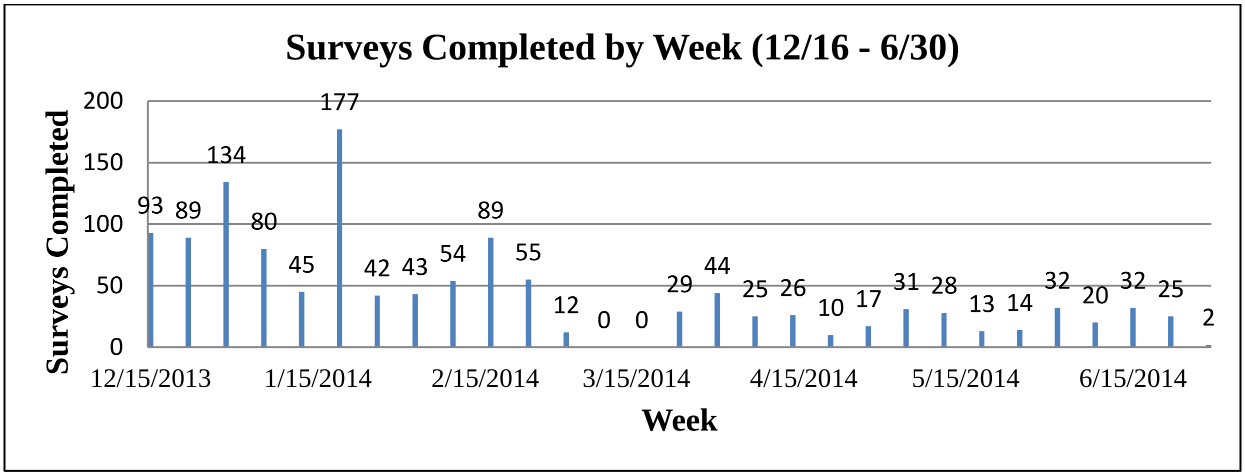


Figure 4-1: Weekly Timeline of Completed Surveys

4.2.2 Data Analysis Focuses & Methods

Comprehensive ITS device familiarity & frequency of use

As mentioned in the literature review section, motorist perception of travel information has primarily been studied with regard to the messages provided on DMS. Although the present study similarly queried driver familiarity and response to DMS and the various message types, an analysis of these results will not be discussed singularly. Instead, the degree of familiarity among respondents with regard to the entire range of MDOT ITS deployments is investigated.

Initially, a descriptive analysis is conducted to show how general user familiarity varies by device. The descriptive analysis is followed by ordered logistic regression modeling to determine how individual device familiarity and frequency of use varies according to characteristics such as age, sex, TOC location, freeway travel time, time of year and relative importance of various information types. User familiarity with the various ITS devices were categorized according to three candidate responses, as follows:

1. "No, not at all."
2. "I have heard about it, but do not know it well."
3. Yes, I know it well."

While device usage frequency could vary from "Never" to "Daily", with "Weekly", "Monthly" and "Yearly" as other options. Those respondents who indicated unfamiliarity with a certain device type were not further questioned about device usage frequency. Ordered logistic regression was chosen as the modeling approach as the qualitative responses to the questions of interest were structured discretely on an ordinal scale. The ordered logistic model determines the nonlinear probability that the latent, dependent variable will cross a certain threshold with respect to a change in the independent variables (Borooah, 2002). The general form of the ordered logit model is as follows (William, 2014):

$$Z_i = \sum_{l=1}^{L} \beta_l X_l$$

Where Z represents the estimated dependent variable and the β parameters are estimated according to the X independent variables. The threshold values that determine the odds of Y (the observed dependent variable) falling within a certain category are the estimated κ-terms in the following equation, where j represents the various discrete, ordered categories, such as 1, 2, and 3 in the user familiarity response example above (Bifulco *et al.*, 2014):

$$P(Y_i > j) = \frac{\exp(Z_i - \kappa_j)}{1 + [\exp(Z_i - \kappa_j)]}$$

Effect of pre-departure travel information on trips

MDOT TOCs disseminate a variety of information through the various ATIS deployments. When not displaying travel time messages, DMS provide information regarding incidents, special events, congestion, weather, construction, AMBER alerts and others. Additionally, Mi Drive provides information regarding construction, camera imagery, current travel speeds, incidents and weather. The current study investigates the impact of pre-departure travel information, regardless of ATIS source, on travel behaviors.

The types of pre-departure travel information under investigation include travel time, current roadway speeds, road work locations, crash/accident locations, road weather information, planned special events and freeway camera images. Respondents were asked to rate the importance of these information types on a scale from “No Need” to “Essential”, with intermediate options including “Not Important”, “Good to Have” and “Important”. A follow up question asked how often respondents perform the following behaviors based on answers to the previous questions: reschedule your trip, change your departure time, change your route and change your transportation mode. Answers to this question could range from “Never” to “Very Frequently”, with “Sometimes” and “Often” as other choices. Similar to the ITS device familiarity and frequency of use analysis, an initial descriptive analysis was performed to identify which information types respondents view as most essential. Following the descriptive analysis, travel behaviors were modeled with an ordered logistic regression according to the same independent characteristics stated in the previous ITS device familiarity section.

4.3 Results and Analysis

4.3.1 Demographics and Exposure

In total, 1,261 surveys were completed (at approximately a 75% completion rate) over the duration of data collection, with an average of 48.5 surveys completed on a weekly basis. As seen in Figure 4-1 during an approximately three-week period beginning on March 6, 2014 and ending on March 24, 2014, no surveys were completed. This absence of data gathering corresponds precisely with a time range in which the link to the survey was missing from the Mi Drive website (although the survey was still accessible). In the “Winter” period (12/16-3/16), 913 surveys were completed, while 291 surveys were completed during the “Spring” period (3/17 – 6/16). 64 percent of respondents were male, which mimics the male majority experienced by similar surveys (Peng et al., 2004; Peeta et al., 2006). As seen in Figure 4-2, the proportion of respondents above and below the age of 50 was approximately equal at 49 percent and 51 percent, respectively. The majority of respondents (64.3 percent) were male, as seen in Figure 4-3. Additionally, respondents were categorized according to TOC location by zip code. The majority of respondents (46.8 percent) resided in areas managed by the Statewide TOC (STOC), with 36.2 percent and 11.6 percent hailing from the Southeast Michigan TOC (SEMTOC) and West Michigan TOC (WMTOC), respectively. The remaining 5.6 percent of participants did not correctly indicate their zip code. As mentioned previously, the overwhelming majority (85.3 percent) of respondents were exposed to the survey through the Mi Drive link, as shown in Figure 4-4. Additional exposure sources included email request, rest area poster, FCP referral card and others.

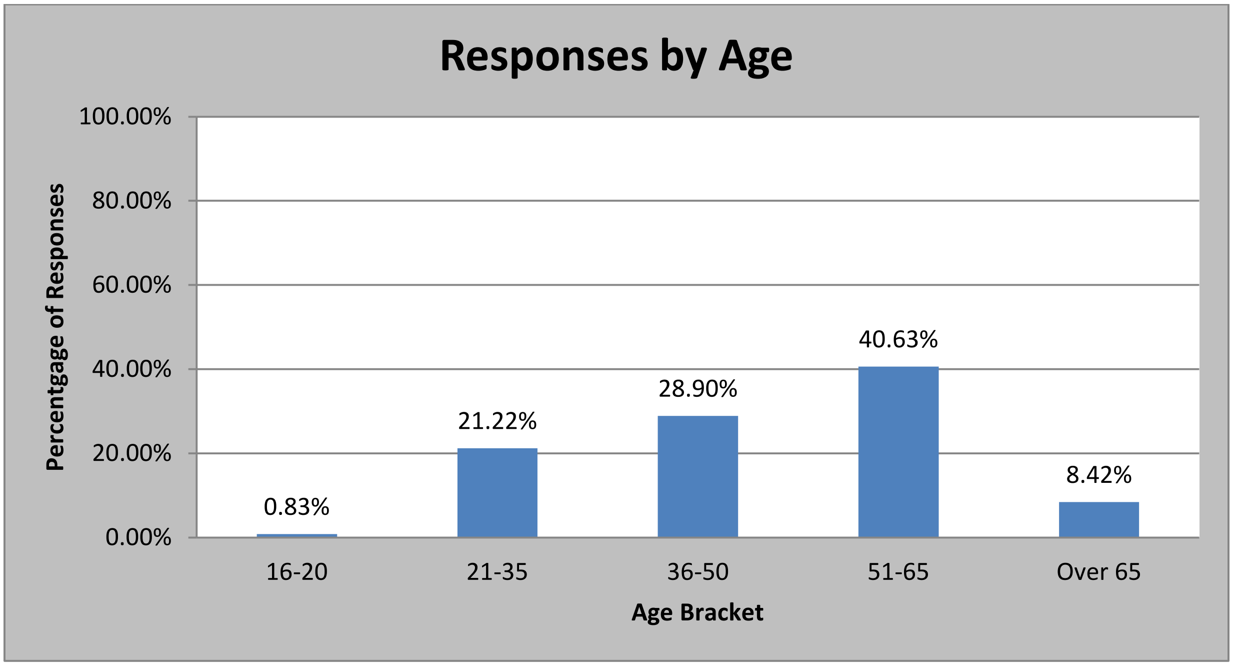


Figure 4-2: Survey Responses by Age

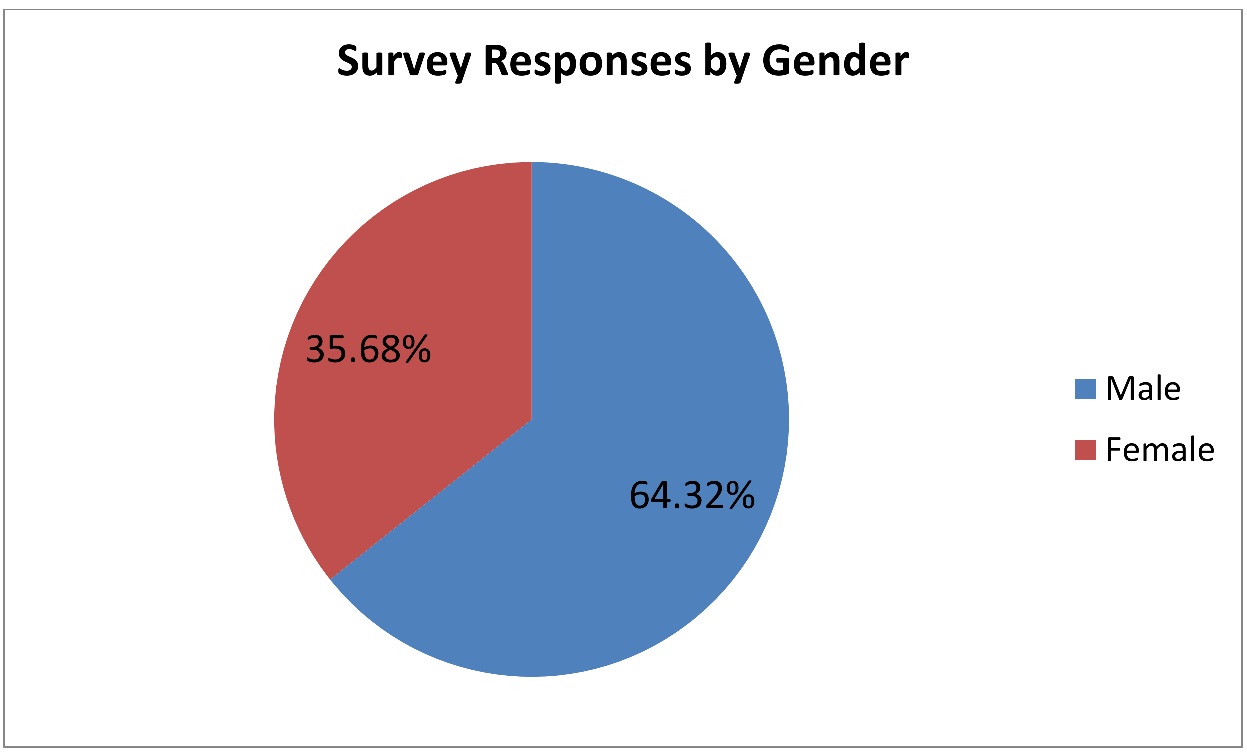


Figure 4-3: Survey Responses by Gender

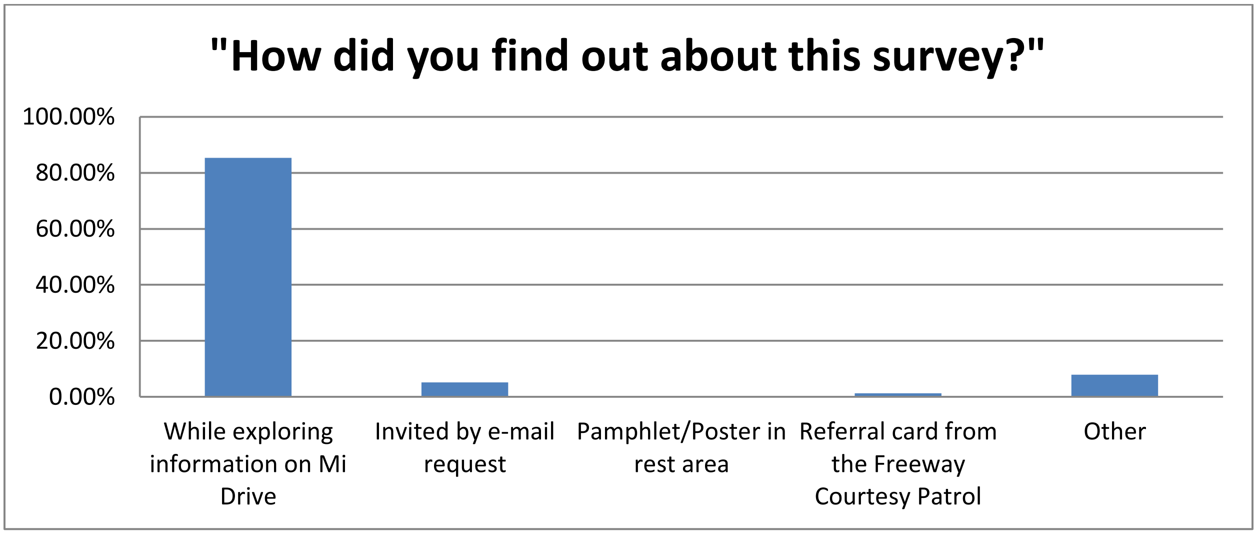


Figure 4-4: Survey Referral Points

4.3.2 ITS Device Familiarity and Frequency of Use

Descriptive Analysis

Descriptive summaries of the responses regarding ITS device familiarity and ATIS source usage frequency are provided in Table 4-1 and Table 4-2. The most well recognized devices were DMS and Mi Drive, while the least recognized devices were RWIS and HAR. While similar studies performed by Gates *et al*. (2012) and Hedden *et al*. (2011) only observed 22.5 percent and 19 percent familiarity with Mi Drive, the comparatively high Mi Drive recognition in the present study was anticipated given that only 16.5 percent of respondents had never used Mi Drive, as indicated in Table 4-2. The weekly variation in Mi Drive familiarity (in addition to DMS and CCTV) chosen as "Not at all." is represented in Figure 4-5. As seen, fewer respondents appeared to be aware of these devices in the spring season compared to the winter season. This observation may be explained by the propensity for harsh Michigan winter weather conditions to draw travelers' attention to these sources of travel information.

Television and radio represented the most frequently used ATIS sources on a daily basis, as seen in Table 4-2. However, Gates *et al*. (2012) similarly observed radio as the most utilized ATIS source, but found that only 23.8 percent of en-route travelers and 31.9 percent of commuters use radio daily. In the survey performed by Hedden *et al*. (2011), 53 percent of respondents reported never listening to radio traffic information and 62 percent never watch TV for travel information. Respondents in the present study use radio and TV much more frequently compared to these other studies conducted in Michigan, likely resulting from the nature of the majority of respondents representing active seekers of travel information, compared to the public at large.

Table 4-1: Familiarity on ITS Devices

Device Type	No, not at all.	I have heard about it, but do not know it well.	Yes, I know it well.
DMS	21 (1.7)	160 (12.7)	**1082 (85.7)**
TTS	186 (14.8)	318 (25.2)	**757 (60.0)**
HAR	**763 (60.5)**	371 (29.4)	127 (10.1)
CCTV	292 (23.2)	421 (33.4)	**548 (43.5)**
RWIS	**623 (49.4)**	411 (32.6)	227 (18.0)
Mi Drive	112 (8.9)	285 (22.6)	**864 (68.5)**

Note: Proportions in parenthesis. Highest proportion bolded.

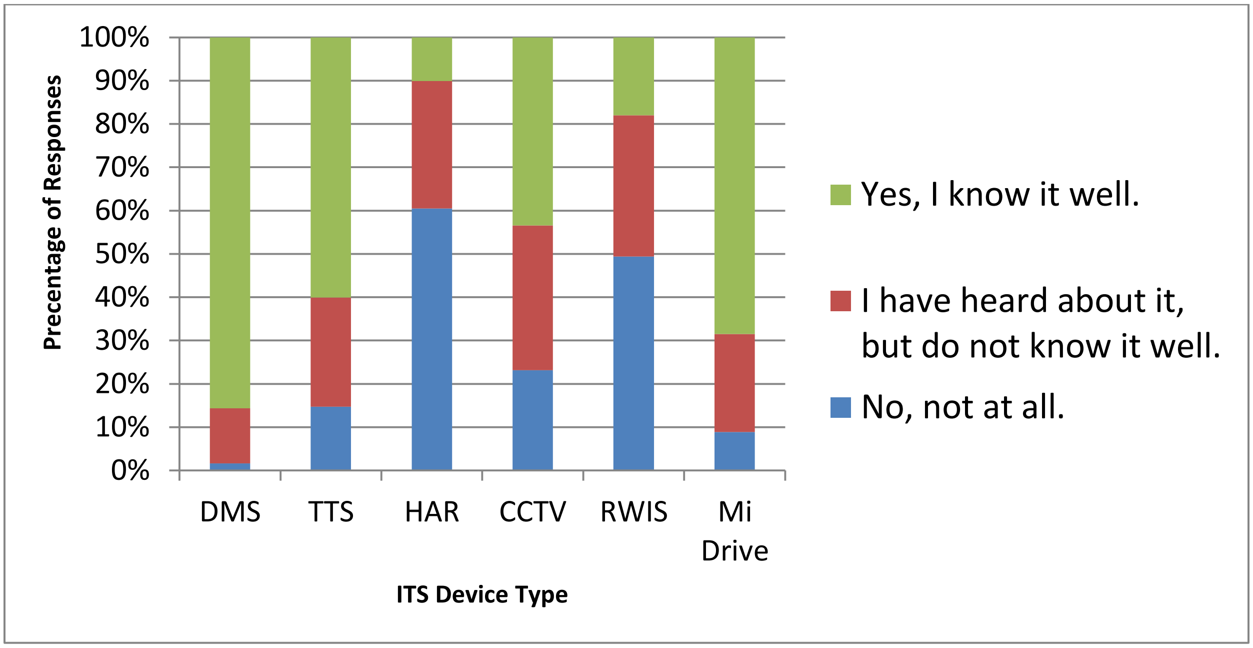


Figure 4-5: ITS Device Familiarity

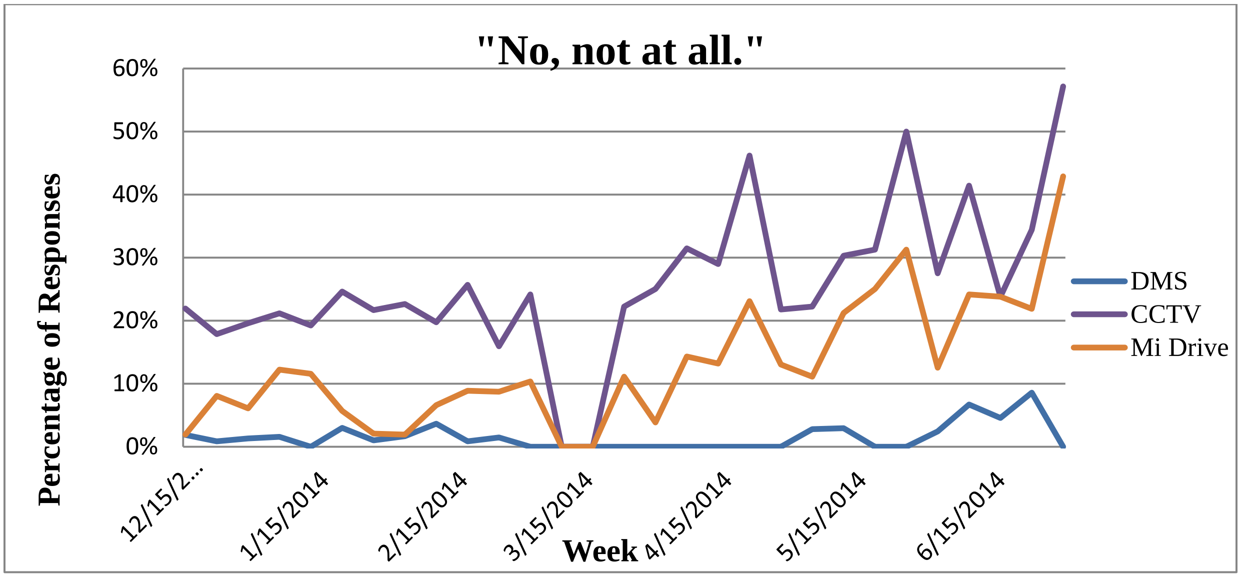


Figure 4-6: "No, not at all." Level of Familiarity vs. Device Type

Table 4-2: Source of Pre-departure Information

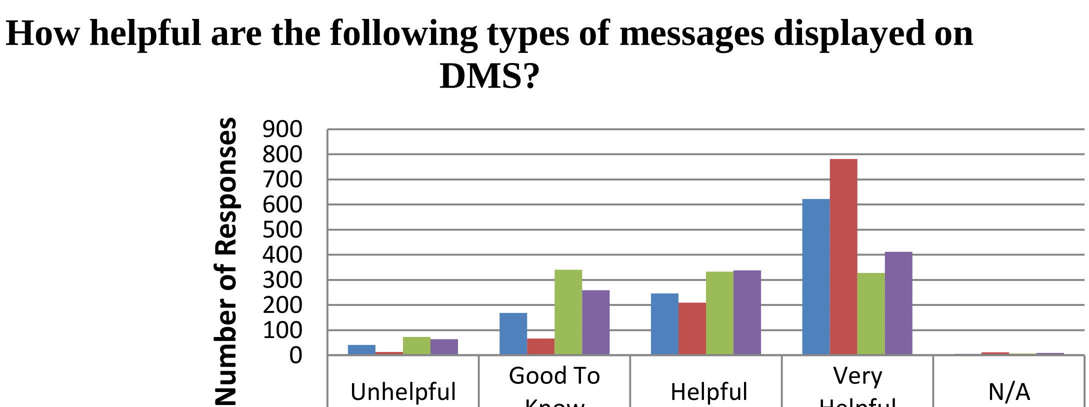
Usage Frequency	Mi Drive	Smartphone	Other websites	TV	Radio
Daily	**381 (30.3)**	298 (23.7)	300 (23.8)	**449 (35.7)**	**582 (46.2)**
Weekly	340 (27.0)	236 (18.7)	**349 (27.7)**	221 (17.6)	224 (17.8)
Monthly	235 (18.7)	99 (7.86)	268 (21.3)	130 (10.3)	124 (9.85)
Yearly	96 (7.55)	30 (2.38)	68 (5.40)	52 (4.13)	43 (3.42)
Never	208 (16.5)	**596 (47.3)**	274 (21.8)	407 (32.3)	286 (22.7)

Note: Proportions in parenthesis. Highest proportion bolded.

Given that respondents displayed a high degree of familiarity with DMS (as expected), the survey included various supplementary questions targeting additional insight into motorists' interaction with DMS. Survey respondents were asked to indicate their perceived usefulness of various types of DMS messages, effect of DMS on travel behaviors and level of trust in DMS information.

Regarding the perceived usefulness of DMS messages by type, four different types of example messages were shown to the respondent, with varying degrees of indicated usefulness ranging from “Unhelpful” to “Very Helpful”. Those respondents who did not indicate at least some familiarity with DMS were barred from accessing this portion of the survey. The descriptive analysis of message types and level of usefulness are indicated in Figure 4-7. As seen, while all messages were seen as being very helpful by most respondents, the most helpful message type indicated was “Incident Ahead: Use Detour Exit 35”. DMS messages displaying travel time information were viewed as the least helpful.

Additionally, respondents were asked how DMS affected their travel behaviors and their level of trust placed in the DMS device. Figures depicting the response-split with respect to these questions are shown in Figure 4-8 and Figure 4-9, respectively. As seen, most respondents stated that DMS either reduced their anxiety or guided them to alternate routes, at 30.4 percent and 29.6 percent of all travel impacts, respectively. Also, the overwhelming majority (93 percent) of respondents were at least somewhat trusting of DMS information.



	Unhelpful	Good To Know	Helpful	Very Helpful	N/A
"Accident Ahead: Expect Congestion"	41	168	246	622	5
"Incident Ahead: Use Detour Exit 35"	13	67	209	781	12
"Travel to Jackson / Distance 30 Miles / Time 25 Minutes"	73	341	333	328	7
"To Detroit: 30 Minutes via I-94, 25 Minutes via M-14"	64	259	338	412	9

Figure 4-7: Helpfulness of DMS Messages

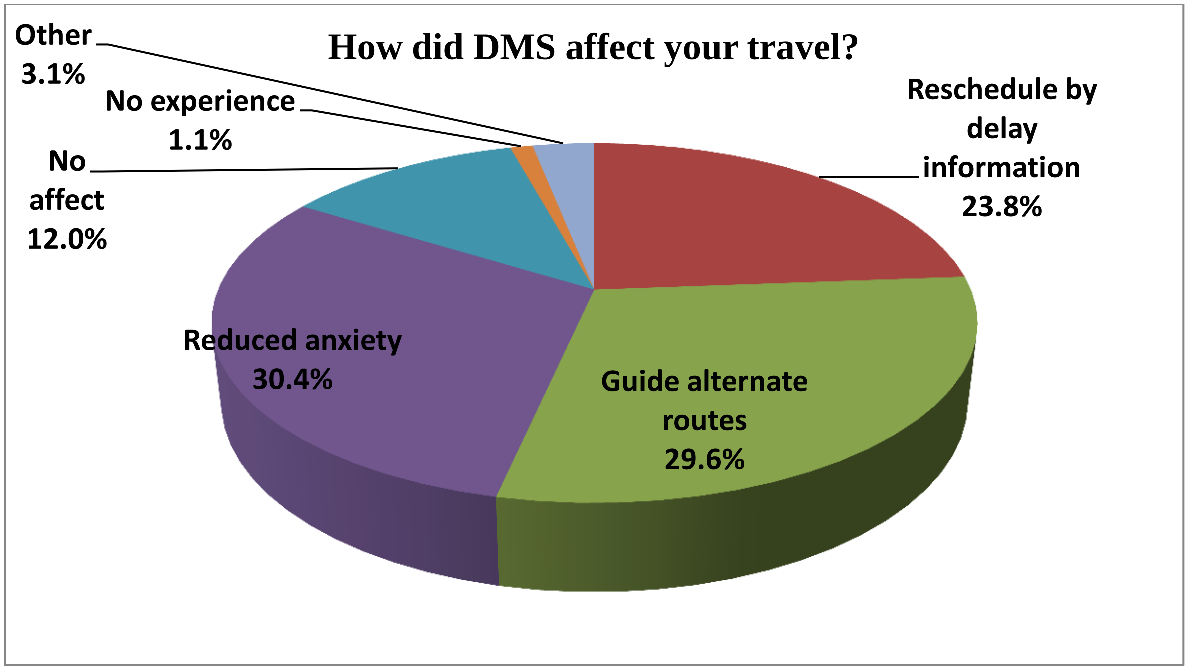


Figure 4-8: Effect of DMS on Travel Decisions

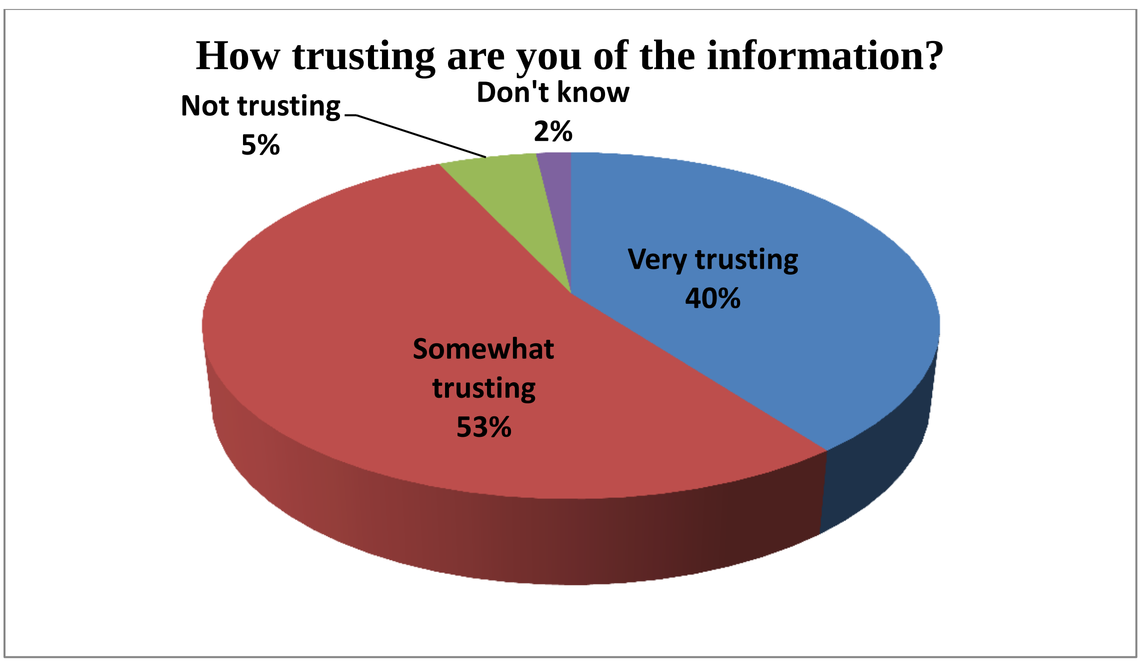


Figure 4-9: Level of Trust in DMS

To gain further insight into the interaction of perceived usefulness and trustfulness of DMS information and travel behaviors as a result, Chi-Square analyses were performed on the survey results. Expected values were calculated as a proportion of the total responses in each category, and compared with observed responses. The sum of the differences between observed and expected values over the sum of expected values results in the Chi-Square value, as shown in the equation below.

$$\chi^2 = \sum \frac{(observed - expected)^2}{expected}$$

Any Chi-Square value that returned an asymptotic significance greater than 0.05 was deemed insignificant and led to a conclusion that there is no difference among level of trust in the responses to the survey question of interest. While a Chi Square test with asymptotic significance less than 0.05 indicated that trust level somehow influences survey responses. The Chi-Square analysis of level of trust versus effect of DMS on travel behaviors is shown in Table 4-3. As seen, those who were very trusting of the information displayed on DMS tended to take the advised alternate route as per the displayed message. Additionally, those who were not trusting of DMS information tended to not adhere to whatever type of information was displayed and did not allow DMS to affect their travel behaviors or decisions. Further, a Chi-Square analysis was conducted on the effect of level of trust on the perceived helpfulness of different message types, as shown in Table 4-4 and Table 4-5. The message type “Incident Ahead: Use Detour Exit 35” is an example of prescriptive message content, while the message type “Travel to Jackson/Distance 30 Miles/Time 25 Minutes” represents a descriptive message aid. A comparison of Table 4-4 and Table 4-5 shows that as displayed information becomes more descriptive rather than prescriptive, even very trusting people lower their degree of perceived helpfulness. For example, 79.7 percent of those very trusting in DMS information felt that the message type “Incident Ahead: Use Detour Exit 35” was very helpful, however only 44.5 percent of the same group felt that the message type “Travel to Jackson/Distance 30 Miles/Time 25 Minutes” was very helpful.

Table 4-3: "How trusting are you of information displayed on DMS" vs. "How did DMS affect your travel?"

Cross Tabulation Frequency/Percent	How did DMS affect your travel? (Select all that apply)							
How trusting are you of the information displayed on DMS?		Helped me in revising my schedule by providing delay information	Helped me avoid congestion by guiding me to alternative routes	Reduced my anxiety by informing me of reasons for congestion	Did not affect my travel	I have not had any experience with DMS	Other	Row Totals
	Very trusting	236	276	263	50	5	19	849
		27.80%	32.51%	30.98%	5.89%	0.59%	2.24%	43.47%
	Somewhat trusting	215	278	316	146	14	28	997
		21.56%	27.88%	31.70%	14.64%	1.40%	2.81%	51.05%
	Not trusting	3	10	9	43	1	10	76
		3.95%	13.16%	11.84%	56.58%	1.32%	13.16%	3.89%
	Dont know	5	7	7	6	4	2	31
		16.13%	22.58%	22.58%	19.35%	12.90%	6.45%	1.59%
	Column Total	459	571	595	245	24	59	1953
	Column Percent	23.50%	29.24%	30.47%	12.54%	1.23%	3.02%	100%

Chi-Square 260.608 P Value 0.000 Degree of Freedom 15

Table 4-4: Level of Trust vs. "Incident Ahead: Use Detour Exit 35"

Cross Tabulation	"Incident Ahead: Use Detour Exit 35"						
How trusting are you of the information displayed on DMS?		Unhelpful	Good To Know	Helpful	Very Helpful	N/A	Row Totals
	Very trusting	1	23	65	376	7	472
		0.21%	4.87%	13.77%	79.66%	1.48%	38.88%
	Somewhat trusting	5	42	156	448	3	654
		0.76%	6.42%	23.85%	68.50%	0.46%	53.87%
	Not trusting	10	13	19	21	3	66
		15.15%	19.70%	28.79%	31.82%	4.55%	5.44%
	Don't know	0	4	5	12	1	22
		0%	18.18%	22.73%	54.55%	4.55%	1.81%
	Column Total	16	82	245	857	14	1214
	Column Percent	1.32%	6.75%	20.18%	70.59%	1.15%	100%

Chi-Square 174.422 p Value 0.000 Degrees of Freedom 12

Table 4-5: Level of Trust vs. "Travel to Jackson/Distance 30 Miles/Time 25 Minutes"

Cross Tabulation	"Travel to Jackson / Distance 30 Miles / Time 25 Minutes"						
How trusting are you of the information displayed on DMS?		Unhelpful	Good To Know	Helpful	Very Helpful	N/A	Row Totals
	Very trusting	9	105	144	210	4	472
		1.91%	22.25%	30.51%	44.49%	0.85%	38.88%
	Somewhat trusting	44	248	209	150	3	654
		6.73%	37.92%	31.96%	22.94%	0.46%	53.87%
	Not trusting	32	20	9	4	1	66
		48.48%	30.30%	13.64%	6.06%	1.52%	5.44%
	Dont know	4	12	4	2	0	22
		18.18%	54.55%	18.18%	9.09%	0%	1.81%
	Column Total	89	385	366	366	8	1214
	Column Percent	7.33%	31.71%	30.15%	30.15%	0.66%	100%

Chi-Square 268.924 p Value 0.000 Degrees of Freedom 12

A secondary portion of the survey was made available to travelers assisted by FCP services. A referral card to the survey was provided to FCP personnel with instructions to pass along to assisted motorists after completion of the service. Despite these exposure efforts, only 63 responses were gathered from FCP-assisted motorists. However, the researchers felt that the analysis of results could still prove insightful and thus are presented below. The three additional questions asked of those assisted by FCP were as follows:

1. How long have you waited for the Freeway Courtesy Patrol (FCP) service?
2. How long would you be willing to wait for the FCP service?
3. Were you satisfied with the FCP service?

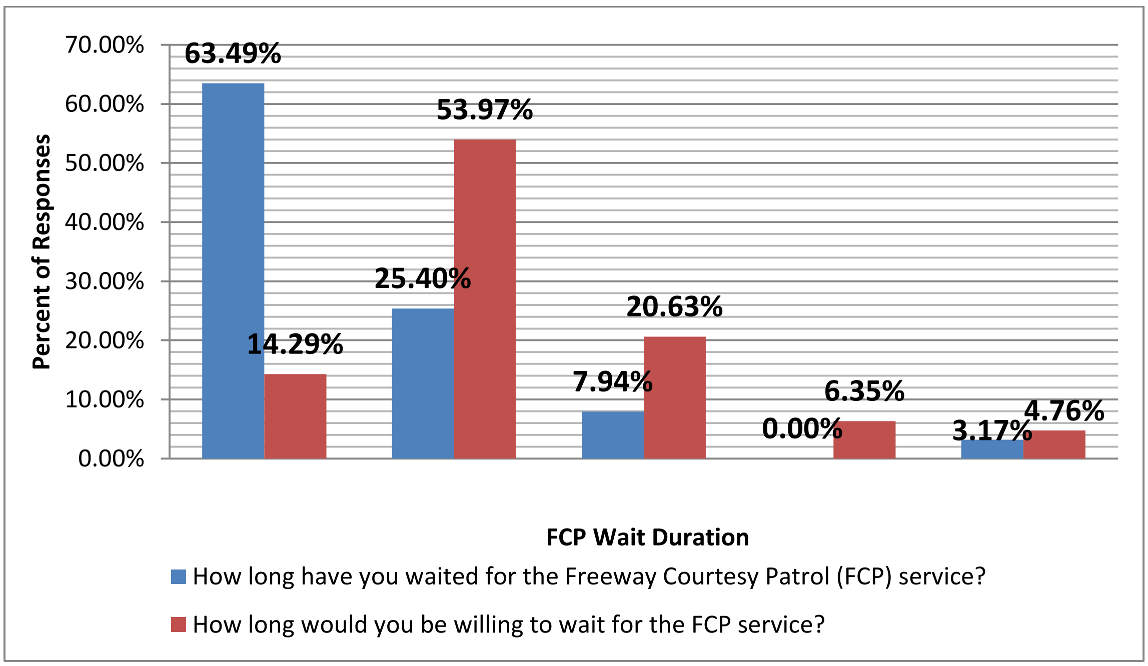


Figure 4-10: FCP Wait Duration

The descriptive results of the answers to these questions are provided in Figure 4-10 and Figure 4-11, respectively. As indicated in Figure 4-10, respondents were willing to wait much longer than actual FCP response time. The majority (63.5 percent) of respondents indicated that they waited less than 15 minutes for FCP service, however, roughly 54 percent answered that they'd be willing to wait up to 30 minutes for an FCP vehicle to arrive at the scene. Additionally, almost all (94 percent) of FCP-assisted survey respondents stated that they were satisfied with both the response time and quality of service provided by FCP.

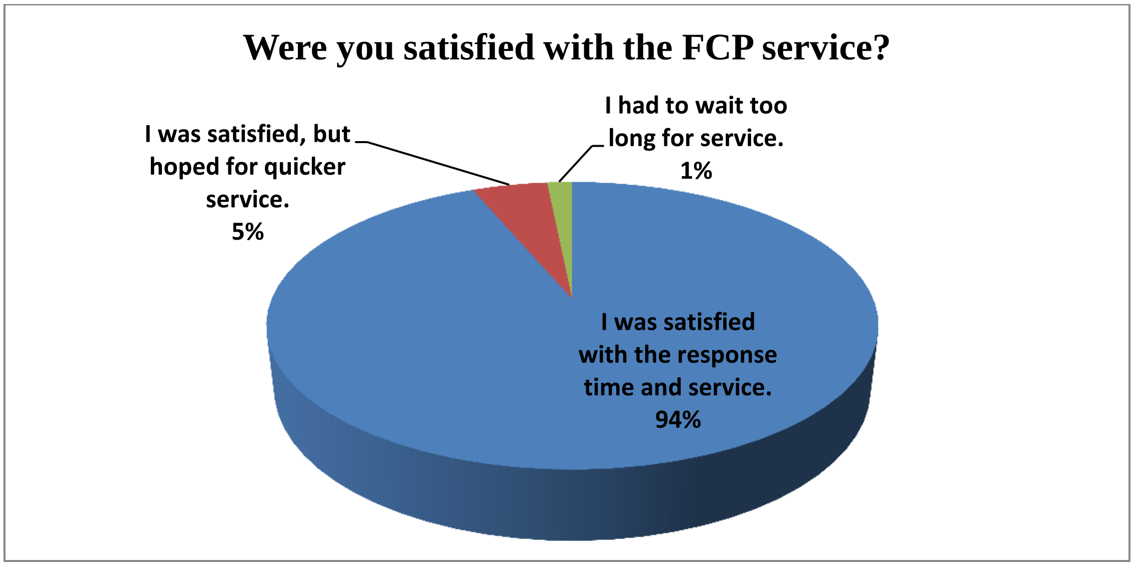


Figure 4-11: FCP Level of Satisfaction

4.3.3 Freeway Travel Frequency and Concerns

To better understand the travel dynamics of those motorists responding to the survey, questions were posed asking the duration of daily travel on freeways on both weekdays and weekends. The responses to these questions are shown in Figure 4-12 and Figure 4-13, respectively. As seen, the "0-30 Minute" time-range represented the most frequently chosen response on both weekdays and weekends. However, weekday daily travel is more evenly distributed between the various time-ranges as compared to the weekend. This likely indicates an acceptable distribution of weekday commuters in the sample.

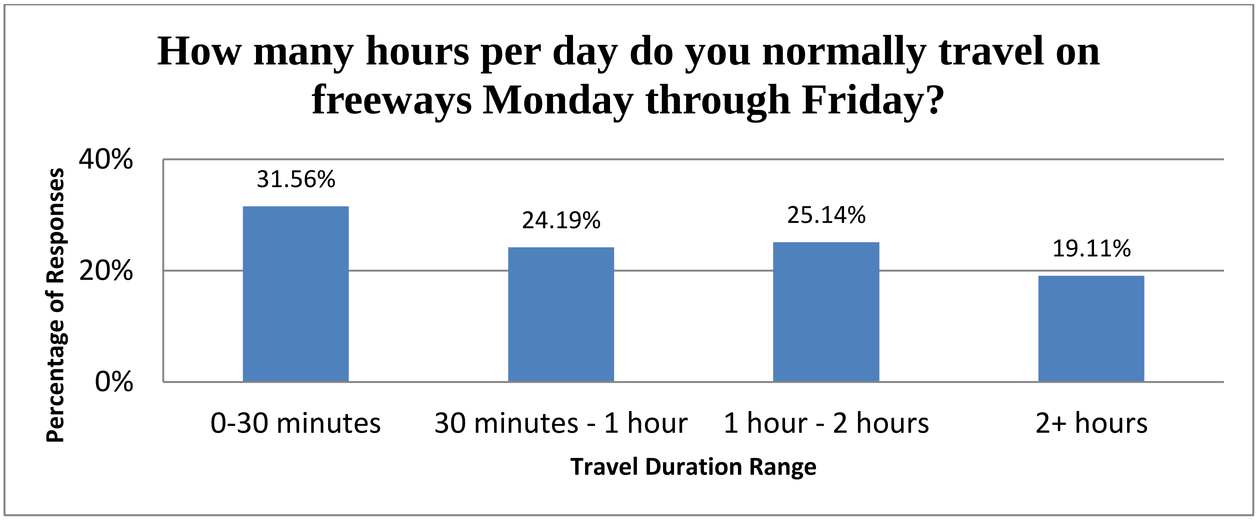


Figure 4-12: Weekday Daily Freeway Travel Duration

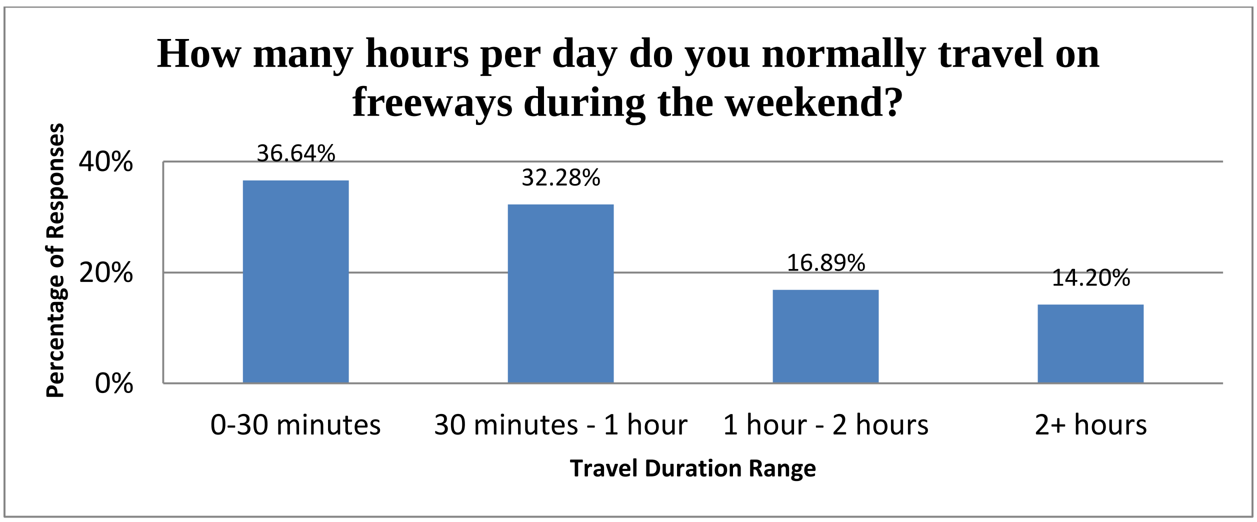


Figure 4-13: Weekend Daily Freeway Travel Duration

Regarding travel behaviors, a question posing, "What is your major concern during your daily travels?" was asked of survey respondents. The results are presented in Figure 4-14. As seen, the most frequently stated concern was "Congestion". However, the frequency of unique messages displayed on DMS does not coincide with the primary concerns of travelers, as seen in Figure 4-15. Despite representing a minor concern of motorists according to the survey results, Incident-type messages were the most frequently displayed message type at both WMTOC and STOC in 2013, at 39 percent and 48 percent of all messages, respectively.

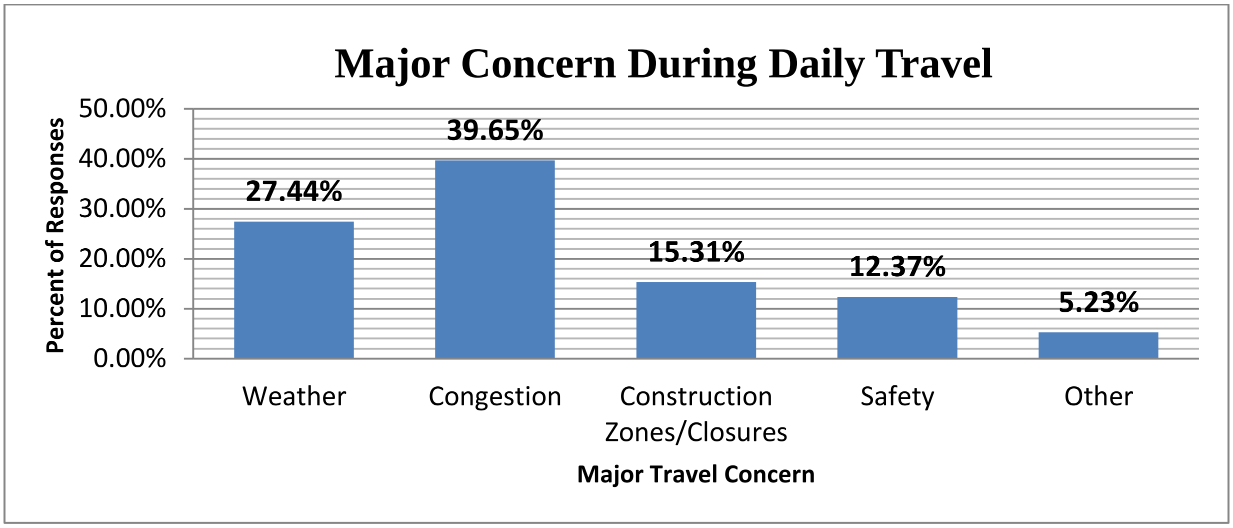


Figure 4-14: Major Concern during Daily Travel

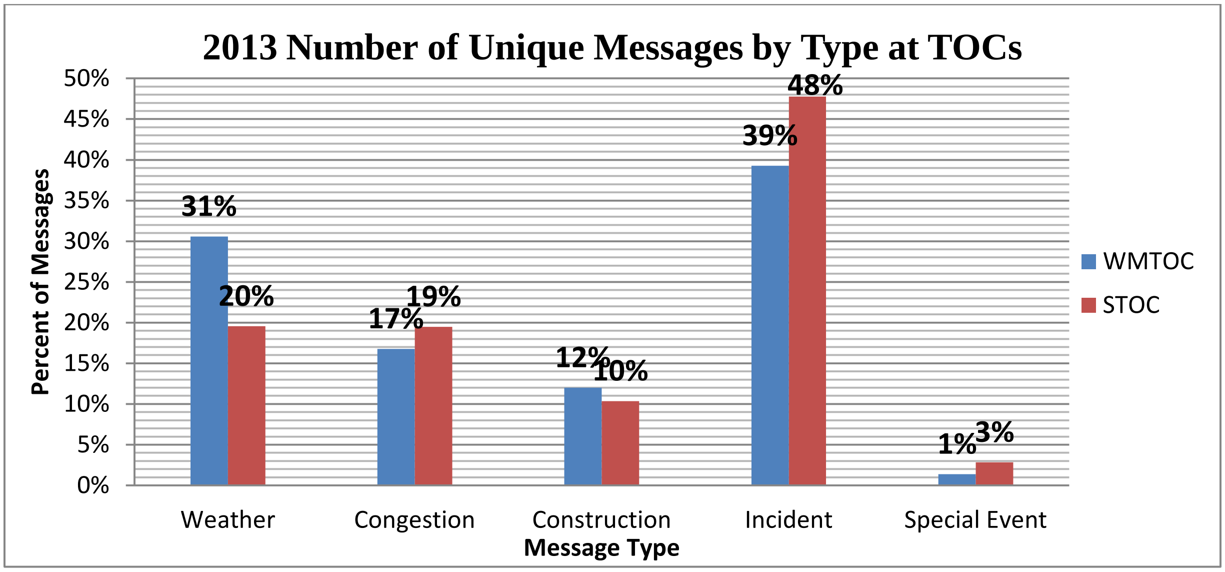


Figure 4-15: 2013 Number of Unique Messages by Type at TOCs

Additionally, a time series analysis was conducted to determine the effect of time of year on daily travel concerns, as presented in Figure 4-16 below. As seen, "Weather" as a primary concern dominates the spectrum from December to March, which coincides with the Michigan winter season, while the focus switches to "Construction Zones/Closures" from March onwards, aligning with the Michigan road construction season. The transfer point in Mid-March where no responses are indicated is due to the aforementioned time-period when the survey was not available online due to a broken link.

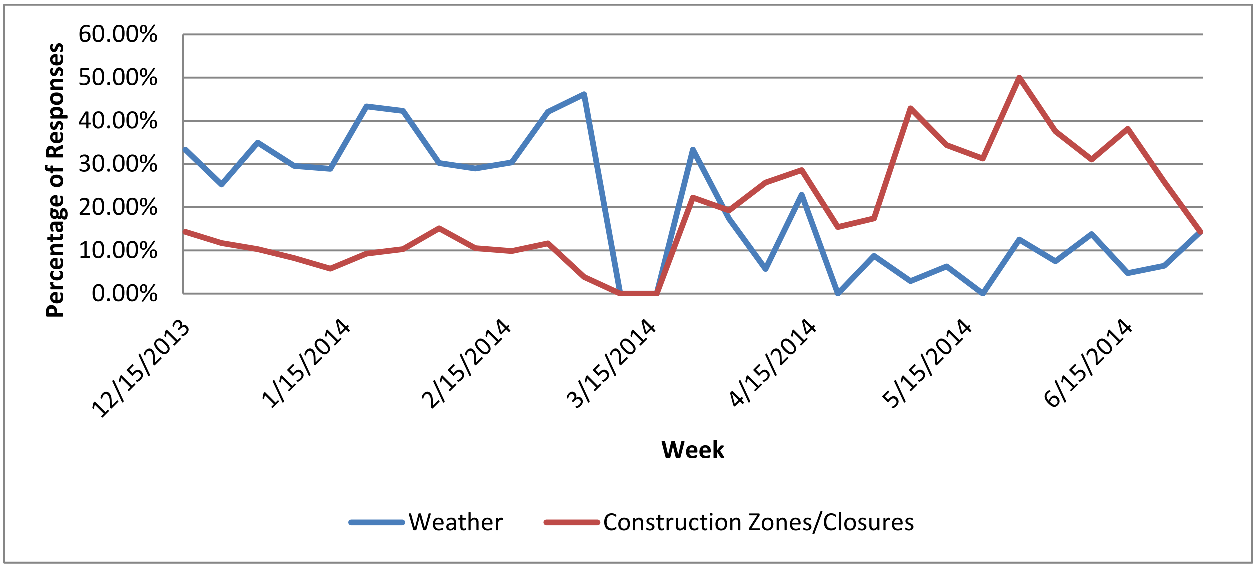


Figure 4-16: Weather and Construction Primary Concern vs. Time of Year

4.3.4 Travel Information

Survey respondents were asked to indicate their level of usage frequency of various sources of advanced travel information. Usage frequency could vary from "Daily" to "Never", while source types included Mi Drive, smartphones, other websites, TV and radio. The seasonal variation of Mi Drive usage frequency is indicated in Figure 4-17. As seen, daily Mi Drive use steadily declined over the duration of the survey period. Radio was the most frequently used source of pre-departure travel information in both the defined spring (March 21 – June 21) and winter (December 21 – March 21) periods, as shown in Table 4-6 and Table 4-7, respectively. However, Mi Drive use dropped from most often used daily in the winter period to only weekly in the spring period.

Further, the survey asked respondents to indicate their perceived level of necessity (from "No Need" to "Essential" of various types of pre-departure travel information, including travel time, speed, work zone, crash, road weather, planned event and CCTV. The descriptive summary of this analysis by time period is shown in Table 4-8. As seen, all information types were seen by the majority of respondents to at least be "Good to Have", while pre-departure crash information was seen to be essential by the most respondents in both the Winter and Spring periods. Regarding Work Zone and Road Weather information, a figure showing the seasonal variation is presented in Figure 4-18. As expected, Road Weather information is viewed as essential by the majority of respondents during the Winter period, while the focus shifts towards Work Zone information in the Spring period, coinciding with the Michigan road construction season.

Given that crash information was viewed as the most essential type of pre-departure travel information, further Chi-Square analyses were conducted on the level of importance placed on crash information by source usage frequency. These analyses according to Mi Drive and TV usage are provided in Table 4-9 and Table 4-10, respectively. As seen, those respondents who felt that crash information was essential tended to use both Mi Drive and TV as sources of pre-departure travel information on a daily basis.

4.3.5 Survey General Comments

At the conclusion of the survey, respondents were asked to leave general comments regarding ITS if desired. The majority of the comments were overwhelmingly, positive. A few choice examples are shown below:

- “This is a very useful app as I commute 45 mins each way to work and travel to other remote locations very frequently. It is useful to know current speeds not only for travel time planning but also to infer road conditions.”
- “LOVE IT!!! Thank you for reducing stress, saving us time & avoiding adding us to the accidents. I share the website with so many people! ...I don't remember seeing weather alerts on the website, but driving speeds usually tell me what to expect anyways.”

In addition, many users indicated a high demand for a standalone, mobile Mi Drive application for their smartphones. Among all ITS devices, many of the comments indicated a desire for increased freeway camera imagery exposure and quality. Some of the negative themes included a general lack of appreciation for special DMS messages such as “Click It or Ticket” and “Don’t Veer for Deer”. Many respondents also felt that provided travel information was not up to date. A compilation of general comments is provided in s separate appendix document.

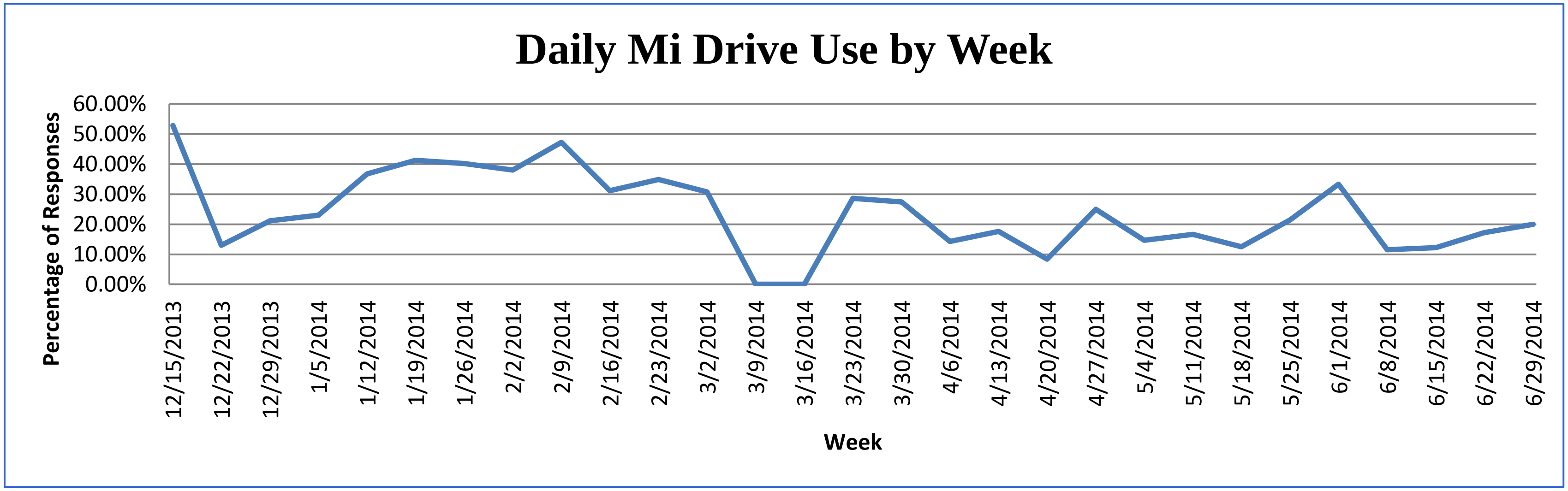


Figure 4-17: Daily Mi Drive Use by Week

Table 4-6: Winter Pre-Departure Information Use Frequency by Source

Winter Pre-Departure Information Use Frequency by Source					
	Source				
Usage Frequency	MiDrive	Smartphone	Other websites	TV	Radio
Daily	**33.92%**	24.59%	25.03%	**35.78%**	**47.42%**
Weekly	27.44%	19.21%	**27.00%**	18.88%	18.22%
Monthly	17.45%	7.90%	20.31%	10.54%	9.33%
Yearly	6.70%	2.09%	4.61%	3.73%	2.85%
Never	14.49%	**46.21%**	23.05%	31.06%	22.17%

Table 4-7: Spring Pre-Departure Information Use Frequency by Source

Spring Pre-Departure Information Use Frequency by Source					
	Source				
Usage Frequency	MiDrive	Smartphone	Other websites	TV	Radio
Daily	21.65%	22.68%	20.27%	**37.11%**	**45.02%**
Weekly	**26.80%**	17.53%	**29.55%**	13.75%	16.84%
Monthly	21.31%	7.90%	24.74%	9.28%	10.65%
Yearly	9.28%	2.06%	7.56%	5.50%	5.15%
Never	20.96%	**49.83%**	17.87%	34.36%	22.34%

Table 4-8: Information Type Necessity by Season

	Information Type Necessity - Seasonal Variation													
Level of Necessity	Travel Time		Speed		Work Zone		Crash		Road Weather		Planned Event		CCTV	
	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring	Winter	Spring
No Need	7.03%	3.44%	4.83%	2.75%	0.66%	0.34%	0.88%	0.69%	1.43%	0.69%	4.50%	3.09%	8.78%	8.93%
Not Important	8.12%	7.22%	8.89%	9.97%	1.76%	0.69%	1.43%	0.34%	2.31%	4.12%	13.50%	12.03%	19.87%	23.02%
Good to Have	**38.86%**	**40.89%**	**37.54%**	**46.05%**	31.50%	24.05%	15.26%	14.78%	17.89%	31.96%	**48.08%**	**44.33%**	**34.91%**	**38.14%**
Important	27.55%	32.65%	30.74%	27.84%	**43.14%**	**38.83%**	37.21%	37.11%	33.04%	**40.21%**	24.92%	27.15%	19.87%	19.93%
Essential	18.44%	15.81%	18.00%	13.40%	22.94%	36.08%	**45.23%**	**47.08%**	**45.33%**	23.02%	9.00%	13.40%	16.58%	9.97%

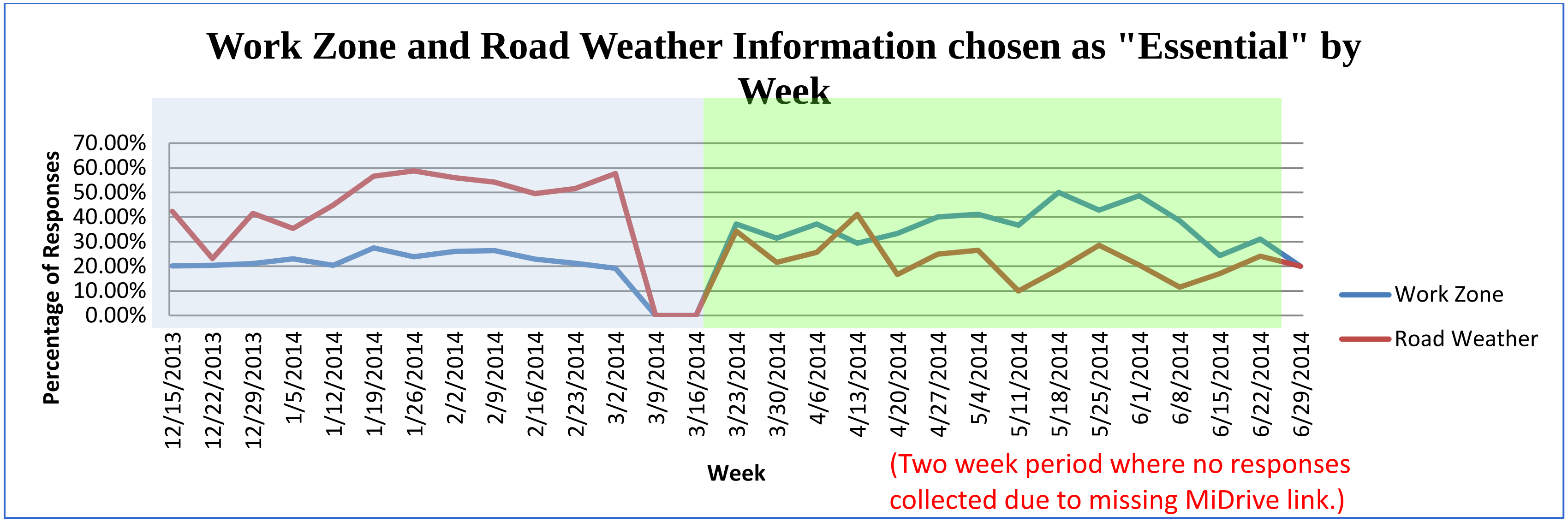


Figure 4-18: Work Zone and Road Weather Information by Week

Table 4-9: Crash Information Necessity vs. Mi Drive Usage Frequency

Cross Tabulation Frequency/Percent	Mi Drive site usage frequency						
Crash/Accident location info necessity		Daily	Weekly	Monthly	Yearly	Never	Row Totals
	No Need	0	1	2	1	6	10
		0%	10%	20%	10%	60%	0.73%
	Not Important	1	1	3	3	9	17
		5.88%	5.88%	17.65%	17.65%	52.94%	1.24%
	Good to Have	41	48	41	26	50	206
		19.90%	23.30%	19.90%	12.62%	24.27%	15.07%
	Important	125	142	112	49	92	520
		24.04%	27.31%	21.54%	9.42%	17.69%	38.04%
	Essential	245	172	96	26	75	614
		39.90%	28.01%	15.64%	4.23%	12.21%	44.92%
	Column Total	412	364	254	105	232	1367
	Column Percent	30.14%	26.63%	18.58%	7.68%	16.97%	100%

Chi-Square 109.084 p Value 0.000 Degrees of Freedom 16

Table 4-10: Crash Information Necessity vs. TV Usage Frequency

Cross Tabulation Frequency/Percent	Television usage frequency						
Crash/Accident location info necessity		Daily	Weekly	Monthly	Yearly	Never	Row Totals
	No Need	1	2	0	0	7	10
		10%	20%	0%	0%	70%	0.73%
	Not Important	2	4	0	1	10	17
		11.76%	23.53%	0%	5.88%	58.82%	1.24%
	Good to Have	59	44	22	9	72	206
		28.64%	21.36%	10.68%	4.37%	34.95%	15.07%
	Important	171	103	76	26	144	520
		32.88%	19.81%	14.62%	5%	27.69%	38.04%
	Essential	247	90	49	18	210	614
		40.23%	14.66%	7.98%	2.93%	34.20%	44.92%
	Column Total	480	243	147	54	443	1367
	Column Percent	35.11%	17.78%	10.75%	3.95%	32.41%	100%

Chi-Square 49.429 p Value 0.000 Degrees of Freedom 16

Ordered logistic regression

An ordered logistic regression was performed on responses to ITS device familiarity and ATIS source frequency use against the explanatory variables defined below:

Age
= 1, if age ≤ 50
= 0, if age > 50
Sex
= 1, if male
= 0, if female
WMTOC
= 1, if zip within WMTOC region
= 0, if zip outside WMTOC region
SEMTOC
= 1, if zip within SEMTOC region
= 0, if zip outside SEMTOC region
Winter
= 1, if completion between 12/16 - 3/16
= 0, if completion after 12/16 - 3/16

Spring
= 1, if completion between 3/17 - 6/16
= 0, if completion before/after 3-17 - 6/16
Wk_Trav_30
= 1, if daily weekday travel ≥ 30 minutes
= 0, if daily weekday travel < 30 minutes
We_Trav_30
= 1, if daily weekend travel ≥ 30 minutes
= 0, if daily weekend travel < 30 minutes
"Info"_Imp
= 1, if at least "Good to Have"
= 0, if "No Need" or "Not Important"

The "Info"_Imp variable refers to the stated level of importance respondents placed on the various types of travel information provided by MDOT ATIS sources as summarized in the note under Table 4-11. The results of the ordered logit models are provided in Table 4-11 and Table 4-12 on the subsequent pages. As seen in Table 4-11, all ITS device familiarity model chi-square values were significant at greater than the 99 percent confidence level, with P > χ^2=0.000 in all cases. The low McFadden R^2 values are expected given that many explanatory variables not under investigation in these models affect ITS device familiarity. Therefore, these models cannot be used to predict device familiarity with any degree of certainty. However, the models provide insight into which factors are significantly correlated with familiarity and use frequency, which is a primary focus of this study.

One of the more notable results is the effect of location on ITS device familiarity. The WMTOC and SEMTOC variables were significant at greater than the 99 percent confidence level, with P > |z| values of 0.000. The coefficient value of -0.995 for the WMTOC variable indicates that if the respondent resided in the WMTOC region, there is a 0.995 decrease in the log-likelihood of being in a higher category of FCP familiarity. This result is intuitive, given that WMTOC does not currently mange a FCP program; unlike SEMTOC whose FCP covers a freeway network of over 320 miles in southeast Michigan. The positive coefficients for the SEMTOC variable with regards to DMS and CCTV familiarity are also to be expected, as 96 DMS and 227 CCTV are currently in operation in the SEMTOC region, compared to 26 DMS and 68 CCTV in the WMTOC region and 54 DMS and 81 CCTV in the STOC region. With regard to the effect of season on ITS familiarity, the positive coefficients for the winter variable with respect to DMS, CCTV and Mi Drive familiarity verify the time trend seen in Figure 4-6. The significant effect of Cam_Imp in all device familiarity models except TTS possibly reflects a relationship between interest in an advanced form of travel information such as freeway camera imagery and general ITS interest.

Table 4-11: ITS Device Familiarity: Ordered Logit Regression

			ITS Device Familiarity						
			FCP	DMS	TTS	HAR	CCTV	RWIS	MiDrive
Model Fit	Model Chi-Sq.		345.60	61.22	46.81	48.52	153.05	38.23	51.38
	Prob. > Chi-Sq.		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Pseudo R-Sq.		0.1263	0.053	0.0199	0.0215	0.0569	0.0148	0.0252
Independent Variables	Age	Coef.	-	0.432	-	-	-	-	0.288
		P>|z|	-	0.013	-	-	-	-	0.022
	Sex	Coef.	0.358	-	-	0.609	0.624	0.409	-
		P>|z|	0.002	-	-	0.000	0.000	0.000	-
	WMTOC	Coef.	-0.995	-	-0.589	-	-	-	-
		P>|z|	0.000	-	0.001	-	-	-	-
	SEMTOC	Coef.	1.55	0.660	-	-	0.684	-	-
		P>|z|	0.000	0.001	-	-	0.000	-	-
	Winter	Coef.	-	0.366	-	-	0.305	-	0.355
		P>|z|	-	0.038	-	-	0.011	-	0.008
	Spring	Coef.	-	-	-	-	-	-	-
		P>|z|	-	-	-	-	-	-	-
	Wk_Trav_30	Coef.	0.719	0.441	0.385	-	-	-	0.464
		P>|z|	0.000	0.013	0.002	-	-	-	0.000
	We_Trav_30	Coef.	0.235	0.379	0.358	0.284	0.283	-	-
		P>|z|	0.046	0.027	0.003	0.018	0.011	-	-
	Spd_Imp*	Coef.	-	-	0.486	-	-	-	-
		P>|z|	-	-	0.002	-	-	-	-
	WZ_Imp*	Coef.	-	-	-	-	-	-	-
		P>|z|	-	-	-	-	-	-	-
	PSE_Imp*	Coef.	0.403	-	-	-	-	-	-
		P>|z|	0.008	-	-	-	-	-	-
	Cam_Imp*	Coef.	0.295	0.583	-	0.532	0.897	0.588	0.571
		P>|z|	0.016	0.001	-	0.000	0.000	0.000	0.000
	Crash_Imp*	Coef.	-	-	-	-	-	-	-
		P>|z|	-	-	-	-	-	-	-
	RW_Imp*	Coef.	-	-	-	-	-	-	-
		P>|z|	-	-	-	-	-	-	-

Note: "-" indicates a non-significant correlation at the 95% confidence level.

*=Information Types: Spd=Travel Speed, WZ=Work Zone, PSE=Planned Special Events, Cam=Freeway Camera, Crash=Crash/Accident, RW=Road Weather

Table 4-12: ATIS Pre-Departure Usage: Ordered Logit Regression

			ATIS Pre-Departure Source Usage Frequency				
			Mi Drive	Smartphone	Other websites	TV	Radio
Model Fit	Model Chi-Sq.		144.30	69.95	75.90	64.90	51.92
	Prob. > Chi-Sq.		0.0000	0.0000	0.0000	0.0000	0.0000
	Pseudo R-Sq.		0.0377	0.0214	0.0199	0.0184	0.0153
Independent Variables	Age	Coef.	-	0.377	0.405	-0.245	-
		P>|z|	-	0.000	0.000	0.018	-
	Sex	Coef.	-	-	-	-	-
		P>|z|	-	-	-	-	-
	WMTOC	Coef.	-	-	-	-	-
		P>|z|	-	-	-	-	-
	SEMTOC	Coef.	-	-	-0.225	-	0.350
		P>|z|	-	-	0.035	-	0.002
	Winter	Coef.	0.553	-	-	-	-
		P>|z|	0.000	-	-	-	-
	Spring	Coef.	-	-	-	-	-
		P>|z|	-	-	-	-	-
	Wk_Trav_30	Coef.	0.491	0.484	-	-	0.432
		P>|z|	0.000	0.000	-	-	0.000
	We_Trav_30	Coef.	-	-	0.483	-	-
		P>|z|	-	-	0.000	-	-
	Spd_Imp*	Coef.	-	0.447	0.344	-	-
		P>|z|	-	0.006	0.025	-	-
	WZ_Imp*	Coef.	-	-	-	-	-
		P>|z|	-	-	-	-	-
	PSE_Imp*	Coef.	-	-	0.475	-	-
		P>|z|	-	-	0.001	-	-
	Cam_Imp*	Coef.	0.912	0.524	0.325	0.669	0.506
		P>|z|	0.000	0.000	0.004	0.000	0.000
	Crash_Imp*	Coef.	1.58	-	-	-	-
		P>|z|	0.000	-	-	-	-
	RW_Imp*	Coef.	-	-	-	1.01	-
		P>|z|	-	-	-	0.000	-

Note: “-“ indicates a non-significant correlation at the 95% confidence level.

*=Information Types: Spd=Travel Speed, WZ=Work Zone, PSE=Planned Special Events, Cam=Freeway Camera, Crash=Crash/Accident, RW=Road Weather

4.3.6 Effect of Pre-Departure Travel Information on Trips

Descriptive analysis

The descriptive summary of the responses to the revealed preference question asking how often pre-departure trip changes were made based on the various types of travel information provided by MDOT ATIS are provided in Table 4-13. The majority of respondents tend to at least sometimes reschedule, change departure time or change route, while few respondents ever change transportation mode as a result of travel information. As seen, the categorical response split for changing departure time and route are almost identical, a result similar to that found by the study performed by Gates *et al*. (2012). However, in the survey performed by Gates *et al*., the plurality of respondents stated that they rarely change route or departure time at 30 percent and 34 percent, respectively. Once again, this deviation between studies is likely explained by the present study primarily consisting of respondents who actively seek and take advantage of travel information.

Table 4-13: Impact of Travel Information on Trip Changes

	Trip Change			
	Reschedule	Change Departure Time	Change Route	Change Mode
N/A	13 (1.03)	5 (0.40)	3 (0.24)	50 (3.97)
Never	360 (28.59)	68 (5.40)	49 (3.89)	**1070 (84.99)**
Sometimes	**737 (58.54)**	**673 (53.46)**	**657 (52.18)**	115 (9.13)
Often	110 (8.74)	377 (29.94)	377 (29.94)	16 (1.27)
Very Frequently	39 (3.10)	136 (10.80)	173 (13.74)	8 (0.64)

Note: Proportions in parenthesis. Highest proportion bolded.

Ordered logistic regression

Ordered logit regression modeling was used to determine which characteristics of respondents influence trip changes. In addition to the explanatory variables used in the regression models of the previous section, variables indicating at least weekly use of the various ATIS sources are included in the trip change model, as shown in Table 4-14 with variables “Wk_MiDrive”, “Wk_Web” and “Wk_TV”.

Table 4-14: Trip Changes: Ordered Logit Regression

			Trip Change			
			Reschedule	Change Departure Time	Change Route	Change Mode
Model Fit	Model Chi-Sq.		66.58	86.21	114.03	16.21
	Prob. > Chi-Sq.		0.0000	0.0000	0.0000	0.0003
	Psuedo R-Sq.		0.0266	0.0311	0.0410	0.0157
Independent Variables	Age	Coef.	-0.319	0.380	-	-
		P>|z|	0.005	0.001	-	-
	Sex	Coef.	-	-0.456	-	-
		P>|z|	-	0.000	-	-
	SEMTOC	Coef.	-	-	0.321	-
		P>|z|	-	-	0.005	-
	Spring	Coef.	-	-	-	-0.824
		P>|z|	-	-	-	0.002
	Wk_Trav_30	Coef.	-	-	0.615	-
		P>|z|	-	-	0.000	-
	We_Trav_30	Coef.	-	0.362	0.265	-
		P>|z|	-	0.002	0.023	-
	Wk_MiDrive	Coef.	-	0.534	-	-
		P>|z|	-	0.000	-	-
	Wk_Web	Coef.	0.446	-	-	-
		P>|z|	0.000	-	-	-
	Wk_TV	Coef.	-	-	-	0.399
		P>|z|	-	-	-	0.031
	Spd_Imp*	Coef.	0.526	-	-	-
		P>|z|	0.001	-	-	-
	Cam_Imp*	Coef.	0.618	-	0.411	-
		P>|z|	0.000	-	0.001	-
	Crash_Imp*	Coef.	-	1.662	1.824	-
		P>|z|	-	0.000	0.000	-
	PSE_Imp*	Coef.	-	-	0.640	-
		P>|z|	-	-	0.000	-
	RW_Imp*	Coef.	-	-	-0.750	-
		P>|z|	-	-	0.007	-

Note: “-“ indicates a non-significant correlation at the 95% confidence level.

*=Information Types: Spd=Travel Speed, PSE=Planned Special Events, Cam=Freeway Camera, Crash=Crash/Accident, RW=Road Weather

As seen in Table 4-14, all models were significant at a greater than 99 percent confidence level with P > χ^2 values less than 0.01. The level of importance placed on many information types proved significant on influencing tendency to change route. Those respondents who placed some degree of importance in freeway camera imagery as well as crash and planned special event (PSE) information were more likely to change routes prior to departure, while motorists who valued road weather information were less likely to change routes. This result is intuitive as unlike a localized event such as an incident or planned special event, weather tends to impact potential alternate routes in the same manner as the intended route. A second notable finding was that only the "Wk_TV" and "Spring" variables had a significant effect on tendency to switch modes, though as indicated in Table 4-13, the majority of respondents never change mode as a result of travel information.

4.4 Impact of Results on Practice

The statewide ITS deployments can be enhanced if the provided information adheres to active user characteristics and requirements, as those who do not seek or trust the information are inherently unlikely to comply. However, even motorists who fail to notice and/or follow travel guidance provided by ITS may benefit from the positive system impacts garnered by those who decide to alter their trips. Allowing motorists to indicate their perception of ATIS and ITS generally through a revealed preference questionnaire survey attached to the ATIS service itself is an innovative and cost-effective approach towards tailoring information according to device/source type, time of year and location, as required by those motorists most likely to acquire and accept the guidance.

The relevance of perceived importance of information type on usage frequency is of critical importance, as these relationships could aid agencies in aligning desired information type to the most suitable ATIS source. For example, as seen in Table 4-13, "Cam_Imp" and "Crash_Imp" have a significant positive effect on Mi Drive usage frequency. This result taken in tandem with the positive effect of the winter variable on Mi Drive usage frequency may indicate that MDOT should highlight freeway camera imagery and crash information during the winter season, especially during major storm events. Similarly, local television media broadcasters may wish to stress CCTV streams and road weather information during their traffic segments. With regard to altering traveler behavior, the results displayed in Table 4-14 indicate that TOC operators should stress CCTV images as well as crash and PSE information to influence route change behaviors. The model also revealed that respondents with a higher affinity towards the television information source are more likely to change transportation modes.

4.5 Conclusion

The present study conducted an extended duration, web-accessible questionnaire survey to determine the degree of device familiarity, frequency of device use, and impact on pre-departure travel behaviors among active ITS users as a result of factors such as age, sex, location, time of year and information type affinity. With regard to ITS device familiarity, DMS and Mi Drive were the most well recognized applications with 98.4 and 91.1 percent of respondents having at least some knowledge of their existence, respectively. Radio and television were the most frequently used ATIS sources on a daily basis at 46.2 and 35.7 percent, respectively. The most common trip changes resulting from travel information were changes in departure time (94.2 percent at least sometimes change) as well as route (95.9 percent at least sometimes change). Almost all of these proportions are significantly higher than similar studies performed in Michigan, which is likely explained by the nature of the population almost wholly representing active consumers of travel information.

A primary focus of this study was to see how responses vary with time, given the six and a half month duration of data gathering. Seasonal variables (winter and spring) were included as explanatory factors in the ordered logistic regression modeling to determine their impact on respondent’s choices. Respondents tended to be more familiar with DMS, CCTV and Mi Drive in surveys completed during the winter period, as all had a significant positive effect in these ordered logit models. This relationship with CCTV and Mi Drive likely results from the nature of harsh winter weather conditions necessitating the use of such applications to plan pre-departure travel decisions. Supporting this notion with regard to Mi Drive, the winter explanatory factor also had a significant positive effect on Mi Drive usage frequency. A respondent being more familiar with DMS in the winter is possibly explained by the increased proportion of displayed weather and incident related messages, as opposed to the typical travel time information that motorists may tend to ignore due to redundancy. The study also sought to investigate the effect of location with respect to survey responses, given that the survey reached the entire state of Michigan, as it was available online. Specifically, responses were categorized according to the three TOC regions: SEMTOC, WMTOC and STOC. The SEMTOC explanatory factor had a significant positive correlation with FCP, DMS and CCTV familiarity. This result is intuitive given that these ITS deployments are overwhelmingly more prevalent in the southeast region of Michigan compared to the rest of the state.

The impact of the various types of travel information provided by MDOT ATIS was investigated to better understand how respondents' primary concerns affect ITS device familiarity, ATIS usage frequency and trip changes. Among the respondents surveyed, those who placed any degree of importance in freeway camera imagery were more likely to be familiar with all ITS deployments except TTS. Likewise, importance placed in freeway camera imagery had a significant positive effect on usage frequency of all sources of travel information. These results mimic a common sentiment in the open response portion of the survey, where a large number of respondents voiced requests for extended publically available CCTV coverage as well as improved image quality. Regarding pre-departure travel behaviors, the degree of importance placed in various types of information, including camera images, crash/accident, planned special events and road weather, primarily affected the decision to change route more than any other trip change. This observation indicates that travel information proves more impactful in route decision than scheduling or mode choices.

The study suffers from some limitations that should be recognized. Most notably, the questionnaire did not pose sufficient driver demographic characteristics, with examples including employment, income level, typical vehicle type, trip purpose and others. Including these factors as explanatory variables would have strengthened the insights gleaned from the regression models. Additionally, using season based on response date as an explanatory variable may not accurately portray the true effect of season on user perception of ITS, given that questions were not posed specifically with time of year as a consideration. Finally, the ordered logit regression model possesses natural inaccuracy given that the ordinal categories under investigation in this study are not rigidly discrete.

Chapter 5 Performance of MDOT ITS

5.1 Summary of MDOT ITS Performance Report

5.1.1 Introduction

The three MDOT TOCs collect performance data to define benefits (or measures of effectiveness) by each ITS system or devices, and collect necessary data to analyze benefits of ITS systems. Performance measures rely on output measures (aggregated traffic data) rather than outcome measures (individual level). Such quantifiable measures include travel time saving, vehicle operating costs saving, crash reduction, travel reliability and emissions. One common approach to measure the benefits of ITS systems is the before-and-after study. Traffic data to be collected and quantified in this report section are traffic operation data, crash data and TOC performance measures. Specific TOC data includes the following:

- Call Tracker/Call Card Microsoft Access database
- Lane Closure and Restrictions website posts
- Stuck in Traffic notifications
- DMS logs
- FCP assists
- MVDS/PTR data
- Mainstar break/fix and preventative maintenance logs
- Monthly and annual performance measure reports
- Statewide ATMS software (PROD & QA databases)
- City of Grand Rapids break/fix and preventative maintenance logs
- RWIS data
- RITIS data
- NAVTEQ data access & archived data

5.1.2 SEMTOC Performance Report Summary

The SEMTOC has published monthly and annual performance reports beginning in 2006. The following discussion will summarize annual reported TOC performance beginning in January 2008 until December 2013, as seen in Table 5-1 below:

Table 5-1: 2006-2013 Annual SEMTOC Performance Summary

	2008	2009	2010	2011	2012	2013
MVDS	52	108	125	192	241	274
CCTV	106	140	147	169	186	216
DMS	48	62	69	81	87	98
Number of Calls	53,968	64,468	71,807	69,113	72,877	71,880
MiDrive Hits	NA	3,131,612	2,127,418	2,071,801	NA	NA
Construction Messages	1,121	1,121	815	1,259	1,025	NA
Number of Incidents	4,725	5,006	5,836	5,395	6,882	8,056
High Impact Incidents	NA	670	819	870	1,006	1,241
Freeway Courtesy Patrol services	49,498	51,384	51,452	49,571	46,619	48,369
Average response time	12.1	12.8	13.9	16.3	15.6	17.1
Average Clearance time	10.0	8.9	8.8	9.9	9.3	11.2

As seen, the number of incidents (and high-impact incidents) has steadily grown since 2008, likely explained by heightened incident detection due to increased ITS coverage. Average FCP response and clearance time has also shown an increasing trend, which might be the result of a growing FCP patrol route area. The FCP is a federally funded service intended to provide traffic control for freeway incidents and enhance mobility by clearing lanes of debris and vehicles. FCP assisted events are logged directly in the SEMTOC Call Tracker. Figure 5-1 below shows the percentage of 2013 SEMTOC FCP assists by type. There were a total of 48,369 FCP assists in SEMTOC in 2013. “Other” assists includes such activities as cellular assists, direction giving, traffic policing, transport, etc. As seen, abandoned vehicles compose the greatest portion of FCP assists, with 10,172 total assists in 2013, according to Table A-1 in the Appendix (which summarizes SEMTOC FCP assists by type from 2008-2013).

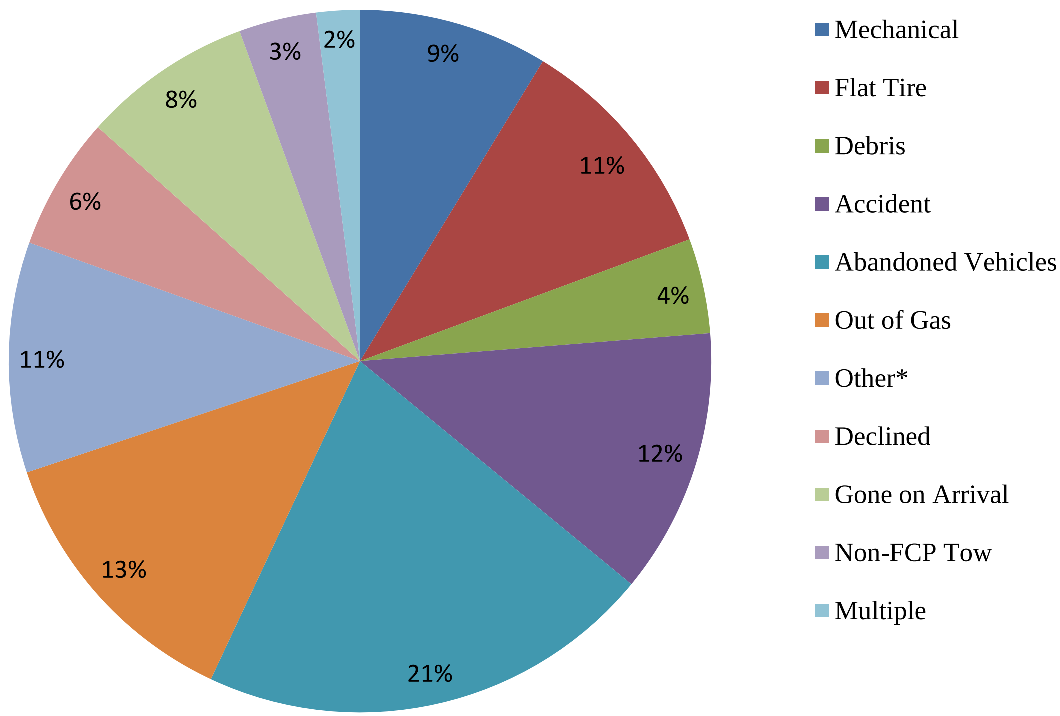
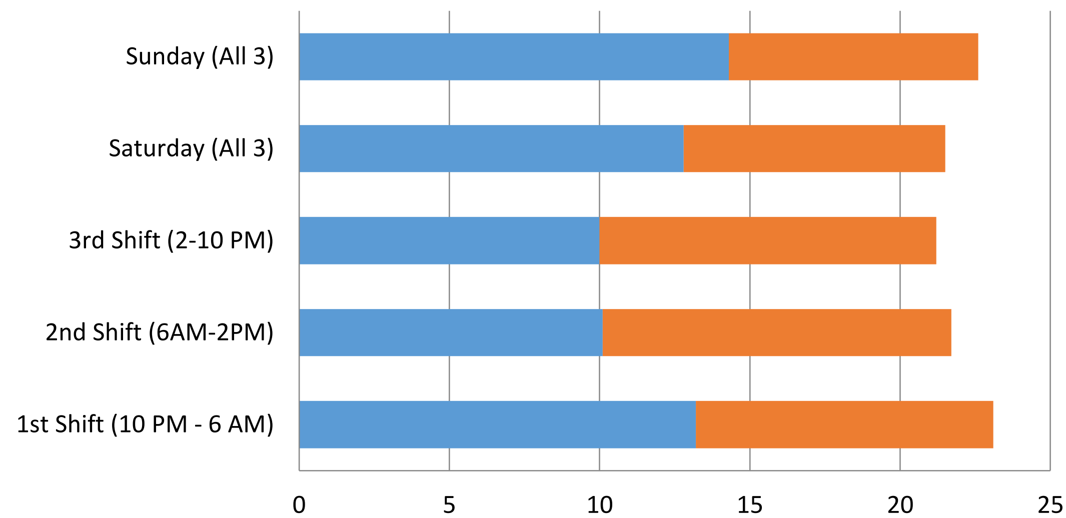


Figure 5-1: 2013 SEMTOC Percentage of FCP Assists by Type

Due to the large number of FCP assists, the SEMTOC patrol schedule operates in three shifts, 24 hours a day, all seven days of the week. The first shift runs from 10 PM – 6 AM, the second shift runs from 6 AM – 2 PM and the third shift runs from 2 PM -10 PM. A summary of the average response and clearance times by shift and weekday vs. weekend is shown in Figure 5-2 below. As seen, the combined average response and clearance times are shorter in the weekday second and third shifts compared to the weekday first shift and weekend shifts. A summary of the average FCP response and clearance times from 2008 to 2013 is shown in Table A-2 in the Appendix.



	1st Shift (10 PM - 6 AM)	2nd Shift (6AM-2PM)	3rd Shift (2-10 PM)	Saturday (All 3)	Sunday (All 3)
Average Response Times	13.2	10.1	10	12.8	14.3
Average Clearance Times	9.9	11.6	11.2	8.7	8.3

Figure 5-2: 2013 SEMTOC Average Response and Clearance Times

In addition to FCP assisted events, those incidents which affected either a shoulder or lane on SEMTOC managed roadways were logged in a separate database from the SEMTOC Call Tracker, known as the Lane Closure and Restrictions (LCAR) database. These types of events are summarized separately from FCP assisted events and classified as “Incidents” in the monthly performance reports from 2011-2013. A summary of these LCAR incidents is shown in Table 5-2 on the following page. As seen, similar to the number of FCP assists, the total number of LCAR incidents shows a trend of growth between 2011 (5,395 incidents) to 2013 (8,056 incidents). This growth can likely be attributed to improved incident detection and verification through increased deployment of CCTV and MVDS devices. Although SEMTOC did not begin to publish specific average LCAR incident duration by month until October 2012, the average LCAR incident duration is shown to decrease from 2012 to 2013, from 55.6 minutes to 48.7 minutes. The yearly LCAR incident duration reduction may be explained by faster incident verification by TOC personnel.

Table 5-2: 2011-2013 SEMTOC Monthly LCAR Incidents

Year	Month	Count			Duration
		Total	High Impact	Normal	
2011	Jan	391	76	315	
	Feb	565	115	450	
	Mar	311	72	239	
	Apr	305	75	230	
	May	448	63	385	
	Jun	445	55	390	
	Jul	490	69	421	
	Aug	470	73	397	
	Sep	615	67	548	
	Oct	475	75	400	
	Nov	465	68	397	
	Dec	415	62	353	
Total/Avg.		5395	870	4525	
2012	Jan	614	86	528	
	Feb	445	58	387	
	Mar	459	86	373	
	Apr	486	70	416	
	May	516	84	432	
	Jun	577	75	502	
	Jul	612	87	525	
	Aug	587	91	496	
	Sep	512	110	402	
	Oct	569	122	447	42.2
	Nov	613	67	546	84.7
	Dec	892	130	762	44.1
Total/Avg.		6882	1066	5816	55.58
2013	Jan	702	99	603	41.8
	Feb	812	98	714	51.2
	Mar	674	98	576	59.3
	Apr	612	109	503	47.0
	May	673	90	583	45.0
	Jun	670	90	580	49.2
	Jul	639	138	501	51.8
	Aug	639	110	529	49.6
	Sep	555	108	447	49.4
	Oct	657	99	558	45.5
	Nov	663	101	562	49.0
	Dec	760	101	659	45.9
Total/Avg.		8056	1241	6815	48.71

5.1.3 WMTOC Performance Report Summary

The WMTOC has published monthly and annual performance reports since 2006. The following discussion will summarize annual reported TOC performance beginning in January 2009 until December 2013, as seen in Table 5-3 below. As seen the total number of calls have grown steadily since 2009. Additionally, the number of managed incidents has more than doubled, from 606 in 2009 to 1,477 in 2013. Incident clearance time showed an increasing trend, to a maximum of 81 minutes in 2011, where it began to fall to 68 minutes in 2013. WMTOC began reporting roadway clearance time in 2012, with a duration of 23 minutes and 24 minutes in 2012 and 2013, respectively. Unlike the SEMTOC, WMTOC does not operate a FCP division. However, all reported incidents are logged in the TOC Call Tracker. Additionally, all abandoned vehicles and disabled vehicles with an incident duration greater than four hours are removed from reported incident duration statistics. Figure 5-3 on the following page shows the percentage of WMTOC incidents by type in 2013. As seen, "Crashes" represent the majority of managed incidents at 61 percent of the 1,477 total incidents. Table A-3 in the Appendix shows percentage of WMTOC incidents by type for all years between 2009 and 2013.

Table 5-3: 2009-2013 WMTOC Annual Performance Summary

	2009	2010	2011	2012	2013
Number of Calls	1059	2712	2703	3492	3789
Construction Messages	451	504	641	491	NA
Number of Incidents	606	1192	1015	1373	1477
Incident Clearance time	58	78	73	69	68
Roadway Clearance time	NA	NA	NA	23	24

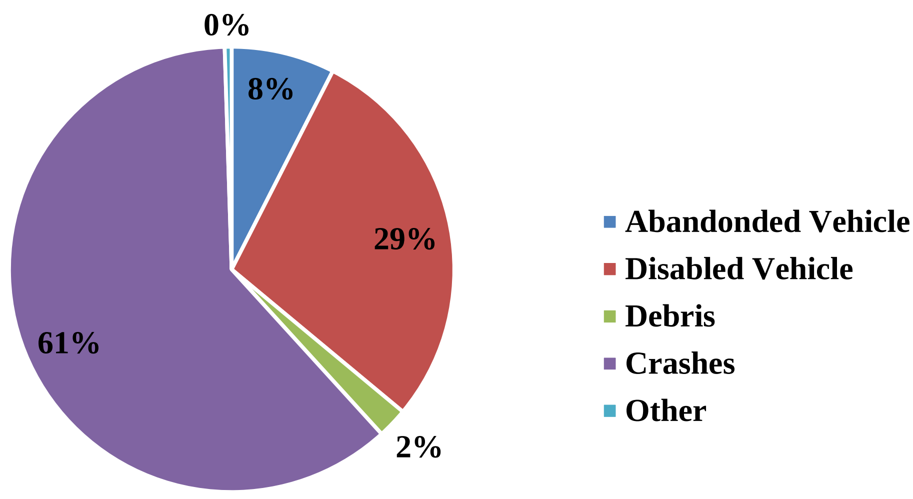


Figure 5-3: 2013 WMTOC Percentage of Incidents by Type

5.1.4 STOC Performance Report Summary

The STOC has published monthly and annual performance reports since 2012. The following discussion will summarize annual reported TOC performance beginning in January 2012 until December 2013, as seen in Table 5-4 below. STOC did not report FCP assist and incident duration information until May 2013. The reported number of "Incidents" in STOC performance reports combines the total number of assists logged in the TOC Call Tracker with incidents logged in the LCAR database. As seen, the number of incidents managed by STOC more than tripled from 2,452 in 2012 to 7,458 in 2013. The average incident duration in 2013 was 58.6 minutes as indicated in Table 5-5, while total FCP incident duration (combination of assist response and clearance time) was 29.4 minutes, as shown in Table 5-4.

The percentage of 2013 STOC FCP assists by type are indicated in Figure 5-4. As seen, "Other" types of assists represent the greatest portion of events assisted by the STOC FCP. "Other" assists might include cellular assists, declined service, FCP tow, non-FCP tow, gave directions, stand by, status check, gone on arrival and transport. Unlike SEMTOC, the STOC FCP does not operate on a shift-schedule. 2013 STOC FCP average response and clearance times by weekday and weekend are indicated in Figure 5-5.

Table 5-4: 2009-2013 Annual STOC Performance Summary

	2012	2013
Number of Calls	3,690	NA
Construction Messages	236	184
Number of Incidents	2,452	7,458
Number of Assists	NA	5,956(1)
Assist Response time	NA	13.1
Assist Clearance time	NA	16.3

(1) Estimated value based on known LCAR incident count since STOC Performance Report data did not report FCP assists until May 2013

Table 5-5: 2013 STOC Incidents

STOC	Incidents	
2013	**Duration**	**Count**
January		183
February		659
March		603
April		560
May	50.3	661
June	71.1	606
July	57.8	657
August	56.8	730
September	45.6	669
October	65.1	746
November	63.7	681
December	59.0	703
Avg./Total	**58.6**	**7458**

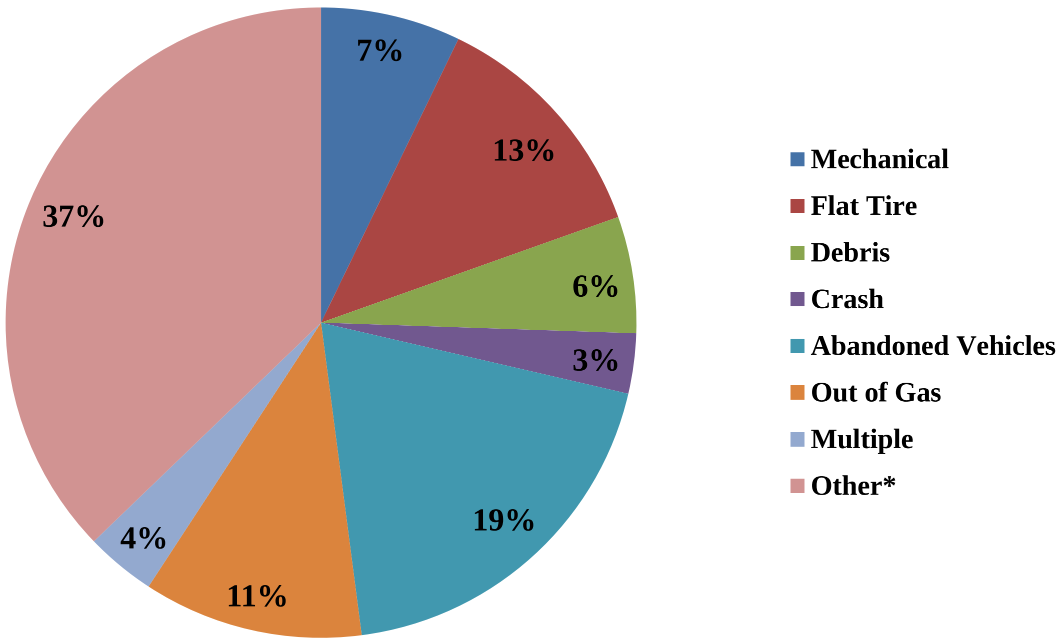
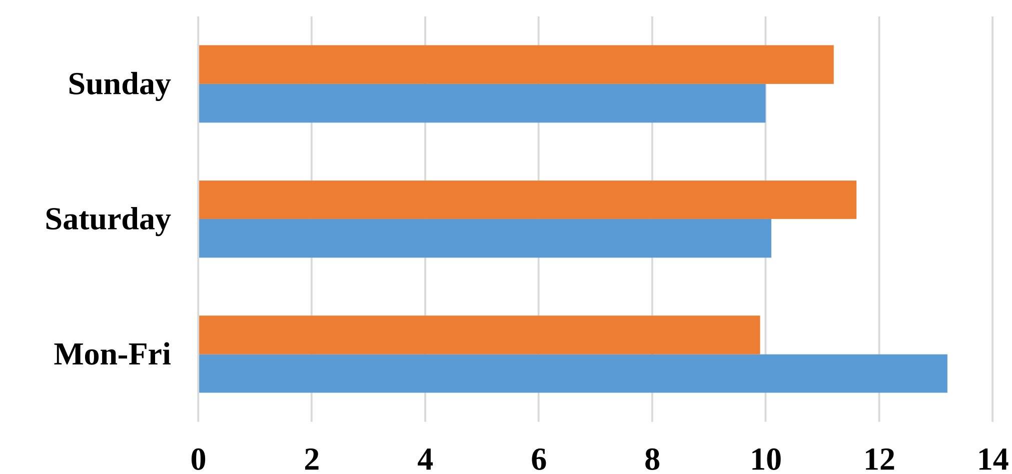


Figure 5-4: 2013 STOC Percentage of FCP Assists by Type



	Mon-Fri	Saturday	Sunday
Average Clearance Time	9.9	11.6	11.2
Average Response Time	13.2	10.1	10

Figure 5-5: 2013 STOC Average FCP Response and Clearance Times

5.2 Traffic Incidents and Delays

5.2.1 Introduction

This section analyzes traffic incidents which occurred by region and their clearance time, as well as delays caused by incidents. Table 5-6 summarizes incident duration reduction in minutes used in previous ITS benefit studies. As seen, most previous studies classify incidents according to type, which may include information regarding lane/shoulder blockage or some other measure of incident severity. Incident duration reduction as a benefit of ITS ranges from 4.3 minutes (Nee, 2001) to 45.9 minutes (Guin, 2007). The remaining portion of this section will describe and summarize the incident duration and delay analysis performed in the present study.

Table 5-6: Incident Duration Reduction from Other Studies

Region	Incident Type	Incident Duration Reduction (minutes)
Boston (Stamatiadis 1997)	minor incident	15.0
	Disabled	25.0
	moved to shoulder	25.0
	debris	30.0
	accident in lane	20.0
Chicago (Fenno 1997)	accidents on the shoulder	20.0
	accidents in 1 lane	35.0
	accidents in 2 or more lanes	40.0
Denver (Cuciti 1995)	lane blockers	10.5
	non-blockers	8.6
Gary, IN (Latoski 1999)	crash/ in lane assist	10.0
	others	15.0
Houston (Hawkins 1993)	minor incident average	16.6
San Francisco (Skabardonis 1995)	breakdowns	16.5
	crashes	12.6
Minnesota (Skabardonis 1995)	stall less than 30	8.0
	stall thirty to an hour	5.0
	stall over an hour	0.0
Virginia (Dougald 2007)	accident	43.5
	breakdown	25.0
	debris	5.0

Washington (Nee, 2001)	disabled	4.3
Missouri (Sun, 2010)	all	15.0
Georgia Navigatorincident (Guin, 2007)	incidents	45.9
Florida (Hagen, 2005)	all	20.0
New Jersey (Ozbay, 2005)	all	7 – 20

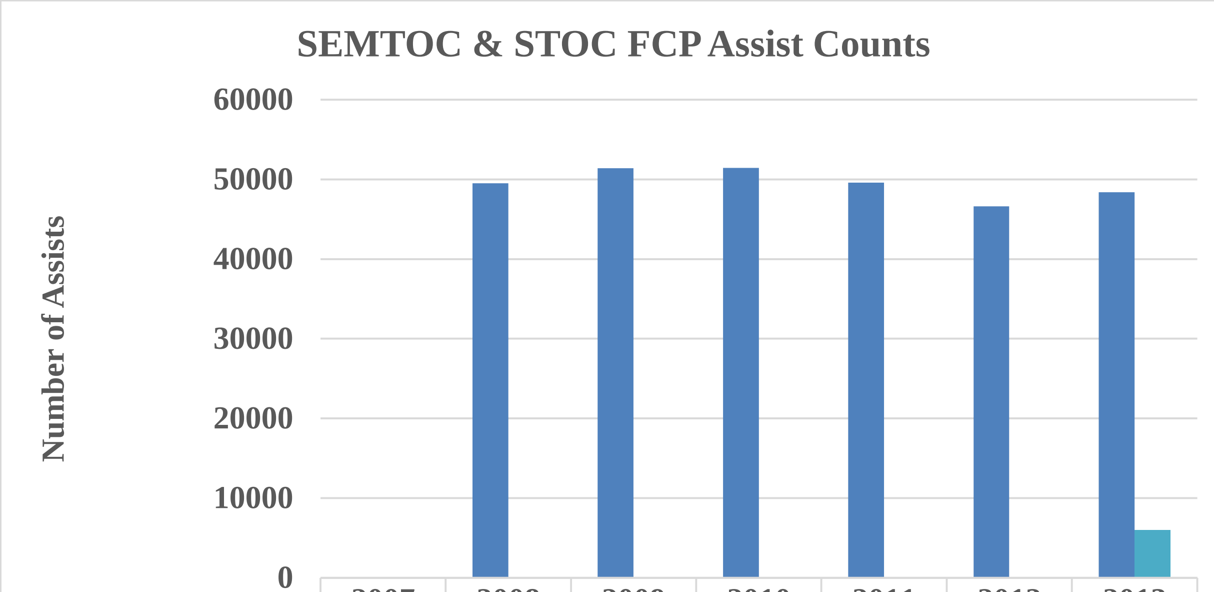
Source) Revised from Moss (2012)

5.2.2 Annual Incident Count by TOC Region

Regarding annual SEMTOC incident analysis, in Figure 5-6 and Figure 5-7 below, it is apparent that more incidents were detected and verified during recent years, however the number of FCP assists has shown a decreasing trend. The increasing trend of incident detection is likely explained by greater implementation of ITS devices (such as CCTVs and MVDSs) during these years.

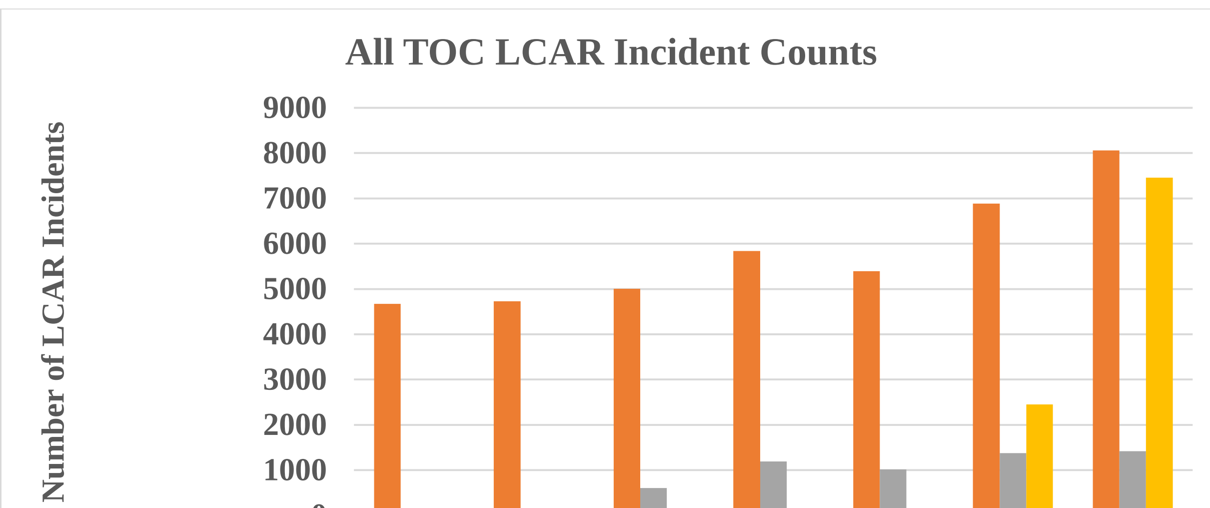
With regards to annual WMTOC incident analysis, in Figure 5-7 below, it is immediately obvious that the total quantity of incidents managed by WMTOC have increased over time. Similar to the SEMTOC case, this is almost assuredly a result of heightened incident detection and verification capabilities as a result of increased ITS deployment from year-to-year.

Concerning annual STOC incident analysis, as depicted in Figure 5-7, the number of incidents increased over time. This trend can likely be explained in accordance with the other two TOCs, in that the number of CCTVs and MVDSs are increasing each year, facilitating improved incident detection. As mentioned in the previous Performance Report summary section, STOC combines assists logged in the Call Log with those incidents in the LCAR database to report the monthly number of managed incidents.



	2007	2008	2009	2010	2011	2012	2013
SEMTOC_Assist		49498	51384	51452	49571	46619	48369
STOC_Assist							5956

Figure 5-6: Annual Reported SEMTOC and STOC FCP Assist Counts



	2007	2008	2009	2010	2011	2012	2013
SEMTOC_Incident	4674	4725	5006	5836	5395	6882	8056
WMTOC_Incident			606	1192	1015	1373	1421
STOC_Incident						2452	7458

Figure 5-7: Annual Reported All TOC LCAR Incident Counts

5.2.3 Incident Duration by TOC Region

Data Gathering & Methodology

Each of the three TOCs supplied the research team with raw Call Tracker information in the form of Microsoft Access databases. This data was used for “Assisted” event information for both the SEMTOC and STOC regions. Additionally, the 2011-2013 statewide LCAR database was provided to gather information about “LCAR” event information for both the SEMTOC and STOC regions. These two databases are distinct and display no overlap of individual incident information. Regarding WMTOC, only its Call Tracker database was used to analyze incident data. Given that the WMTOC does not currently operate an FCP division, these incident are considered unassisted. The table below describes how each of the two databases are utilized for purposes of the monthly performance reports summarized in the previous section.

Table 5-7: TOC Performance Report Database Utilization

TOC	Monthly TOC Performance Report Measures	
	"FCP Assists"	"Incidents"
SEMTOC	Call Tracker	LCAR
WMTOC	Inapplicable	Call Tracker
STOC	Call Tracker	Call Tracker + LCAR

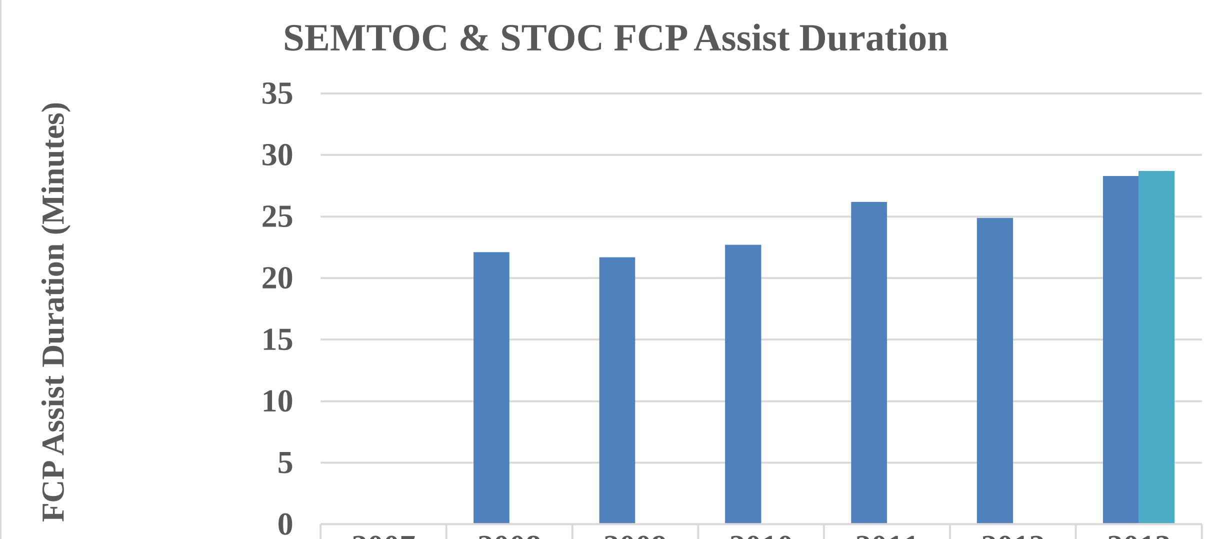
In order to determine the benefits gleaned from ITS with regard to incident duration reduction and delay analysis, individual incidents were aggregated according to the 2012 MDOT Sufficiency database roadway segments described in Chapter 3. In the case of FCP assisted incident information, this process resulted in the loss of many incidents due to missing incident location information in the Call Tracker database. However, all LCAR incidents were described with accurate geographic coordinates, thus no incidents were lost in the segment aggregation process.

All TOC Annual Incident Duration Descriptive Statistics

As seen in Figure 5-8, the temporal trend of SEMTOC assisted incident duration is not clear. This can likely be explained because the recently implemented ITS devices are mostly located in suburban and rural areas, whereas a significant portion of the urban SEMTOC region was already saturated with ITS deployments prior to 2008. Traffic incidents in suburban and rural areas usually have longer durations. However, the temporal trend of LCAR incident duration shown in Figure 5-9 shows a decreasing trend. Also, the average incident duration in the LCAR data is much larger than the Call Tracker database. This could likely be explained by the nature of LCAR incidents to typically exhibit a higher-impact with lane or shoulder closures.

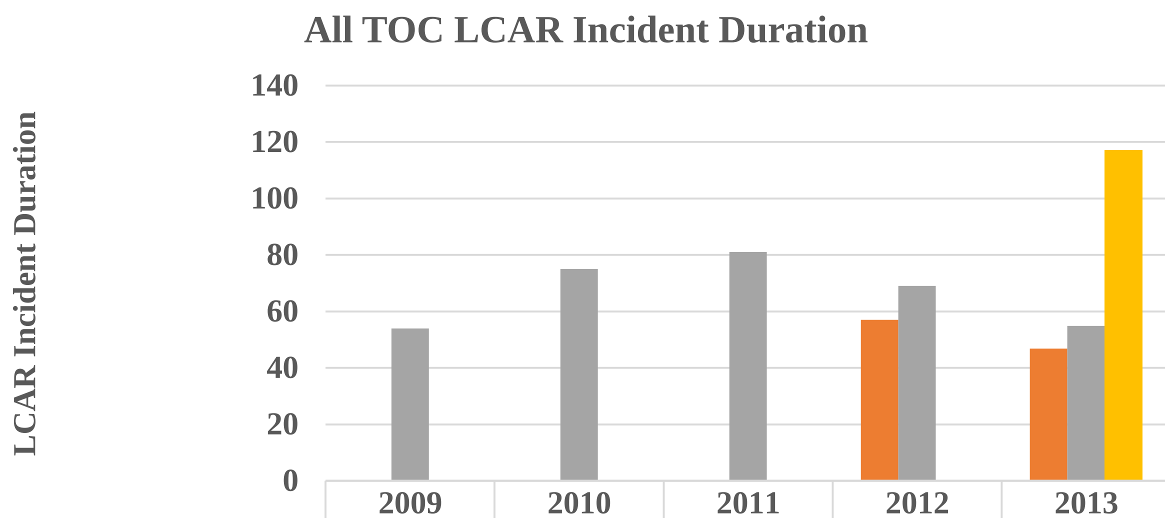
Regarding the WMTOC, an observation that mimics that found in the SEMTOC region is the failure to establish a clear temporal trend with regard to average incident duration. Once again, this may be explained by a greater number of incidents being detected in rural regions outside of the metropolitan Grand Rapids area, resulting in longer detection, verification and response. However, from 2011 to 2013, the incident duration in WMTOC shows a decreasing trend.

For the STOC, reported incident and assist duration is only available for the year 2013, thus no temporal trend can be established.



	2007	2008	2009	2010	2011	2012	2013
SEMTOC_Assist		22.1	21.7	22.7	26.2	24.9	28.3
STOC_Assist							28.7

Figure 5-8: SEMTOC and STOC Reported FCP Assist Duration



	2009	2010	2011	2012	2013
SEMTOC_Incident				57	46.8
WMTOC_Incident	54	75	81	69	54.9
STOC_Incident					117.2

Figure 5-9: All TOC LCAR Incident Duration

2013 SEMTOC Incident Duration Reduction Analysis

As explained, incidents were aggregated according to nearest 2012 MDOT Sufficiency file segments in order to determine the benefit of ITS with regard to reducing incident duration. Figure 5-10 shows the change in 2013 incident duration according to incidents occurring on segments with any ITS (DMS, CCTV, or MVDS) or with only a CCTV or MVDS versus incidents occurring on segments with no ITS presence. According to statistical tests, in the SEMTOC region, no significant difference in 2013 incident duration was detected with respect to presence of ITS devices at a 95% confidence level. However, one notable result is the 2.02 minute reduction of LCAR incident duration for those incidents occurring within the “Detroit” ITS region compared to those outside the region. No 2013 FCP assist duration reductions were observed with regard to ITS influence. This may be explained by the nature of roadway segments with ITS devices to experience higher traffic volumes, thus affecting the ability of FCP patrol vehicles to quickly respond and clear an incident.

Further, 2013 SEMTOC LCAR incidents were classified by type according to either shoulder affected, number of lanes blocked, or other as shown in Table 5-9. A comparison was made between LCAR incidents occurring anywhere within the SEMTOC region versus those occurring within the defined "Detroit" ITS region. As seen, very little difference was noticed in incident duration, regardless of type, as affected by ITS. The most positive scenario appears to be incidents classified as "Shoulder" or "One Lane" blocked, 0.93 minute and 3.3 minute reductions, respectively.

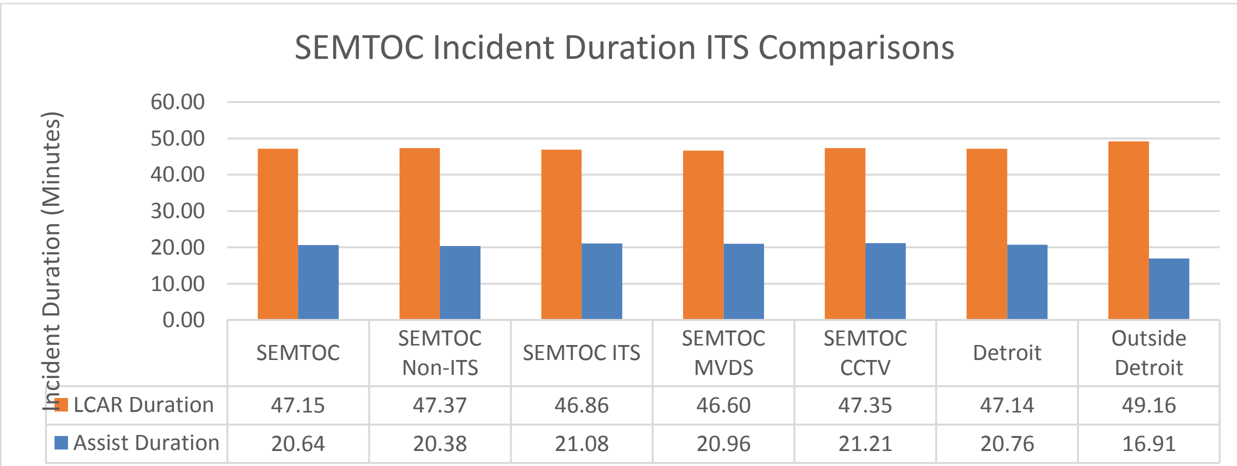


Figure 5-10: 2013 SEMTOC Incident Duration ITS Comparisons

Table 5-8: 2013 SEMTOC Incident Duration Reductions

SEMTOC	LCAR		Assist	
	Average Incident Duration	Reduction of Incident Duration	Average Incident Duration	Reduction of Incident Duration
Incidents in the area with no ITS	47.37	-	20.38	-
Incidents in the area with ITS	46.86	0.51	21.08	-0.7
Incidents in the area with MVDS	46.6	0.77	20.96	-0.58
Incidents in the area with CCTV	47.35	0.02	21.21	-0.83
Incidents outside Detroit	49.16	-	16.91	
Incidents within Detroit	47.14	2.02	20.76	-3.85

Table 5-9: 2013 SEMTOC LCAR Incident Duration by Lanes Blocked

Type	SEMTOC		Detroit		Outside Detroit	
	Count	Average Duration (Min)	Count	Average Duration (Min)	Count	Average Duration (Min)
Shoulder	5207	45.83	5190	45.83	17	46.76
1 Lane	1443	38.05	1434	38.03	9	41.33
2+ Lanes	118	21.96	118	21.96	0	-
All Lanes	230	124.86	226	125.54	4	86.50
Other	812	53.43	805	53.51	7	43.71
Total/Avg.	**7810**	**47.15**	**7773**	**47.14**	**37**	**49.16**

2013 WMTOC Incident Duration Reduction Analysis

As with the SEMTOC data, statistical analysis was performed to determine the impact of ITS on 2013 incident duration in WMTOC. Figure 5-11 compares the incident duration on segments with ITS presence versus those without ITS devices installed and operating according to year 2013. Positively, a revealing trend is found by comparing the incident duration at segments within the defined "Grand Rapids" ITS region and those outside the region. As of year 2013, the average incident duration on "Grand Rapids" segments is 20.89 minutes lower than the average duration on segments outside the region. CCTVs are found to be most effective in reducing incident duration, at an improvement of 0.79 minutes on any segment with at least one CCTV within the entire WMTOC region.

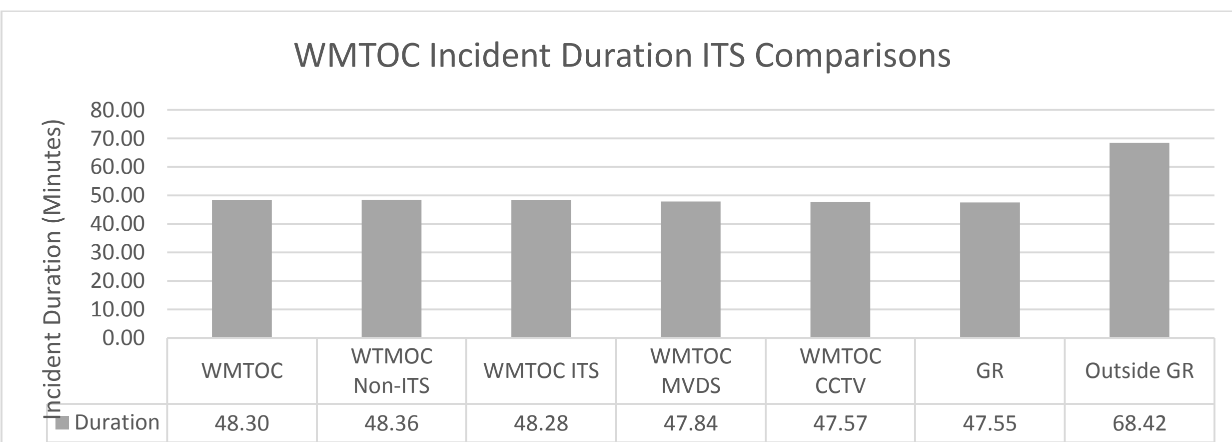


Figure 5-11: 2013 WMTOC Incident Duration ITS Comparisons

Table 5-10: 2013 WMTOC Incident Duration Reductions

WMTOC	Incident	
	Average Incident Duration	Reduction of Incident Duration
Incidents in the area with no ITS	48.36	-
Incidents in the area with ITS	48.28	0.08
Incidents in the area with MVDS	47.84	0.52
Incidents in the area with CCTV	47.57	0.79
Incidents outside Grand Rapids	68.42	
Incidents within Grand Rapids	47.55	20.87

STOC Incident Duration Reduction Analysis

Regarding 2013 STOC incident duration, as shown in Table 5-11 assist duration is sharply decreasing with time. The average assist duration decreased significantly from 63.2 minutes in 2012 to 28.7 minutes in 2013. This result differs from the other TOC regions and might be explained by rapid deployment of ITS devices and FCP services in STOC managed corridors in 2013.

Once again, a statistical analysis was performed to verify the impact of ITS on reducing incident duration, as depicted in Figure 5-12. As of year 2013, the average assist duration on ITS segments is 5.47 minutes lower than on non-ITS segments. CCTVs are found to be effective in reducing assist duration, showing a 5.82 minute improvement. Similar trends were observed for the STOC LCAR data. As of year 2013, the reduction of incident duration is found to be 44.87 minutes for general ITS devices and 57.66 minutes for CCTVs.

Given that LCAR data is utilized in the STOC region for reporting purposes, a similar analysis was conducted as for the SEMTOC case to determine the impact of ITS on incident duration by type of incident, as shown in Table 5-13. The results show that average incident duration is reduced in STOC ITS regions one and two by 49.45 minutes and 67.17 minutes, respectively. The largest benefit of ITS appears to occur during incidents blocking either one-lane or all lanes.

Table 5-11: Comparison of Incident Duration (STOC – Assisted)

Year	Average Incident Duration	Reduction of Incident Duration
2011	71.8 minutes	-
2012	64.4 minutes	7.4 minutes
2013	28.7 minutes	35.7 minutes

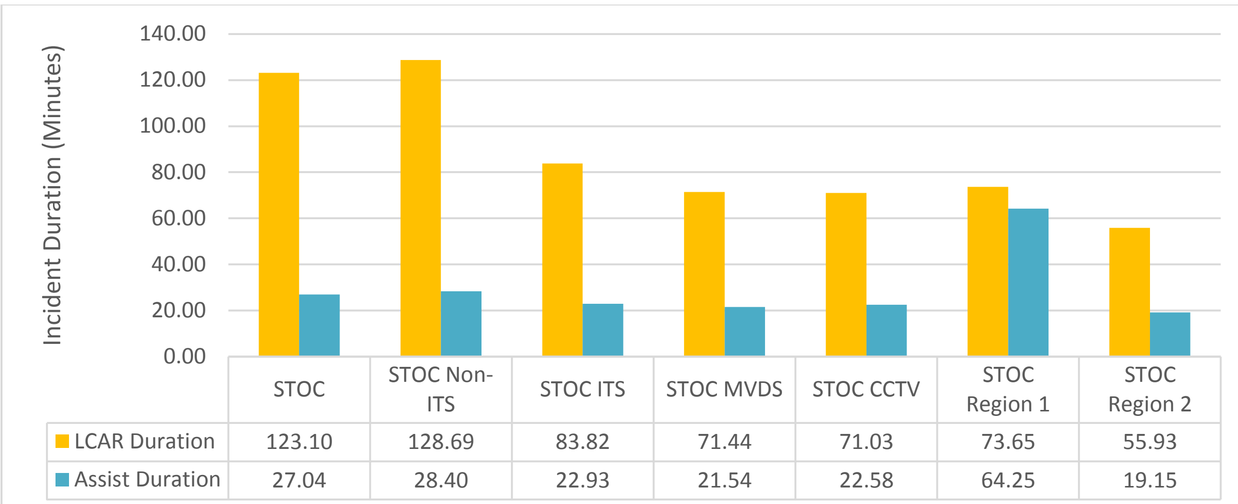


Figure 5-12: 2013 STOC Incident Duration ITS Comparisons

Table 5-12: 2013 STOC Incident Duration Reductions

STOC	LCAR		Assist	
	Average Incident Duration	Reduction of Incident Duration	Average Incident Duration	Reduction of Incident Duration
Incidents in the area with no ITS	128.69	-	28.4	-
Incidents in the area with ITS	83.82	44.87	22.93	5.47
Incidents in the area with MVDS	71.44	57.25	21.54	6.86
Incidents in the area with CCTV	71.03	57.66	22.58	5.82
Incidents within STOC Region 1	73.65	55.04	64.25	-35.85
Incidents within STOC Region 2	55.93	72.76	19.15	9.25

Table 5-13: 2013 STOC LCAR Incident Durations by Lanes Blocked

Type	STOC		STOC Reg_1		STOC Reg_2		STOC No ITS	
	Count	Average Duration (Min)	Count	Average Duration (Min)	Count	Average Duration (Min)	Count	Average Duration (Min)
Shoulder	303	74.52	42	78.21	25	52.12	237	76.35
1 Lane	546	89.81	89	65.58	39	53.51	457	91.79
2+ Lanes	8	48.00	1	49.00	2	47.00	7	50.14
All Lanes	576	180.99	36	90.75	5	80.40	557	183.12
Other	69	125.33	4	57.50	4	77.25	57	119.86
Total/Avg.	**1502**	**123.10**	**172**	**73.65**	**75**	**55.93**	**1315**	**128.69**

5.3 Summary

This section of the report focused on incident analysis by first introducing and summarizing officially reported measures of effectiveness by each of the three MDOT TOCs. A descriptive statistical incident duration analysis followed based on processed data provided by the TOCs, in an effort to determine incident reduction as a result of ITS. Finally, incident delay analysis as affected by ITS was performed.

The most notable effect of ITS observed in reducing incident duration occurred in the STOC region, which saw a 35.7 minute assisted incident reduction as a result of ITS. For LCAR incidents, the reduction was more substantial at 44.9 minutes for all ITS and 57.7 minutes for CCTVs. Additionally, in the defined STOC ITS Regions One and Two, average LCAR incident duration is reduced by 49.5 minutes and 67.2 minutes, respectively, with the largest benefit occurring with regard to incidents blocking either one lane or all lanes. Through incident delay analysis, it was determined that ITS can reduce average incident delay by 8.2%, from 0.61 to 0.56 minutes per vehicle.

Chapter 6 Modeling ITS Corridors

6.1 Introduction

The objective of corridor microsimulation is to quantify detailed benefits resulting from MDOT ITS. In this project, the research team selected a sample of representative corridors from each of the three MDOT TOCs. The Quadstone Paramics traffic microsimulation software package was utilized to quantify benefits from "with/without" ITS scenarios with regards to freeway incident management. MDOT's incident management programs strive to produce savings in congestion cost, reduce incident duration, reduce motorist delay, and improve safety by minimizing the probability of secondary crash occurrence.

In the United States, freeway and arterial incident management programs have reduced incident duration from 15 to 70 percent (Bertini 2001, Dougald 2008, Petrov 2002). Simulation studies are more suitable for urban roadways where traffic signals and congestion are more frequent. They have been used in the past to evaluate the following ITS applications:

- ICM deployment
- Crash prevention and safety
- Work Zone Management
- System impact of TMCs
- Impact of ATIS

The devices under investigation in the present simulation study with regards to freeway and arterial traffic incident management are DMS, CCTV and MVDS. These ITS devices are investigated with regards to their effect to induce short-term, near-incident alternate route diversion. In addition, the impact of FCP's ability to reduce incident duration is simulated through various incident duration reduction scenarios. The nature of ATIS to delay or cancel a vehicle trip or seek a more long-term, corridor-level alternate route diversion is investigated through network vehicle demand reduction scenarios.

6.2 Selection of Corridors

Seven major MDOT freeway corridors were selected for the simulation study. The corridor characteristics under consideration for site selection included AADT, ITS device density, economic impact and crash/incident history. The goal of the study was to choose a representative selection of corridors whose analysis and subsequent results could be transferrable to other corridors statewide. A list and description of the corridors ultimately selected is below with a more comprehensive summary depicted in Table A-13 in the Appendix:

- SEMTOC SS1 – I-75 between I-696 & M8 (5.25 mi)
- SEMTOC SS2 – I-94 between Weir & I-96 (3.3 mi)
- SEMTOC SS3 – I-275 between M-14/I-96 & I-696 (7 mi)
- WMTOC SS4 – US-131 between M-11(28th St.) & I -196 (4.9 mi)
- WMTOC SS5 – I-196 between I-96 & Lake Michigan (5.7 mi)
- STOC SS6 – I-96 between Grand River & US-23 (6.75 mi)
- STOC SS7 – I-75 between Holland & Dixie (4.8 mi)

Figure 6-1 below depicts the locations of the seven selected sites, numbered according to the list above. A more detailed rendition of spatial locations of ITS devices on the seven corridors are provided in Figure A-1 through Figure A-7 in the Appendix.

Figure 6-1: Proposed Study Sites Selected

6.3 Modeling Procedure

6.3.1 Introduction

The corridor microsimulation model procedure is a thorough and sequential process, as depicted in Figure 6-2 below. In addition to using the Paramics microsimulation software package, other software such as ArcGIS, TransCAD, and Excel are used to perform all required tasks. TransCAD is used to develop the Sub-Area Origin-Destination matrices from regional travel demand models, when available (all study sites barring STOC SS6 and STOC SS7). When a regional travel demand model is not available, Paramics Estimator is used to estimate a Sub-Area O-D matrix. MVDS and PTR data were used to formulate time-of-day travel patterns, vehicle classification and model validation. The model development procedure is iterative in order to achieve a desirable level of accuracy.

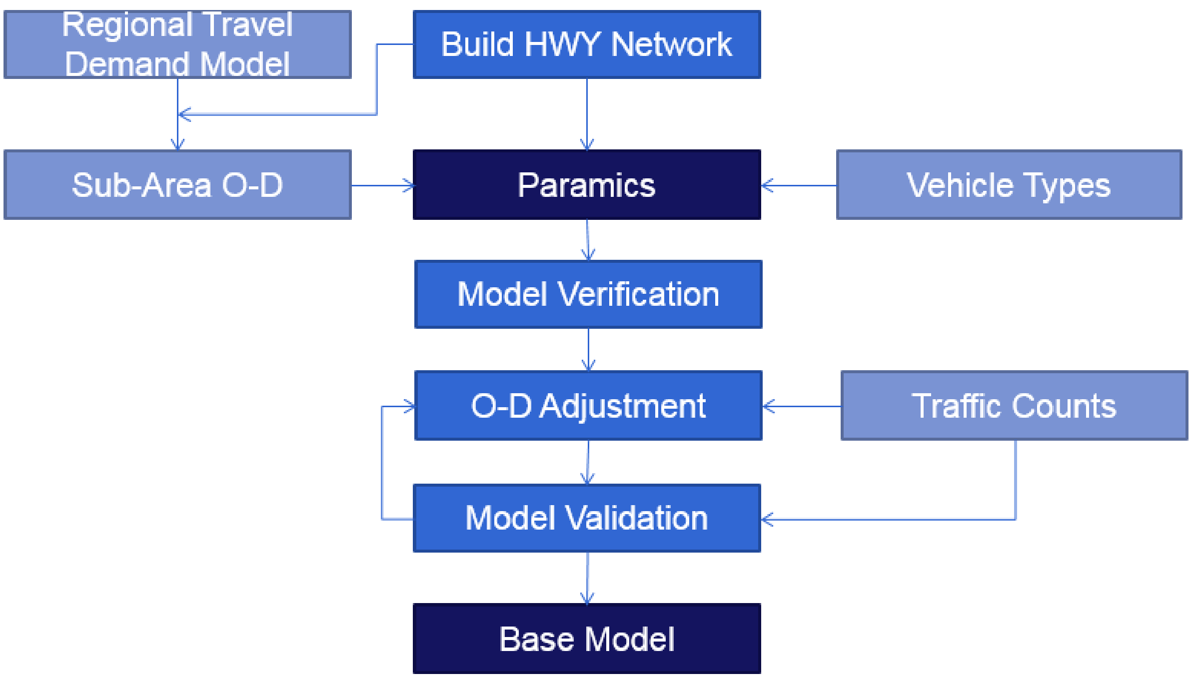


Figure 6-2: Simulation Model Development Procedure

6.3.2 Network Development

Model development begins with coding of the highway network in Paramics Modeller. In Paramics, building a network consists of placing node "Junction" at key locations, typically either at roadway intersections or points on the roadway where the number of lanes changes. Once two corresponding junctions are coded, a roadway "Link" is coded, connecting the two nodes. Paramics has a built-in, scalable Bing Maps overlay map tool, considerably hastening the network coding process. Once the network of "Junctions" and "Links" are coded, various other network attributes can be altered, such as lane attributes, signal control, control points, zone elements, etc. An example of the WMTOC SS5 coded network is shown in Figure 6-3 below (network represented in yellow):

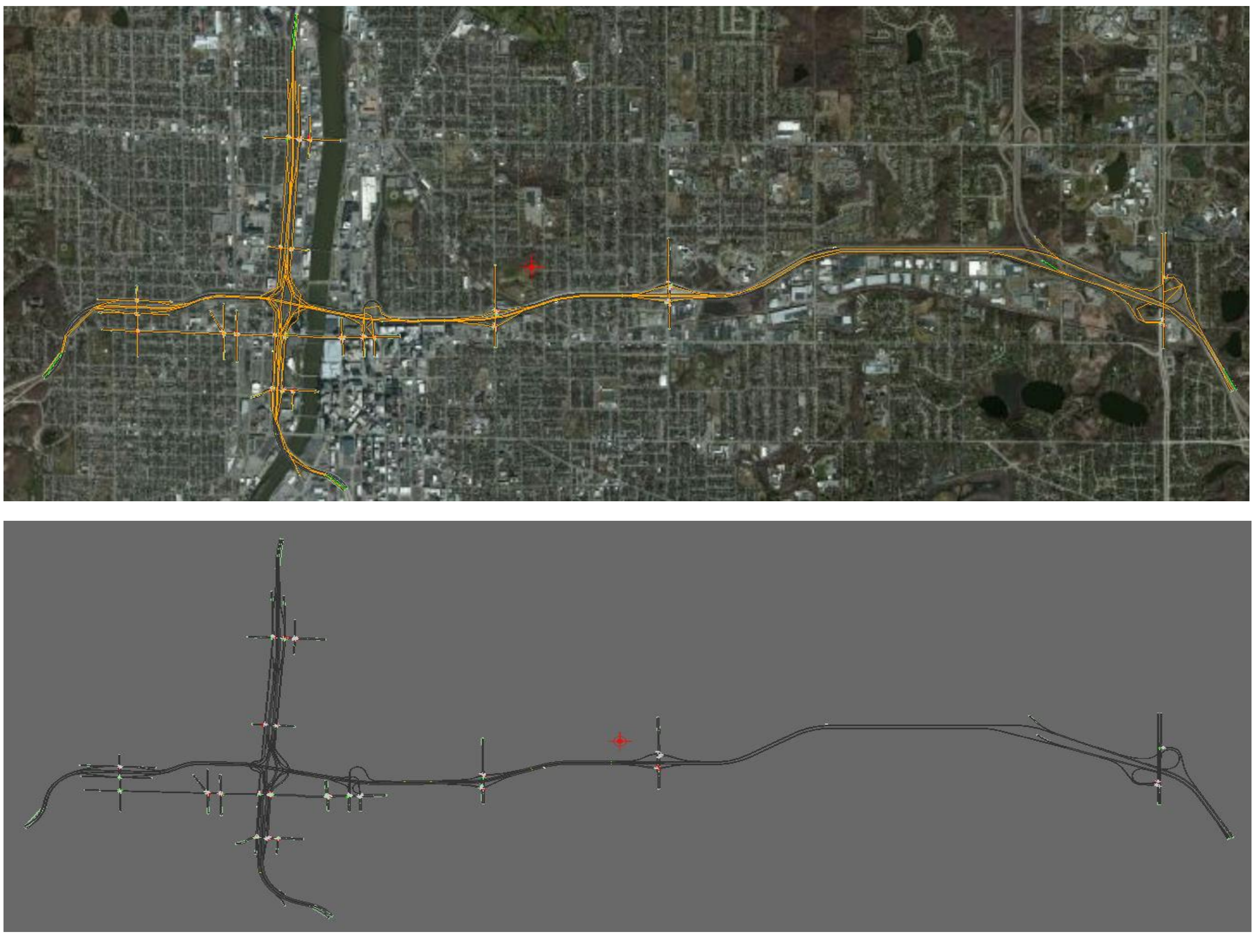


Figure 6-3: WMTOC SS5 Paramics Network

Following network coding is development of subarea O-D matrices, either based on MPC regional travel demand models or estimated through Paramics Estimator. The Southeast Michigan Council of Governments (SEMCOG) and Grand Valley Metropolitan Council (GVMC) provided their latest regional travel demand models in TransCAD files. Subarea polygons were developed in TransCAD to accurately contain the entire study region around the selected corridors. A TransCAD map of the GVMC and SEMCOG travel demand models are shown in Figure A-8 and Figure A-9 the Appendix. The map in Figure 6-4 reveals the defined subarea polygon (colored black) for WMTOC SS5.

Once the subarea is defined, TransCAD is used to develop the subarea O-D matrix. The TransCAD subarea O-D nodes are converted to Paramics “Zones” and inputted into Modeller in the Demand Editor tool. If a regional travel demand model was not available, such as in the case of STOC SS6 and STOC SS7, Paramics Estimator was used to estimate the network O-D matrix based on supplied link counts and intersection turn volumes. After defining the network O-D matrix for a corridor, it is necessary to classify vehicle types and proportions on the network. The FHWA 13-Category vehicle classification scheme was used to code vehicle dimensions, while PTR data on the corridors was used to determine the vehicle mix. The vehicle mix for WMTOC SS5 is shown in Table 6-1 below.

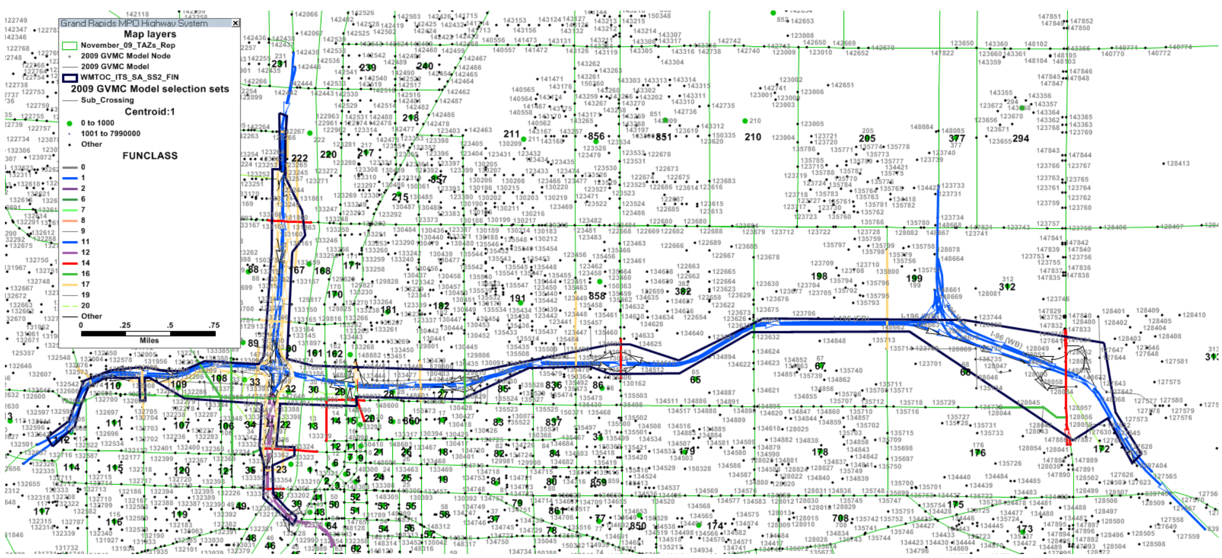


Figure 6-4: WMTOC SS5 TransCAD Subarea

Table 6-1: WMTOC SS5 Vehicle Mix

Vehicle Class	Definition	Proportion
C1	Motorcycle	0.0030
C2	Passenger Car	0.7239
C3	Other 2 Axle, 4-Tire Single Unit	0.2026
C4	Bus	0.0016
C5	2 Axle, 6 Tire, Single-Unit Truck	0.0071
C6	3 Axle Single-Unit Truck	0.0033
C7	4+ Axle Single-Unit Truck	0.0005
C8	4 or less Axle Single-Trailer Truck	0.0038
C9	5 Axle Single-Trailer Truck	0.0424
C10	6+ Axle Single-Trailer Truck	0.0046
C11	5 or less Axle Multi-Trailer Truck	0.0017
C12	6 Axle Multi-Trailer Truck	0.0014
C13	7+ Axle Multi –Trailer Truck	0.0042

Additionally, it is necessary to define a time-of-day (ToD) traffic volume profile for the simulation. ToD patterns were determined for each of the seven corridors based on provided MVDS and PTR vehicle detector data from 2011 to 2013. The ToD pattern for WMTOC SS5 is shown in Figure A-10 in the Appendix. Only the AM Peak period, defined as 5 AM – 10 AM was simulated for all seven study corridors. Calculated measures of effectiveness are then adjusted based on the proportion of total AADT observed in the AM Peak period.

Finally, ITS devices, such as DMS and MVDS are added to the network. Network detectors are used to later validate the model by comparing simulated freeway traffic speed-flow curves versus observed speed-flow curves at the same location during the same time period. DMS in Paramics can be coded to perform many tasks, however in this simulation study, they were set to update vehicles route choice when dynamic feedback was enabled.

6.3.3 Model Verification, Calibration and Validation

Once the network model has been coded and vehicle demand loaded onto the network, the model is verified by visual inspection. Aspects such as vehicle behavior, signal coordination and route choice are adjusted and verified to mimic observed conditions as close to reality as possible. A primary goal is to reduce areas of unrealistic or unexpected vehicle congestion and delay. An image of the signal coordination process at the Pearl Street and US-131 interchange on the WMTOC SS5 simulation corridor is shown in Figure 6-5 on the following page.

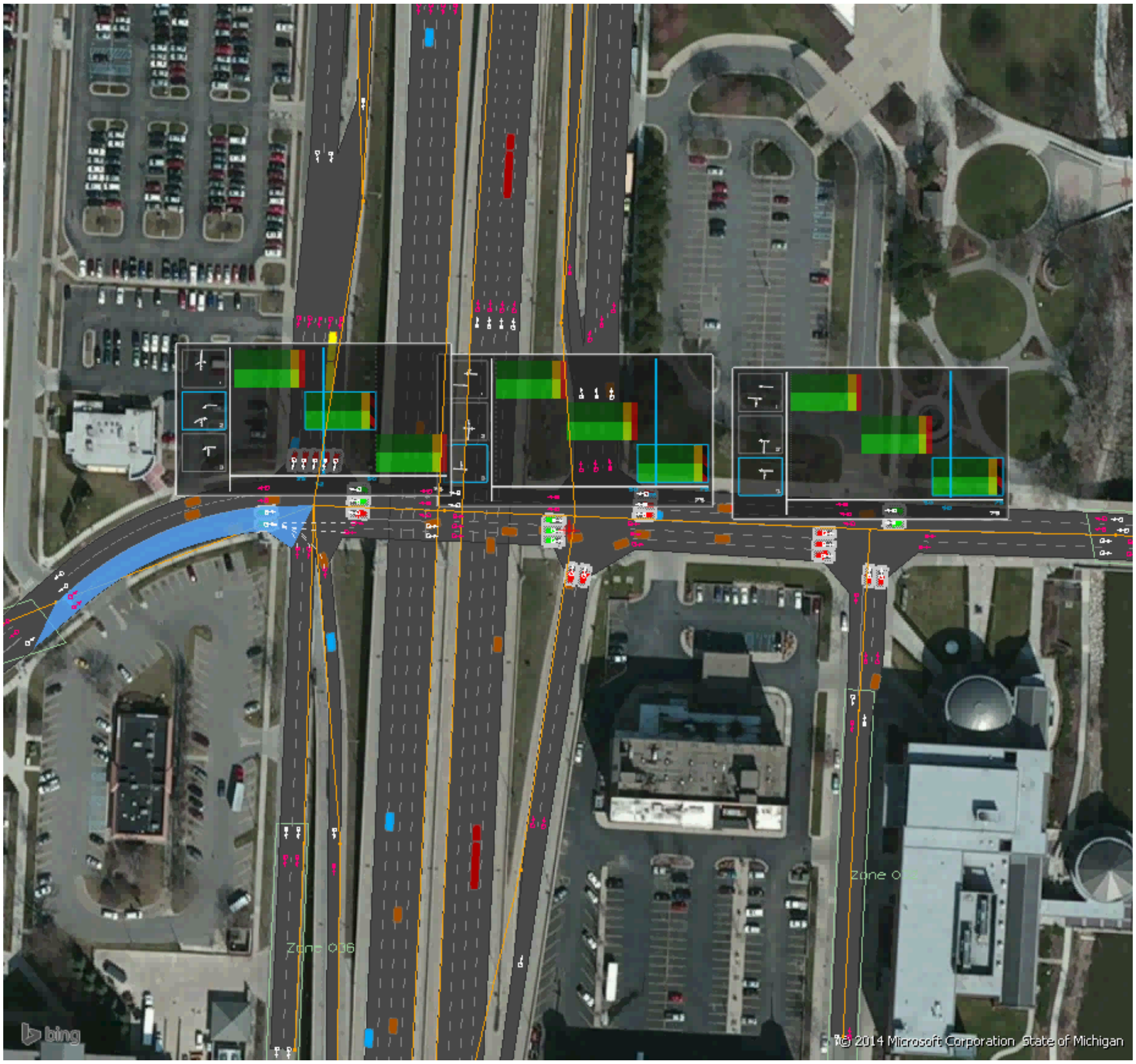


Figure 6-5: WMTOC SS5 Model Verification (Signal Coordination)

Additionally, link count and travel times are compared against observed data in the field to calibrate the model. Paramics Estimator is used to adjust the network O-D matrix provided by the regional travel demand model and correct for any major differences between simulated and field link volumes. An example of the O-D demands from zone-to-zone for WMTOC SS5 is shown in Figure 6-6 on the following page. The bandwidth and color of the web lines indicate the intensity of demand from origin to destination. As seen, the majority of trips are accurately and realistically either staying on the freeway links or traveling from freeway-to-freeway. The model is then validated by comparing simulated speed-flow curves at detector locations against observed speed-flow curves at the same location. An example of such a comparison for a MVDS on WMTOC SS5 (I-96 Westbound) is provided in Figure 6-7 below. As seen, the shape of the simulated curve closely mimics curve produced by the field detector if congested condition data values are ignored.

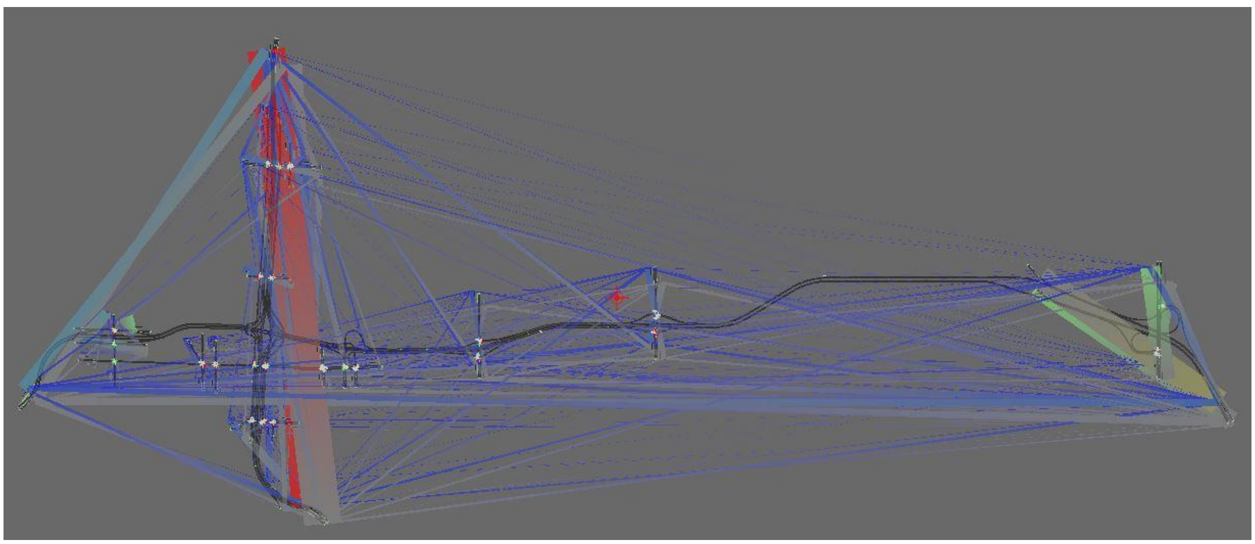


Figure 6-6: WMTOC SS5 OD Demands Zone-to-Zone

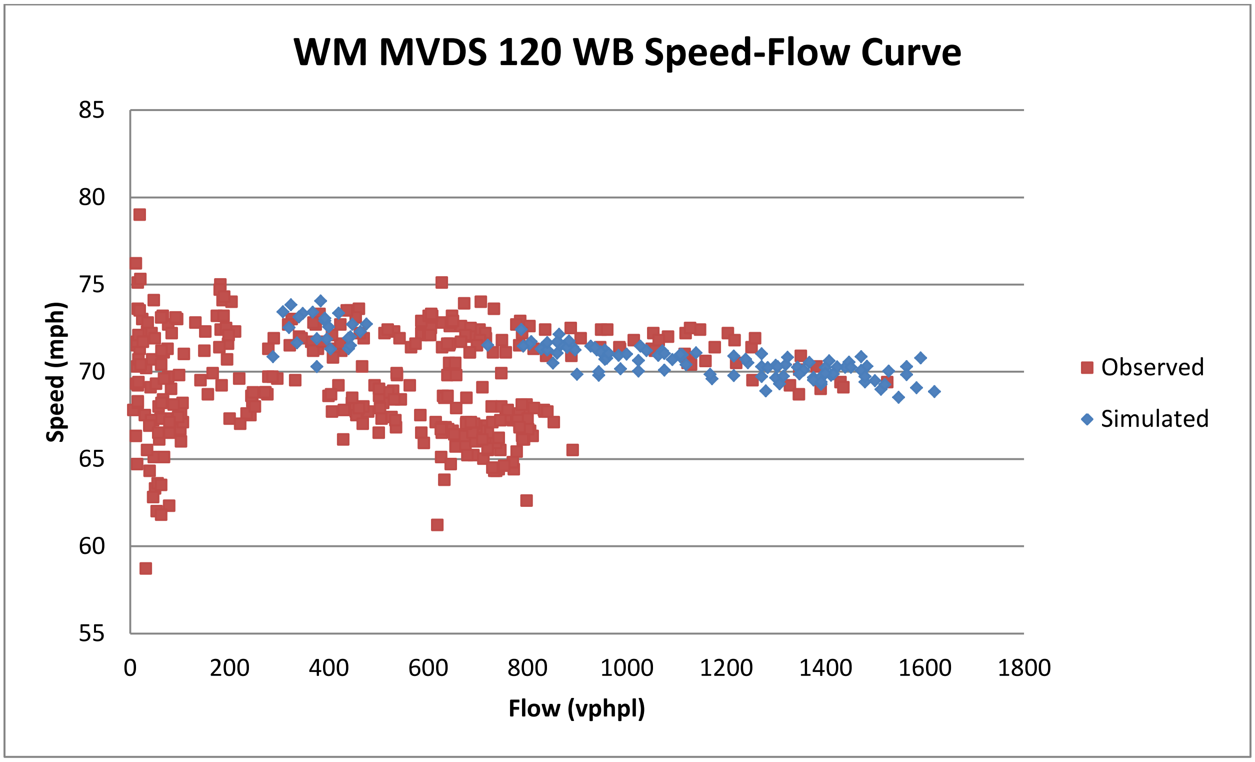


Figure 6-7: WMTOC SS5 Simulated vs. Observed Detector Speed-Flow Curves

6.3.4 Simulation Scenarios

In order to evaluate ITS benefits as a result of incident management, various "Base" and "ITS" case scenarios were developed. Based on the results of the incident duration reduction analysis performed in the previous section, incidents in duration of 60 minutes to 40 minutes were modelled on sections of the study site corridors. Locations were chosen based on proximity to a DMS and route diversion possibilities. Alternate route corridors were modelled in the network based on MDOT Emergency Routing plans in the WMTOC and SEMTOC, while most probable routes were modeled for the STOC study corridors. An example of a modeled incident and potential alternate routes for the WMTOC SS5 corridor are shown in Figure 6-8 and Figure 6-9. In Figure 6-8, the incident is circled in yellow with detail about remaining incident duration. As seen, a queue is building behind the incident. In Figure 6-9, the primary route for vehicles traveling westbound on I-96 is highlighted in red, while potential alternate routes as a result of diversion are highlighted in blue.

Figure 6-8: WMTOC SS5 Modeled Incident

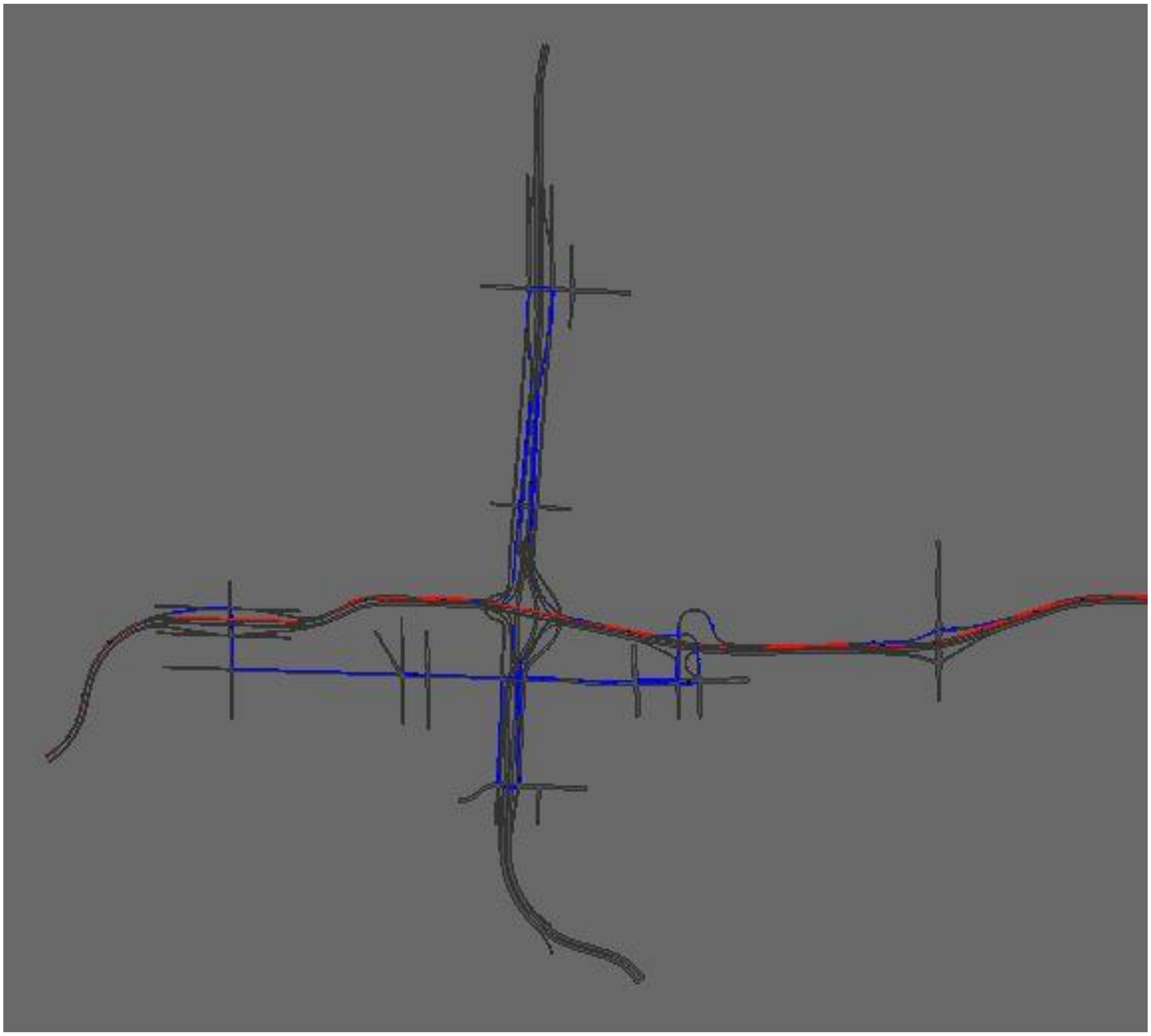


Figure 6-9: WMTOC SS5 Alternate Routes Example

For base versus ITS case comparisons, the base case is considered to be a simulation run with no dynamic feedback enabled. Vehicles make route choices based on route cost calculations made as they are first generated on the network. An ITS case is one where dynamic feedback is enabled (with route cost calculations updated at one minute intervals) and the closest DMS in proximity of the incident advises vehicles to make a route choice reevaluation. All vehicles approaching the DMS update their route choice at each simulation time-step while on the link the DMS is located. Five simulation runs over the entire five hour AM Peak period were made per scenario, with simulation seed values being held constant over all scenarios in order to obtain reliable and comparable results. A map of simulated scenarios (indicated by a check mark) is provided below:

Table 6-2: Simulation Scenario Map

Demand	Simulation Scenarios Modelled									
	No ITS (Base)					With ITS				
	0 Min	40 Min	45 Min	50 Min	60 Min	0 Min	40 Min	45 Min	50 Min	60 Min
100%	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
95%							✓	✓	✓	✓
90%							✓	✓	✓	✓
85%							✓	✓	✓	✓
80%							✓	✓	✓	✓
75%							✓	✓	✓	✓

"No Incident" scenarios were modeled to calculate the delay expected due to an incident without ITS. Incident delay reduction as a result of ITS is calculated with respect to this value, according to incident duration and/or network vehicle demand reduction. In total, 150 simulation runs were performed across all scenarios per study corridor.

6.4 Results & Benefits

The benefits of CCTVs, MVDSs, and the FCP (for STOC and SEMTOC cases) in incident management are evaluated according to incident duration reduction scenarios, for example reducing total incident duration (the total time lapse beginning at incident detection until incident clearance from the roadway) from 60 minutes to 40 minutes. The benefit arising from ATIS, such as the Mi Drive service, is analyzed according to network impacts of reduced vehicle demand during the time of the incident. The benefits under investigation are system-wide travel time delay reductions in vehicle hours traveled (VHT), total emission (CO_2 and NO_x) reductions in tons, and fuel consumption reductions in grams. Cost values are placed on each of these benefits.

6.4.1 Total Vehicle Hours Traveled and Delay

Total network vehicle hours traveled represents a pivotal network performance measure in this study, as it allows for calculation of total vehicle hours of delay according to the various simulation scenarios. A primary mobility benefit of ITS is the ability to reduce motorist vehicle hours of delay. Thus, a delay reduction analysis was performed on the simulation results. Total delay due to an incident of X duration was calculated as follows:

$$Total\ Delay\ Due\ to\ Incident = Total\ VHT_{X,No\ ITS} - Total\ VHT_{No\ Incident,No\ ITS}$$

The total delay saved by reducing an incident of X duration (at 100% demand) to Y duration (of variable demand) was calculated as shown below:

$$Total\ Delay\ Saved\ = Total\ VHT_{X,No\ ITS} - Total\ VHT_{Y,ITS}$$

The total delay saved as result of incident duration reduction alone at 100 percent demand (with no ITS influence) was calculated as below:

$$Total\ Delay\ Saved\ due\ to\ Duration\ Reduction = \ Total\ VHT_{X,No\ ITS} - Total\ VHT_{Y,No\ ITS}$$

Finally, the total delay saved as a result of vehicles detouring due to ITS was calculated as follows:

$$\begin{aligned} &Total\ Delay\ Saved\ due\ to\ ITS \\ &\qquad = Total\ Delay\ Saved - Total\ Delay\ Saved\ due\ to\ Duration\ Reduction \end{aligned}$$

A summarized version of the results at just the 100 percent demand case is provided below in Table 6-3. As seen, the delay saved due to incident duration reduction is highest in high duration, high reduction scenarios, such as the reduction from 60 minutes to 40 minutes. The results vary by corridor, but all corridors show a positive result in delay savings due to duration reduction.

However, the delay saved as a result of ITS in detouring traffic to alternate routes at a given incident duration tends to vary. The results show that ITS is more effective in reducing delay in high duration incident scenarios.

Table 6-3: Delay Saved at 100 Percent Demand

Corridor	Total Delay Saved Due to Duration Reduction						Delay Saved Due to Detour at Given Incident Duration		
	60-40	60-45	60-50	50-40	50-45	45-40	50	45	40
SEMTOC SS1	778	774	591	188	183	4	326	241	279
SEMTOC SS2	188	157	119	69	38	31	111	79	56
SEMTOC SS3	129	105	78	51	27	24	29	17	8
WMTOC SS1	523	488	426	97	62	35	215	109	129
WMTOC SS2	106	77	53	53	24	30	167	161	130
STOC SS1	309	237	171	138	66	72	50	43	11
STOC SS2	1294	981	562	732	419	313	63	46	102

6.4.2 Emissions and Fuel Consumption

CO_2 and NO_x Emissions

The emission metrics under consideration in this study are CO_2 and NO_x. The Paramics CMEM API plug-in calculates cumulative emissions during the duration of the simulation period. The representative measure of emissions in this study are total network emissions Total emissions due to an incident of X duration was calculated as follows:

$$Total\ Emissions\ Due\ to\ Incident = Total\ Emissions_{X,No\ ITS} - Total\ Emissions_{No\ Incident,No\ ITS}$$

The total emissions saved by reducing an incident of X duration (at 100% demand) to Y duration (of variable demand) was calculated as shown below:

$$Total\ Emissions\ Saved = Total\ Emissions_{X,No\ ITS} - Total\ Emissions_{Y,ITS}$$

The total emissions saved as result of incident duration reduction alone at 100 percent demand (with no ITS influence) was calculated as below:

$$Total\ Emissions\ Saved\ due\ to\ Duration\ Reduction = Total\ Emissions_{X,No\ ITS} - Total\ Emissions_{Y,No\ ITS}$$

Finally, the total emissions saved as a result of vehicles detouring due to ITS was calculated as follows:

$$Total\ Emissions\ Saved\ due\ to\ ITS = Total\ Emissions\ Saved - Total\ Emissions\ Saved\ due\ to\ Duration\ Reduction$$

A summary of the emissions saved by corridor at the 100 percent demand scenario is shown in Table 6-4 and Table 6-5. As seen, greater benefit is typically experienced from duration reduction in high duration, high reduction scenarios over all corridors. Additionally, total emissions benefit saved by ITS tends to be highest at higher incident duration scenarios, regardless of duration reduction.

Table 6-4: CO_2 Emissions Saved at 100% Demand

Corridor	Total Emissions Saved Due to Duration Reduction, Grams						Total Emissions Saved by ITS at Given Duration, Grams		
	60-40	60-45	60-50	50-40	50-45	45-40	50	45	40
SEMTOC SS1	4,129,533	3,547,523	2,637,383	1,492,149	910,139	582,010	1,780,214	1,335,916	1,067,009
SEMTOC SS2	1,173,304	879,978	586,652	586,652	293,326	293,326	812,488	543,255	324,317
SEMTOC SS3	596,178	493,056	342,482	253,696	150,574	103,122	299,700	216,514	181,334
WMTOC SS1	3,058,668	2,912,915	2,487,231	571,437	425,684	145,753	584,980	373,945	363,249
WMTOC SS2	505,320	370,129	266,342	238,978	103,788	135,190	490,834	623,413	424,167
STOC SS1	1,925,212	1,463,234	1,038,905	886,307	424,329	461,978	293,116	224,718	16,025
STOC SS2	2,296,329	1,722,247	1,148,164	1,148,164	574,082	574,082	1,612,707	986,864	510,227

Table 6-5: NO_x Emissions Saved at 100% Demand

Corridor	Total Emissions Saved Due to Duration Reduction, Grams						Total Emissions Saved by ITS at Given Duration, Grams		
	60-40	60-45	60-50	50-40	50-45	45-40	50	45	40
SEMTOC SS1	6,858	4,858	3,634	3,225	1,225	2,000	2,683	1,970	655
SEMTOC SS2	2,188	1,641	1,094	1,094	547	547	1,735	1,247	897
SEMTOC SS3	531	462	351	179	110	69	691	597	611
WMTOC SS1	4,704	3,528	2,352	2,352	1,176	1,176	2242	828	144
WMTOC SS2	688	573	445	244	128	116	232	559	235
STOC SS1	3,131	2,399	1,653	1,478	746	732	496	280	158
STOC SS2	1,613	1,210	806	806	403	403	1,573	1,713	1,854

Fuel Consumption

The total fuel consumption saved by vehicles during an incident situation represents another key potential environmental benefit of ITS. Similar to the emissions outputs, the Paramics CMEM API Plug-in generates cumulative network wide total vehicle fuel consumption during the entirety of the simulation period. The fuel consumption saved as result of incident duration reduction and ITS-influenced detour were calculated in a similar manner as delay and emissions, as explained earlier. A summary of the fuel consumption saved at the 100% demand scenario by study corridor is provided in below:

Table 6-6: Fuel Consumption Saved at 100% Demand

Corridor	Total Fuel Consumption Saved Due to Duration Reduction						Total Fuel Consumption Saved by ITS at Given Duration		
	60-40	60-45	60-50	50-40	50-45	45-40	50	45	40
SEMTOC SS1	1,536,162	1,312,239	977,128	559,034	335,111	223,923	626,992	468,474	366,302
SEMTOC SS2	463,732	380,174	282,370	181,362	97,804	83,558	298,529	212,381	157,988
SEMTOC SS3	215,670	177,211	118,237	97,433	58,974	38,459	116,319	84,164	71,117
WMTOC SS1	1,064,183	1,023,200	875,670	188,513	147,530	40,983	371,594	57,166	170,057
WMTOC SS2	174,151	129,697	92,364	81,787	37,334	44,453	138,624	182,262	107,999
STOC SS1	711,590	541,366	380,189	331,402	161,177	170,224	112,027	78,196	4,914
STOC SS2	846,667	635,000	423,333	423,333	211,667	211,667	660,153	601,623	543,093

As seen above, the fuel consumption benefit is highest at high duration, high reduction scenarios, similar to other studied benefits. Another expected result is that total fuel consumption saved by ITS tends to be greatest at high incident duration scenarios.

6.5 Conclusion

The simulation study provided valuable insight into the operational performance of ITS on the corridor level. Analysis determined that ITS was most beneficial in high duration, high reduction scenarios. Many factors governed the results according to each corridor, namely, traffic volume, network configuration and ITS device placement. Given the complexity of the analysis and the random nature of incident occurrence, the results of this study should be viewed as a limited, representative sample of ITS performance on the corridor-level. However, given that ITS functions as a cohesive system, rather than in isolation, accurate cost-benefit analysis was performed on the TOC level, as covered in the following chapter.

Chapter 7 Cost and Benefit Analysis

7.1 Introduction

A cost-benefit analysis was performed at two levels: (1) by TOC and (2) by device. For purposes of cost-benefit analysis, the base year was assumed to be 2012. The analysis period extends for 20 years after base ITS deployment, while applying a 3 percent discount rate over the duration. All calculation was based on present value as of 2012 by applying the discount rate, as shown in the equation below:

$$PV = \frac{FV}{(1+i)^t}$$

Where:

PV= Present discounted value of a future payment from year *t*

FV = Future Value of payment in year *t*

i = Discount rate applied

t = Years in the future for payment (where base year of analysis is *t* = 0)

Three measures are typically used in cost-benefit analysis, as described below:

Benefit-Cost ratio (BCR):

$$BCR = \frac{Present\ Value\ ITS\ Benefits}{Present\ Value\ ITS\ Costs}$$

Net Present Value (NPV):

$$NPV = Present\ Value\ Benefit - Present\ Value\ Cost$$

Internal Rate of Return (IRR) is a rate of return to measure the profitability of investments. IRR is the rate that makes the net present value of all cash flows equal to zero. If the IRR is greater than the discount rate, the project is regarded as acceptable.

7.2 Cost Estimation

Cost estimation is based on two components: construction costs and operations and maintenance costs. Construction costs were estimated based on the statewide average cost per device, as ITS constructions were managed at the state level. Operations and maintenance (O&M) costs were estimated based on the latest costs based on the number of devices used and the costs spent by TOC.

In this study, it was assumed that all devices were installed at the same time during the base year (2012) in order to avoid complexity in estimating benefits with partial ITS deployments. It was also assumed that the lifespan of ITS devices was 20 years. O&M costs were applied during the analysis period (2013 – 2032) and assumed to be the same for all years.

Table 7-1: Summary of ITS Costs by TOC

Period		SEMTOC	WMTOC	STOC	Total
Number Devices		589	214	171	974
	DMS	98	27	45	170
	CCTV	216	67	56	339
	MVDS	274	120	65	459
	TTS	1	0	5	6
Construction Cost		86,519,413	30,765,154	27,788,750	145,073,317
	DMS	28,732,112	7,915,990	13,193,317	49,841,419
	CCTV	18,908,122	5,865,019	4,902,106	29,675,248
	MVDS	38,780,462	16,984,144	9,199,745	64,964,351
	TTS	98,717	-	493,583	592,299
Annual O&M Costs		5,426,092	1,303,177	2,020,119	8,749,387
Annual FCP Cost		1,933,333	-	366,667	2,300,000

7.3 Benefit Estimation

The key focus of MDOT ITS is managing traffic incidents and providing recurrent and non-recurrent traffic information. In this study, ITS benefits are estimated from these activities. The benefits of ITS are comprised of travel time saving, secondary incident reduction, fuel consumption saving, emission cost saving, and crash reduction. Another considered benefit is using MiDrive to acquire travel information to potentially alter motorist travel decisions.

7.3.1 Travel Delay and Emission Estimation

One of the major benefits of ITS is travel delay saved by reducing incident duration. The time lapse of an incident consists of six primary stages, which includes reporting time, verification time, dispatch time, arrival time, clearance time and time to return to normal flow. A figure depicting these six stages is included below:

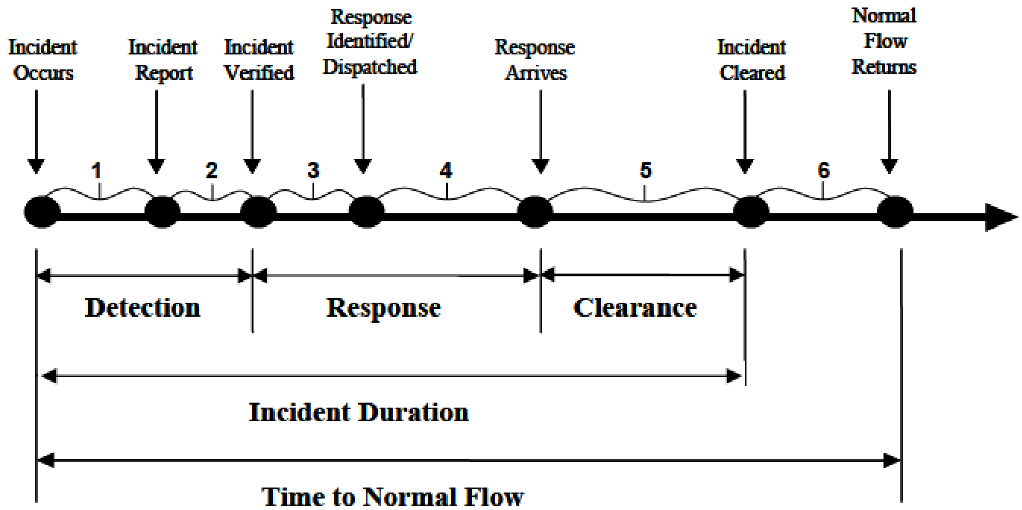


Figure 7-1: Timeline of Incidents

In this study, the report time could not be obtained as true time of incident occurrence is practically impossible to glean from TOC Call Log information. Instead, the first stage of the incident timeline begins with the reporting of an incident to TOC staff through various means, either motorist call, police dispatch or FCP patrol vehicle. Once the incident has been reported, verification can occur through different scenarios, which include TOC operator using a CCTV, FCP patrol vehicle on the scene, or law enforcement personnel on the scene. The time from the reporting of an incident to verification is classified as verification time, and comprises the entire incident detection stage. Once an incident has been detected, the response stage begins. The response stage begins with dispatch time, which is the time from incident verification to FCP or 911 personnel dispatch. In this study, the dispatch time for any particular incident is unknown due to data limitations. The second component of incident response is the time it takes from vehicle dispatch to arrive at the incident scene, known as the response time. Once again, in the present study the true response time is unknown due to data limitations. After a dispatch vehicle arrives at the scene, the personnel begin clearing the incident. Incident clearance can consist of two stages: roadway clearance and shoulder clearance. The clearance times obtained from TOC Call Log information were assumed to be complete incident clearance times. Finally, once the incident is cleared from the shoulder, roadway traffic begins to return to normal conditions. The time between incident clearance and the return to normal flow is known as the recovery time. In the present analysis the "Incident Duration" timespan indicated in Figure 7-1 is considered as the total time lapse from the reporting of an incident to complete removal according to TOC Call Log and LCAR database information.

Determining Incident Duration Reduction

Reduction of incident duration was estimated by comparing incident durations from those incident occurring in the areas with ITS versus those without ITS influence. While the difference for the SEMTOC area was almost negligible, the difference was evident in WMTOC and STOC. The determination of incident duration reduction is covered in more detail in Chapter 5 of the report. A summary of incident duration reduction resulting from ITS is shown in Table 7-2 below:

Table 7-2: Estimated Incident Duration Reduction

	SEMTOC	WMTOC	STOC	TOTAL
Total Number of Incidents	56,425	1,477	7,458	65,360
LCAR Incidents	8,056	1,477	1,502	11,035
FCP Assisted	48,369	-	5,956	54,325
Average Duration	24.2	54.9	46.5	27.5
LCAR Incidents	47.1	54.9	117.2	57.7
FCP Assisted	20.4	-	28.7	21.3
Average Duration Reduced by ITS	24.5	23.9	32.3	25.38
LCAR Incidents	24.5	23.9[1)]	18.9[2)]	23.66
FCP Assisted	24.5	-	35.7	25.73

1) 24.5 minute reduction for incidents within the ITS dense area; 10 minute reduction for those outside
2) 44.9 minute reduction for incidents within the ITS dense area; 10 minute reduction for those outside

Estimation of Incident Delay and Emission

Incident delay was estimated by applying the queue concept in Figure 7-2. As shown in the figure, the reduced capacity by an incident is the main source of delay. The total delay includes the time to dissipate the queue after the incident is cleared. The total delay is reduced when the incident duration is reduced by ITS services.

Based on the concept of queueing, a delay computation model was developed to quantify the ITS benefit. The model procedure is outlined below:

Step 1: Input incident characteristics

- Location, incident type, incident duration, incident start time

Step 2: Determine location (segment) characteristics from the location data

- Free flow speed, number of lanes, AADT, percentage of commercial vehicles

Step 3: Determine capacity and speed reduction factors and set t = 0

Step 4: Run until t > incident duration and queue = 0

4-1: Determine demand based on time-of-day traffic pattern

4-2: Determine capacity, speed, queue length, and delay with/without ITS

4-3: Compute emission and fuel consumption based on the speed

Step 5: Quantify the amount of total delay and emission

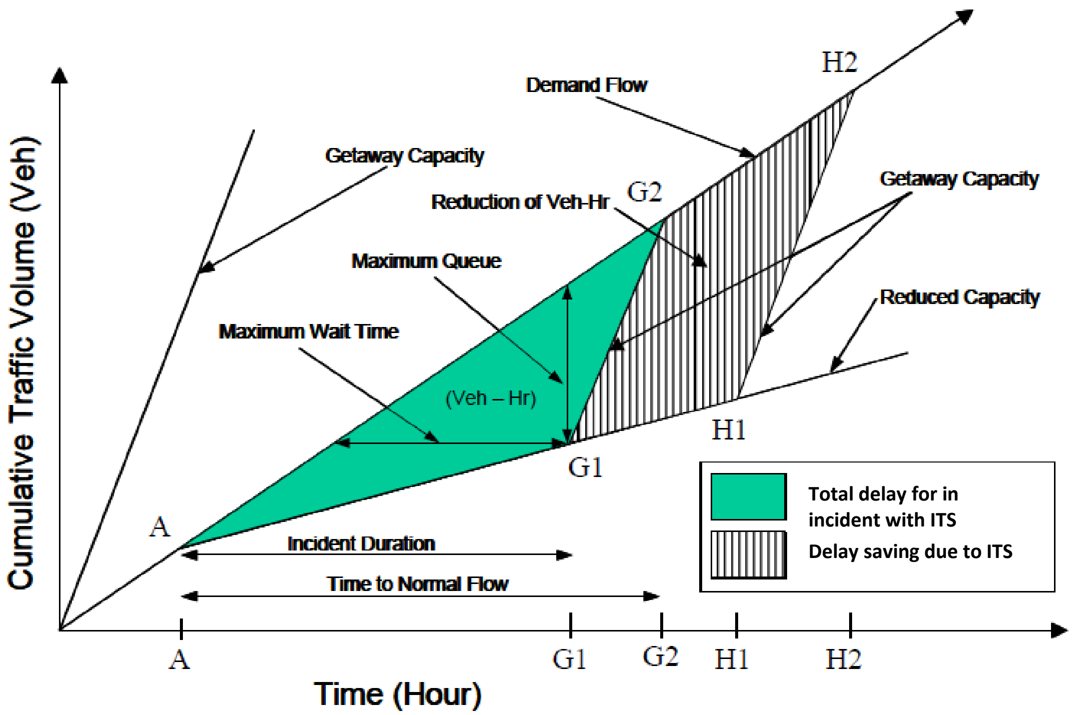


Figure 7-2: Estimation of Incident Delay

Traffic demand for each time period (1 minute) is estimated from the 2013 AADT of the segment and time-of-day traffic pattern. Based on the type of incident, the capacity reduction Table 7-3) and the speed reduction factor (Table 7-4) are determined. After calculating the capacity, the number of vehicles in the queue is determined when the demand exceeds the capacity. Speed of the segment is calculated based on the speed-flow relation in the 2010 Highway Capacity Manual (Figure 7-3) and the amount of emissions is quantified by the emission rates (Figure 7-4) drawn from United States Environmental Protection Agency's (EPA) Motor Vehicle Emission Simulator (MOVES).

Table 7-3: Capacity Reduction by Lane Block

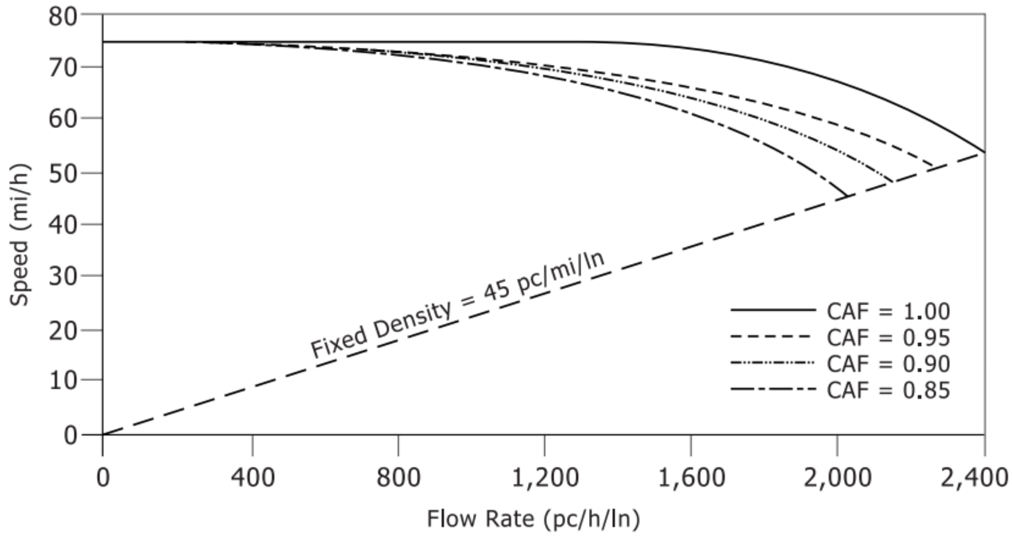
Lanes	Shoulder	Shoulder Crash	One Lane Block	Two Lane Block	Three Lane Block
	1	2	3	4	5
2	0.95	0.81	0.35	0	0
3	0.99	0.83	0.49	0.17	0
4	0.99	0.85	0.58	0.25	0.13
5	0.99	0.87	0.65	0.4	0.2
6	0.99	0.89	0.71	0.5	0.26
7	0.99	0.91	0.75	0.57	0.36
8	0.99	0.93	0.78	0.63	0.41

Source) 2010 Highway Capacity Manual Exhibit 10-17

Table 7-4: Free flow Speed Adjustment Factor

	Shoulder	One Lane Block	Two Lane Block
Non crash	0.99	0.79	0.61
PDO	0.86	0.79	0.61
Injury	0.86	0.79	0.61
Fatal	0.86	0.79	0.61

Source) Guide for Highway Capacity and Operations of Active Transportation and Demand Management Strategies: Analysis of Operational Strategies under Varying Demand and Capacity Conditions, June 2013.



Note: Free-flow speed = 75 mi/h (base conditions); *CAF* = capacity adjustment factor (proportion of available capacity).

Figure 7-3: Speed-Flow Relation

Source) 2010 Highway Capacity Manual

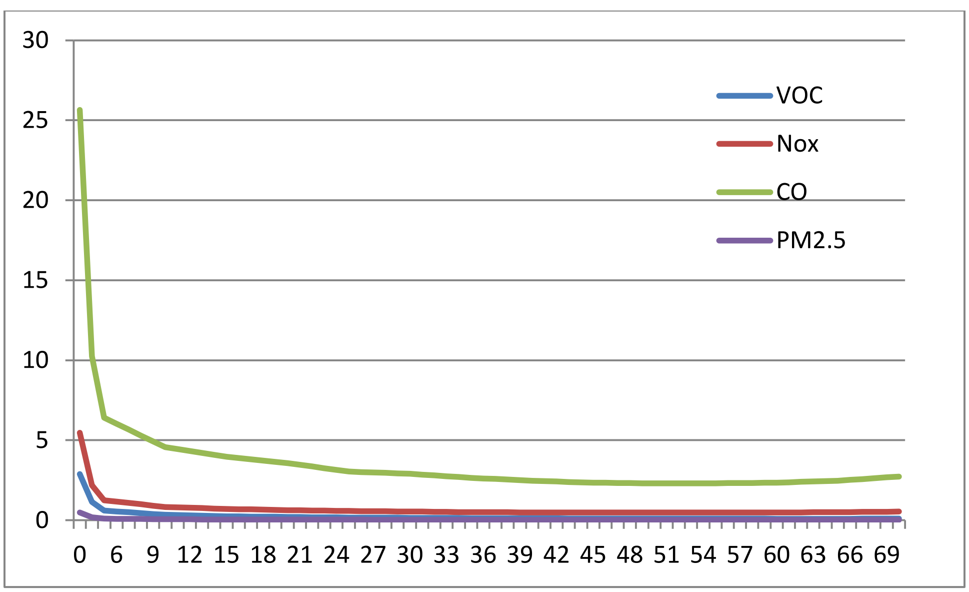


Figure 7-4: Emission Rates by Speed

Table 7-5 summarizes the average delay and saving estimated by each TOC. The delays are monetized by applying value of time (VOT) suggested by MDOT ($17.7 per hour for passenger cars and $31.22 for commercial vehicles). The total delay saving estimated is $26.3 Million from 65,360 incidents observed by MDOT ITS.

Table 7-5: Summary of Incident Delay and Saving

	SEMTOC	**WMTOC**	**STOC**	**TOTAL**
Average Incident Delay without ITS (hours / incident)	48.5	234.3	148.6	64.15
LCAR (hours / incident)	307.2	234.3	718.1	353.39
FCP (hours / incident)	5.5	-	5.0	5.40
Average Incident Delay Saving (hours / incident)	19.3	106.3	24.3	21.80
LCAR (hours / incident)	114.4	106.3	105.3	112.08
FCP (hours / incident)	3.4	-	3.8	3.47
Average Incident Delay Cost ($ / incident)	$895	$4,351	$2,772	$1,188
LCAR ($ / incident)	$5,667	$4,351	$13,394	$6,543
FCP ($ / incident)	$101	-	$93	$100
Average Incident Delay Cost Saving ($ / incident)	$355	$1,974	$453	$403
LCAR ($ / incident)	$2,110	$1,974	$1,965	$2,072
FCP ($ / incident)	$63	-	$71	$64
Total Incident Delay Saving ($)	$20,053,665	$2,916,013	$3,374,840	$26,344,518
LCAR ($)	$16,999,350	$2,916,013	$2,950,967	$22,866,331
FCP ($)	$3,054,315	-	$423,873	$3,478,188

Fuel consumption and emissions reduction by ITS are also estimated for each TOC, as shown in Table 7-6. By applying the 2013 gas price per gallon ($2.687) and unit monetary values ($39/ton for CO2; $1,999/ton for VOC; $7,877/ton for NOx), fuel and emission cost savings are quantified.

Table 7-6: Summary of Fuel and Emission Saving

	SEMTOC	WMTOC	STOC	TOTAL
Fuel Saving (gallon)	483758.4	69886.1	80517.9	634162.4
VOC (ton)	74.9	13.2	15.1	103.1
NOx (ton)	144.6	24.7	28.9	198.2
CO (ton)	678.7	115.3	135.6	929.6
Fuel Cost Saving	$1,301,310	$187,994	$216,593	$1,705,897
Emission Cost Saving	$1,315,257	$225,470	$263,126	$1,803,853

7.3.2 Estimation of Secondary Incident Reduction

Another key impact of ITS is secondary incident reduction. Secondary incident likelihood is intrinsically related to the duration of an incident. The probability of a secondary incident is minimized as primary incident duration is reduced as result of ITS incident management capabilities. Previous studies have shown that 15-25 percent of all incidents are secondary incidents (Change et al, 2002; Raub, 1997). The present study assumed that 20 percent of observed incidents managed by TOC staff are indeed secondary incidents. The benefit of ITS in managing secondary incidents was included as a complimentary part of incident delay reduction, and was calculated as follows:

$$Secondary\ Incidents = 0.2 * \frac{PI\ Duration_{No\ ITS} - PI\ Duration_{ITS}}{PI\ Duration_{No\ ITS}} * PI\ Observed$$

$$IDS_{SI\ Avoided} = (Incident\ Delay_{X,No\ ITS} - Incident\ Delay_{Y,No\ ITS})$$

$$IDS_{Base\ Benefit} = IDS_{SI\ Avoided} * (CV_{\%} * CV_{VoT} + PV_{\%} * PV_{VoT})$$
$$SI_{Benefit} = IDS_{Base\ Benefit} * Secondary\ Incidents$$

Where:

$Secondary\ Incidents$ = The estimated number of secondary incidents avoided by ITS

$PI\ Duration_{No\ ITS}$= Average duration of incident without ITS

$PI\ Duration_{ITS}$=Average duration of incident with ITS

$PI\ Observed$=Observed number of incidents managed by TOC

$IDS_{SI\ Avoided}$ =Incident delay saving due to reducing number of secondary incidents

$Incident\ Delay_{X,No\ ITS}$=The total incident delay for incident of X duration without ITS

$Incident\ Delay_{Y,No\ ITS}$=Total incident delay for incident of Y duration without ITS

$IDS_{Base\ Benefit}$=Monetary incident delay benefit due to base incident duration reduction

$CV_{\%}$ =Percentage of commercial vehicle traffic

CV_{VoT}=Commercial vehicle value of time

$PV_{\%}$=Percentage of passenger vehicle traffic

PV_{VoT} =Passenger vehicle value of time

$SI_{Benefit}$=Monetary benefit of secondary incident reduction

The secondary incident delay saving by as a result of ITS by TOC is shown in Table 7-7 below:

Table 7-7: Secondary Incident Delay Saving

	SEMTOC	WMTOC	STOC	TOTAL
Number of secondary incidents	11,285	295	1,492	13,072
Number of secondary incidents avoided	4,479	134	244	4,857
Secondary incident delay saved (hours)	217,419	31,410	36,188	285,017
Secondary incident delay saved ($)	$4,010,733	$583,203	$674,968	$5,268,904

7.3.3 Crash Reduction

Crash analysis was performed to quantify the impact of ITS on the number of crashes observed. When modeling crash counts, Poisson regression analysis or Negative Binomial (NB) regression analysis can be used (Yaacob et al, 2011; Zlatoper, 1989; Lord, 2006; Chin and Quddus, 2003; Miaou and Lum, 1993; and Noland and Quddus, 2004). The relationship between the mean and the variance dictates the choice between the two model types. If the mean is equal to the variance, the data is assumed to follow a Poisson distribution, and hence the Poisson regression analysis can be performed. However, as a result of possible positive correlation between observed accident frequencies, overdispersion may occur (Hilbe, 2011). Accident frequency observations are said to be overdispersed if their variance is greater than their mean. If overdispersion is detected in the data, NB regression analysis should be used. Standard textbooks (for example Hilbe 2011; Greene 2012; and Washington et al 2011) present clear derivation of the Poisson, and Negative Binomial (NB) models. According to the Poisson distribution, the probability $P(y_i)$ of intersection *i* having y_i crashes in a given time period (usually one year) can be written as:

$$P(y_i) = \frac{EXP(-\lambda) \cdot \lambda_i^{y_i}}{y_i!}$$

where λ_i denotes the Poisson parameter for intersection *i*. By definition, λ_i is equal to the expected number of crashes in a given time period for intersection *i*, $E[y_i]$. According to Washington et al. (2011), the expected number of crash occurrences λ_i, can be related to a vector of explanatory variables, $\boldsymbol{X}_i$ as follows:

$$\lambda_i = EXP(\boldsymbol{\beta X}_i)$$

where $\boldsymbol{\beta}$ represents a vector of estimable parameters. Under the Poisson assumption, the mean and variance of crashes occurring at an intersection in a year are equal (i.e. $E[y_i] = Var[y_i]$). With *N* observations, the parameters of the Poisson model can be estimated by maximum likelihood method with a function which can be shown to be as follows:

$$LL(\beta) = \sum_{i=1}^{N} [-EXP(\boldsymbol{\beta X}_i) + y_i \boldsymbol{\beta X}_i - \ln(y_i!)]$$

The Poisson assumption of equal mean and variance of the observed crash occurrences is not always true. To handle the cases where the mean and variance of crashes are not equal, the Poisson model is generalized by introducing an individual, unobserved effect, ε_i, in the function relating crash occurrences and explanatory variables as follows:

$$\lambda_i = EXP(\boldsymbol{\beta X}_i + \varepsilon_i)$$

in which $EXP(\varepsilon_i)$ is a gamma-distributed error term with mean one and variance α^2. With such a modification, the mean λ_i becomes a variable that follows binomial distribution. The mean-variance relationship becomes:

$$Var[y_i] = E(y_i) \cdot [1 + \alpha E(y_i)] = E[y_i] + \alpha E(y_i)^2$$

If α is equal to zero, the negative binomial distribution reduces to Poisson distribution. If α is significantly different from zero, the crash data are said to be overdispersed (positive value) or underdispersed (negative value). As stated earlier, overdispersion is a result of possible positive correlation between observed accident frequencies. When α is significantly different from zero, the resulting negative binomial probability distribution is:

$$P(y_i) = \frac{\Gamma((1/\alpha) + y_i)}{\Gamma(1/\alpha) y_i!} \left(\frac{1/\alpha}{(1/\alpha) + \lambda_i} \right)^{1/\alpha} \left(\frac{\lambda_i}{(1/\alpha) + \lambda_i} \right)^{y_i}$$

where $\Gamma(x)$ is a value of the gamma function, y_i is the number of crashes for segment *i* and α is an overdispersion parameter.

In this study, crash analysis employed the negative binomial model focusing on the impact of the number of DMS and other ITS (CCTV and MVDS) on 2013 crashes. Table 7-8 presents the descriptive statistics of the data while Table 7-9 presents the model results.

Table 7-8: Descriptive Statistics

Variable	Description	Min	Mean	Max	Std. Dev.
crashes_13	Number of crashes in the segment in 2013	0	13.77	327	17.30
dms_13	Number of DMS in the segment in 2013	0	0.02	3	0.16
other_its_13	Number of other ITS in the segment in 2013	0	0.91	16	0.53
num_lanes	Number of lanes of the segment	1	2.53	6	0.84
median_divided	Median type (1 = divided, 0 = otherwise)	0	0.44	1	0.50
AADT_13_K	Annual Average Daily Traffic (in 1000s)	0	15.45	98.1	16.15
wmtoc	West Michigan TOC (1 = yes, 0 = no)	0	0.11	1	0.32
semtoc	Southeast Michigan TOC (1 = yes, 0 = no)	0	0.19	1	0.39
length	Length of the segment (mi)	0.01	1.66	21.74	1.92

Table 7-9: Model estimation results

crashes_13	Coef.	Std. Err.	z-Statistic	p-Value	[95% Conf. Interval]	
dms_13	-0.181	0.061	-2.99	0.003	-0.30	-0.06
other_its_13	-0.019	0.017	-1.13	0.257	-0.05	0.01
num_lanes	0.375	0.014	26.92	0.000	0.35	0.40
median_divided	-0.176	0.023	-7.71	0.000	-0.22	-0.13
AADT_13_K	0.030	0.001	30.60	0.000	0.03	0.03
wmtoc	0.416	0.030	13.72	0.000	0.36	0.48
semtoc	0.127	0.029	4.40	0.000	0.07	0.18
length	0.274	0.006	46.20	0.000	0.26	0.29
_cons	0.514	0.039	13.07	0.000	0.44	0.59
alpha	0.527	0.010			0.51	0.55
Number of obs = 7233 LR chi2(8) = 4446.83 Prob > chi2 = 0.0000 Log likelihood = -24232.36 Pseudo R2 = 0.0840						

The model indicates that one DMS is likely to reduce 100*(1-EXP(-0.181)) = 16.6% of crashes per year, when other factors in the model are controlled. Similarly, the model indicates that one ITS other than DMS is likely to reduce 100*(1-EXP(-0.019)) = 1.9% of crashes per year, when other factors in the model are controlled. By using the percentage reduction and the observed crashes, it was determined that the following (Table 7-10) crashes were most likely reduced by ITS in 2013.

Table 7-10: Number of crashes reduced by region

	Observed Crashes	Reductions by DMS	Reductions by Other ITS	Total Reduction	Segments
SEMTOC	5,559	556	211	**767**	204
WMTOC	2,543	155	31	**286**	99
STOC	1,508	116	30	**146**	73
TOTAL	**9,610**	**827**	**372**	**1,199**	**376**

Based on the number of injuries by severity, an average of Michigan crash costs was estimated as shown in Table 7-11. The crash reduction saving was estimated by multiplying the average cost of Michigan crashes. As shown in Table 7-12, the total saving from crash reduction by MDOT ITS was estimated at $20 million.

Table 7-11: Average Crash Cost

Type	Crash Cost	Number of Injuries in Michigan	Percentage
Fatal	$ 4,567,329.60	892	0.2%
Incapacitated	$ 239,583.40	4,668	1.0%
Evident	$ 63,565.51	14,614	3.0%
Possible Injury	$ 29,657.05	41,352	8.5%
PDO	$ 2,500.00	427,272	87.4%
Total		488,798	100.0%
Average	$ 17,217.62		

Source) National Safety Council, Estimating the Costs of Unintentional Injuries, 2012

Table 7-12: Crash Reduction Saving

	SEMTOC	WMTOC	STOC	TOTAL
Number of crashes reduced	767	286	146	1199
Total crash reduction saving	$13,205,914	$4,924,239	$2,513,772	$20,643,926

7.3.4 Mi Drive User Benefit

MDOT provides traffic information via the Mi Drive webpage and mobile app. In 2013, there were a total of 1,707,873 sessions with each session lasting 18.8 minutes on average. The total amount of time spent was 535,140 hours. The amount of time is regarded as an ITS benefit, because users willingly spend their time to acquire traffic information worth more than the time spent. The amount of time spent in Mi Drive is monetized by applying the value of time (VoT) per person ($12.42) as suggested by the TIGER Benefit-Cost Analysis Resource Guide (2014). The total benefit from the Mi Drive is estimated at $6,646,434. A time-series chart depicting the number of Mi Drive hits from 2011 to 2013 is shown in Figure 7-5 below.

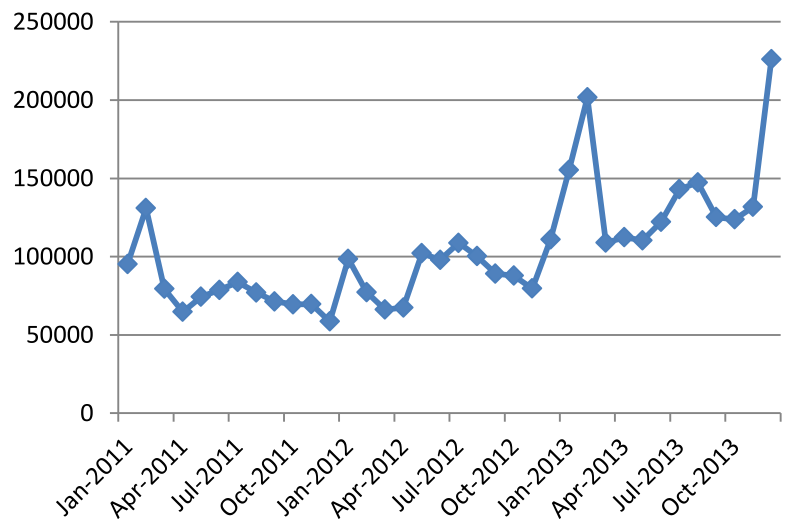


Figure 7-5: Number of Sessions Accessed to Mi Drive

7.3.5 FCP User Satisfaction Benefit

FCP provides assistance to motorists. The benefit is typically valued between $50 - $100 per assist according to the auto manufacturers and automobile clubs. A previous study (URS, 2006) conducted a survey in Georgia and obtained an average of $60.25 per assist. In this research, the user satisfaction benefit was quantified by adopting the same value. Table 7-13 below shows the estimated user satisfaction benefit obtained for each TOC and in total.

Table 7-13: User Satisfaction Benefit

	SEMTOC	WMTOC	STOC	TOTAL
Number of FCP assisted	48,369	0	5,956	5,4325
FCP User Satisfaction Benefit	$2,914,232	$0	$358,849	$3,273,081

7.4 Cost and Benefit Analysis Results

7.4.1 Cost and Benefit by TOC

This section summarizes costs and benefits estimated for each TOC. As summarized in Table 7-14, the total annual benefit is estimated at $65.7 million for all three TOCs. Among the three TOCs, SEMTOC covers more than 70 percent of the total.

Benefit-cost ratios are presented at four different levels of benefits. As shown in Table 7-15, benefit-cost ratios were all greater than 1.0:1, even at the base level, which includes delay, fuel consumption and emissions savings. When including all benefits, the BCR combined for all three TOCs was 3.16:1. Among the three TOCs, SEMTOC showed the highest BCR of 3.55:1. STOC was the lowest, but showed an acceptable BCR of 2.04:1. Based on the estimated costs and benefits, it can be stated that MDOT’s ITS investment was cost effective, even though its history was relatively short, except in the SEMTOC coverage area.

Table 7-14: Summary of Costs and Benefits

	SEMTOC	WMTOC	STOC	TOTAL
Construction Cost	$86,519,413	$30,765,154	$27,788,750	$145,073,317
Annual O&M Cost	$5,426,092	$1,303,177	$2,020,119	$8,749,387
Annual FCP Cost	$1,933,333	$0	$366,667	$2,300,000
Total Annual Benefit	**$46,764,939**	**$10,246,404**	**$8,675,271**	**$65,686,613**
LCAR Delay saving	$16,999,350	$2,916,013	$2,950,967	$22,866,331
FCP Delay Saving	$3,054,315	$0	$423,873	$3,478,188
Secondary Incident Delay Saving	$4,010,733	$583,203	$674,968	$5,268,904
Fuel Saving	$1,301,310	$187,994	$216,593	$1,705,897
Emission Saving	$1,315,257	$225,470	$263,126	$1,803,853
Crash Saving	$13,205,914	$4,924,239	$2,513,772	$20,643,926
MiDrive User Benefit	$3,963,827	$1,409,484	$1,273,122	$6,646,434
FCP Satisfaction Benefit	$2,914,232	$0	$358,849	$3,273,081

Table 7-15: Summary of Benefit Cost Ratios

		SEMTOC	WMTOC	STOC	TOTAL
Sum of Present Value (Cost)		$196,009,067	$50,153,131	$63,298,098	$309,460,296
Sum of Present Value (Benefit)	A: Delay + Fuel + Emission	$396,945,383	$58,210,798	$67,387,927	$522,544,108
	BCR	2.03	1.16	1.06	1.69
	B: A + Crash	$593,416,042	$131,471,044	$104,786,514	$829,673,599
	BCR	3.03	2.62	1.66	2.68
	C: B + Mi Drive	$652,387,782	$152,440,611	$123,727,361	$928,555,754
	BCR	3.33	3.04	1.95	3.00
	D: C + FCP Satisfaction	$695,744,199	$152,440,611	$129,066,128	$977,250,938
	BCR	3.55	3.04	2.04	3.16

7.4.2 Costs and Benefits by Device

One of the key characteristics of ITS is integration of transportation information and management systems to provide benefits to motorists and travelers. ITS devices deployed by MDOT also work together as a system. However, it may be necessary to investigate costs and benefits at the individual device level to determine future investment decisions. While it is difficult to separate ITS benefits by device, there might be differences in utilization of devices and their effectiveness. In order to identify the difference, the research team conducted phone interviews with TOC operators to understand the proportion each device type is utilized for daily operation activities. The overall consensus was that an operator spent 64%, 24% and 12% of their time for activities related with CCTV, DMS, and MVDS, respectively.

In this study, while the construction costs by device type were estimated by multiplying the average construction cost, the O&M cost for a device type was estimated by applying the proportion of the operators' time for the device type. The benefits were also divided according to the proportion after allocating the FCP's portion. The FCP's portion of benefits was estimated based on the proportion of delay saving. Crash cost savings were based on the estimated number of crashes in the crash model.

As shown in Table 7-16, the benefit-cost ratio (BCR) of CCTV was the highest, while that of MVDS was the lowest. Both FCP and DMS also showed high BCR values. Even though MVDS are the backbone of ITS through providing basic traffic information, the analysis result showed a low BCR, due to relatively low utilization. However, it should be noted that TOC operators are using travel time information obtained from traffic sensors for their proactive operations decisions.

Table 7-16: Summary of Benefit Cost Ratios by Device

	DMS	**CCTV**	**MVDS**	**FCP**
Construction Costs	$50,433,719	$29,675,248	$64,964,351	$0
Annual O&M Costs	$5,249,632	$2,624,816	$874,939	$2,300,000
Annual Benefits	$22,940,145	$28,596,776	$5,361,895	$8,787,797
Sum of PV Cost	$89,484,354	$107,776,519	$77,981,230	$34,218,192
Sum of PV Benefit	$341,291,433	$425,447,811	$79,771,465	$130,740,229
BCR	**3.81**	**3.95**	**1.02**	**3.82**
NPV	$251,807,079	$317,671,292	$1,790,235	$96,522,037

Chapter 8 Conclusion

8.1 Summary of Research

MDOT's vision for ITS focuses on deploying and maintaining a program which enhances safety, traffic operations and transportation system integration in a cost-effective and sustainable manner. As of 2013, three TOCs (SEMTOC, WMTOC and STOC) operate and maintain 149 DMSs, 275 CCTVs and 367 MVDSs, as well as FCP programs, on over 500 miles of Michigan highways. Given that in recent years, the deployment of new ITS devices into the system has rapidly escalated, the research team was tasked with evaluating the benefits reaped from MDOT ITS as a system approach and at the individual device level.

To meet this objective, the research team conducted a comprehensive and rigorous statewide cost-benefit analysis. A complex spatiotemporal database was developed through GIS software, fusing 2006-2013 ITS device locations and operation dates, 2006-2013 annual AADT/CADT, 2010-2012 NAVTEQ minute-by-minute travel time and delay information, 2008-2013 UD-10 vehicle crash information, 2011-2013 statewide LCAR incident logs and 2007-2013 statewide TOC Call Log data. Further, five ITS device-concentrated regions were defined within the three TOCs in order to extract the impact of ITS on various performance metrics, including vehicle delay, crash and incident occurrence, emissions, fuel consumption and others.

A detailed cost analysis was performed based on construction and O&M costs of over 50 MDOT ITS projects between 2006 and 2013. Construction costs included design, construction and system manager costs, while O&M costs included maintenance, TOC contracts, FCP contracts, utility costs and MDOT staff costs. All costs were summarized by year and TOC.

Given that traditional cost-benefit analyses purposed for ITS performance evaluation are limited in their ability to quantify the benefits extracted from travel information dissemination and motorist behaviors, an online user perception survey was administered to Michigan residents through the Mi Drive web application. The survey was innovative in its execution and approach by considering ITS deployments as a cohesive system while gathering responses over an extended duration across the entire state of Michigan. Statistical analysis was performed on the survey results to determine interactions between location, time of year, travel behaviors, ITS device familiarity and travel information perceived usefulness and frequency of use. Some key findings included that DMS, TTS, CCTV and Mi Driver were the most well-known ITS applications (while familiarity with these devices varied depending on time of year); radio, TV and Mi Drive were the most frequently used sources of pre-departure travel information; the overwhelming majority (93 percent) of users at least somewhat trust DMS information and most often find it to relieve anxiety and guide them to alternate routes (results showed preference towards prescriptive message types); and FCP assisted motorists were willing to wait at least 15 minutes longer (many up to 30 minutes longer) than actual, experienced wait times.

The previously mentioned ArcGIS database was used to perform a cross-sectional analysis of the impact of ITS on reducing incident duration, a key player in user delay reduction. As described, individual LCAR incident and TOC Call Log events were aggregated to their associated roadway segments. For each of the roughly 7,300 defined MDOT highway segments, ITS device density (per unit of length in miles) was determined. The study compared 2013 incident and FCP assist durations on segments both with and without ITS influence and obtained 18.9 to 24.5 minute reductions for LCAR incidents and 24.5 to 35.7 minute reductions for FCP assisted events. These incident duration reductions fall in line with results estimated in other influential studies. The STOC experienced the largest incident duration reductions as a result of 2013, likely due to mass ITS device deployments in 2012.

In order to better understand the impact of ITS on the operational level, a traffic microsimulation study was conducted on seven selected study corridors in Michigan. These corridors were chosen on the basis of ITS density, daily travel volume and system importance. Simulation scenarios were developed by varying demand level, incident duration, and with vs. without ITS to estimate the benefits of ITS with respect to vehicle delay, emissions and fuel consumption according to observed incident duration reductions. The simulation study revealed that the benefits of ITS as a result of incident duration reduction (through FCP or other means) are highest in high duration, high reduction scenarios (such as from 60 minutes to 40 minutes) and that the benefits experienced as result of ITS recommending route detours are greatest in high incident duration scenarios (50 minutes).

Finally, a cost-benefit analysis was performed at the TOC level as well as by individual ITS device. The base year was assumed to be 2012 with a one-time initial construction cost of all current ITS devices in operation. The lifespan of all ITS devices was assumed to be 20 years. O&M costs were applied during the entire analysis and assumed to remain constant. A 3% discount rate was applied. Costs varied according to TOC. The total 2012 construction cost ranged from $27,788, 750 in the STOC to $86,519,413 in SEMTOC for a grand statewide total of $145,073,317. Annual O&M costs ranged from $1,303,177 in WMTOC to $5,426,092 in SEMTOC for a grand statewide total of $8,749,387. Statewide FCP cost was $2,300,000.

The annual benefits estimated included travel delay savings, secondary incident reduction, fuel consumption saving, emission cost saving, crash reduction, Mi Drive value of time, and FCP customer satisfaction. A queuing model was developed to evaluate all 2013 statewide incidents to ascertain the total travel delay, emissions and fuel consumption benefits on the basis of reduced capacity resulting from an incident. Total incident delay savings were highest in SEMTOC at $20,053,665 and the total incident delay saving statewide was $26,344,518. Similarly, SEMTOC dominated the overall fuel consumption and emissions savings, at $1,301,310 and $1,315,257, respectively. Statewide, fuel and emissions savings were $1,705,897 and $1,803,853, respectively. The benefits of secondary incident reduction were evaluated as an additional component of incident delay reduction based on the assumption of TOC managing 20 percent of incidents as secondary incidents. The statewide secondary incident delay savings was $5,268,904. A crash reduction model was developed based on Negative Binomial regression analysis. It was determined that one DMS is likely to reduce 16.6 percent of crashes per year while a single MVDS or CCTV is likely to reduce 1.9 percent of crashes per year. Based on a calculated average crash cost from Michigan crash frequency and severity, the crash reduction saving resulting from ITS was estimated at $20,643,926 statewide. Mi Drive user benefit was estimated based on the number of website hits and browsing duration per access. Total Mi Drive benefit was estimated at $6,646,434 on the basis of user value of time. Utilizing an average value of $60.25 per FCP assist, the total FCP user satisfaction benefit was estimated at $3,273,081. The total statewide annual benefit of ITS was estimated at $65,686,613 for a benefit of 3.16 per dollar spent. To help aid future investment decisions, an investigation was performed of the costs and benefits on an individual ITS device basis. Benefits were appropriated by device according to the utilization proportion of each device by TOC operators, based on phone interviews. Based on a 64 percent, 24 percent and 12 percent split between CCTV, DMS and MVDS, the estimated

BCRs were 3.81, 3.95 and 1.02 per dollar spent, respectively. FCP's benefit was estimated based on the proportion of delay spent and resulted in a 3.82:1 BCR.

8.2 Recommendations

While positive and reinforcing, the final estimated statewide MDOT ITS deployment BCR of 3.16:1 is a conservative estimate compared to similar evaluations performed in other states. The research team believes that this estimate can be greatly improved on execution of a few key recommendations, as follows:

1. The development and strict operation and maintenance of a consistent statewide incident database shared between all three MDOT TOCs will aid in communication between agencies and facilitate ease in cost and benefit estimation for future studies.
2. Deployment of an FCP program in the WMTOC region is expected to result in similar incident duration reductions as witnessed in the SEMTOC region (up to 24.5 minute duration reduction).
3. Future investments should focus on DMS and CCTV installation, while deployment of MVDS needs further studies in conjunction with the coming wake of Connected Vehicle technology.
4. TV and radio media outlets should focus on exposing safety-related travel information and operators should tailor Mi Drive information according to seasonal trends.

These recommendations stem from both challenges faced throughout the duration of the study as well as insight gleaned from the analysis in its entirety.

As a supplemental aid, the research team performed a prescriptive analysis of potential candidate highway segments best suited for future ITS deployment based on a cost-benefit analysis. The corridor analysis determined that to reasonably expect a BCR of ITS greater than 1:1 on any given highway segment, the segment should display an accident density in excess of 31.5 crashes/mile. Based on this finding, a hotspot analysis was performed on 2012 MDOT sufficiency file segments within the STOC region that adhere to this requirement and yet contain no ITS presence as of 2013, as shown in Figure 8-1.

In the figure, regions skewing toward the blue color spectrum display the greatest concentration of highway segments with highest potential for positive ITS benefit. Individual segments are highlighted in black which experienced a 2013 AADT in excess of 25,000, another key indicator of ITS potential according to the simulation corridor cost-benefit analysis. In total, 63 segments were identified and a summary of these segments is included in Appendix 5. Segments are identified according to 2012 MDOT Sufficiency database PR number pointer values.

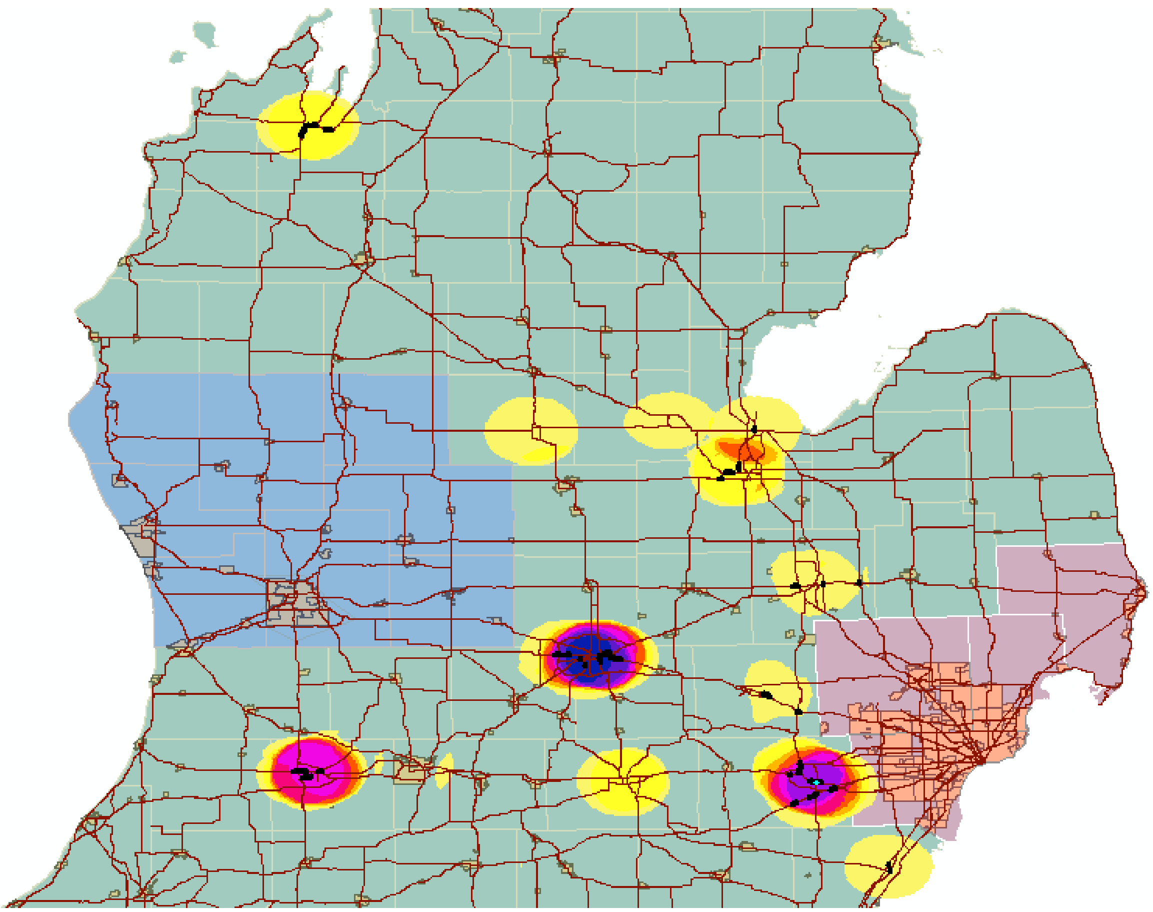


Figure 8-1: ITS Candidate Corridor Hotspots

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Appendix

Appendix 1: Survey Questionnaire

Background Information

1. From which source of information did you find out about this survey?
    a. While exploring information from MiDrive
    b. Invited by E-mail request
    c. Pamphlet/Poster in rest area
    d. Referral card from Freeway Courtesy Patrol
    e. Other

2. How many hours per day you normally travel on freeways?
    a. 0-30 minutes
    b. 30 minutes - 1 hour
    c. 1 hour - 2 hours
    d. 2+ hours

3. What are your major concerns during your daily travel?
    a. Recurrent congestion
    b. Non-recurrent congestion (due to incidents/accidents)
    c. Congestion due to highway work zones
    d. Traffic crashes and safety
    e. Other

4. Are you familiar with each of the following?

	No, I do not know at all.	I have heard about it, but do not know well.	Yes, I know well.
Freeway Courtesy Patrol (FCP)	☐	☐	☐
Dynamic Message Signs (DMS)	☐	☐	☐
Travel Time Signs (TTS)	☐	☐	☐
Highway Advisory Radio (HAR)	☐	☐	☐
Closed-Circuit Television Cameras (CCTV)	☐	☐	☐
Road Weather Information Systems (RWIS)	☐	☐	☐
MiDrive traffic website or mobile application	☐	☐	☐

Pre-trip Information (MiDrive)

5. How often do you typically obtain travel information before your departure from the following sources?

	Daily	Weekly	Monthly	Yearly	Never
MiDrive	❑	❑	❑	❑	❑
Other Websites (e.g. Google Maps)	❑	❑	❑	❑	❑
Television	❑	❑	❑	❑	❑
Radio	❑	❑	❑	❑	❑

6. Please rate the importance of the following types of information before your departure?

	No Need	Not Important	Good to Have	Important	Essential
Travel Time	❑	❑	❑	❑	❑
Current Speeds	❑	❑	❑	❑	❑
Road Work Locations	❑	❑	❑	❑	❑
Incident Locations	❑	❑	❑	❑	❑
Road Weather Information	❑	❑	❑	❑	❑
Planned Special Events	❑	❑	❑	❑	❑
Freeway Camera Images	❑	❑	❑	❑	❑

7. Based on the types of travel information in the previous question, how often do you typically make the following changes in your travel behaviors?

	Never	Sometimes	Often	Very Frequently	N/A
Reschedule the trip	❑	❑	❑	❑	❑
Change departure time	❑	❑	❑	❑	❑
Change route to use	❑	❑	❑	❑	❑
Change transportation mode	❑	❑	❑	❑	❑

En Route Trip Information (MiDrive)

8. How frequently do you use the following devices to receive travel information while traveling?

	Never	Sometimes	Often	Very Frequently	N/A
Smart Phone	☐	☐	☐	☐	☐
Car Navigation	☐	☐	☐	☐	☐
Radio	☐	☐	☐	☐	☐
Dynamic Message Signs	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐

9. How helpful are the following types of information displayed on Dynamic Message Signs?

	Very Unhelpful	Unhelpful	Somewhat Helpful	Very Helpful	N/A
Accident Ahead: Expect Congestion	☐	☐	☐	☐	☐
Incident Ahead: Use Detour Exit 35	☐	☐	☐	☐	☐
30 Minutes to Battle Creek	☐	☐	☐	☐	☐
To Detroit: 30 Minutes via I-94, 25 Minutes via M-14	☐	☐	☐	☐	☐

10. Which of the following were impacts of Dynamic Message Signs (DMS) on your travel? (Select all that apply)

a. Helped me in revising my schedule by providing delay information
b. Helped me in avoiding congestion by guiding alternative routes
c. Reduced my anxiety by informing reasons for congestion
d. Did not impact on my travel
e. I have not had any experience with DMS
f. Other

11. How much do you trust the information displayed on Dynamic Message Signs (DMS)?

a. Very trustful
b. Somewhat trustful
c. Not trustful
d. I do not know

12. Have you ever been assisted by Freeway Courtesy Patrol (FCP) services?
    a. Yes
    b. No (Skip questions 13-15)

13. How long have you waited for FCP service?
    a. Less than 15 minutes
    b. 15-30 minutes
    c. 30-45 minutes
    d. 45-60 minutes
    e. More than 60 minutes

14. Were you satisfied with FCP service?
    a. I was satisfied with the response time and service.
    b. I was satisfied, but hoped for quicker service.
    c. I had to wait too long for service.

15. How long would you be willing to wait for the service?
    a. Less than 15 minutes
    b. 15-30 minutes
    c. 30-45 minutes
    d. 45-60 minutes
    e. More than 60 minutes

Additional Information

16. Please provide your comments or suggestions for better ITS services:

17. Please enter your home zip code:

18. What is your sex?
    a. Male
    b. Female

19. What is your age?
    a. 16-20
    b. 21-35
    c. 36-50
    d. 51-65
    e. Over 65

20. Please provide your contact information if you are willing to be contacted regarding your comments:
First Name

Last Name

Phone

Email Address

Appendix 2: MDOT ITS Performance Data

Table A-1: 2008-2013 SEMTOC Number of FCP Assists

SEMTOC Annual Number of FCP Assists	2008		2009		2010		2011		2012		2013	
Type of Assist	Number of Assists	Percent of Assists	Number of Assists	Percent of Assists	Number of Assists	Percent of Assists	Number of Assists	Percent of Assists	Number of Assists	Percent of Assists	Number of Assists	Percent of Assists
Mechanical	10873	22%	11561	23%	11705	23%	11525	23%	8935	19%	4216	9%
Flat Tire	9120	18%	9377	18%	9218	18%	9294	19%	7264	16%	5151	11%
Debris	1773	4%	2868	6%	3172	6%	2602	5%	2486	5%	2112	4%
Accident	2961	6%	2483	5%	2443	5%	2395	5%	3185	7%	5909	12%
Abandoned Vehicles	13826	28%	13959	27%	12777	25%	10988	22%	10489	23%	10172	21%
Out of Gas	6851	14%	5780	11%	6731	13%	7559	15%	6604	14%	6234	13%
Other*	1662	3%	5352	10%	5402	11%	5163	10%	7653	16%	5131	11%
Declined											2960	6%
Gone on Arrival	2645	5%									3790	8%
Non-FCP Tow											1728	4%
Multiple											966	2%
Total	49498	100%	51384	100%	51452	100%	49571	100%	46619	100%	48369	100%

Table A-2: 2008-2013 Annual SEMTOC FCP Performance

	1st Shift (10 PM - 6 AM)	2nd Shift (6AM-2PM)	3rd Shift (2-10 PM)	Saturday (All 3)	Sunday (All 3)
	2008				
Average Response Time	13.2	10.1	10	12.8	14.3
Average Clearance Time	9.9	11.6	11.2	8.7	8.3
	2009				
Average Response Time	13.3	10.4	11.4	14.6	14.3
Average Clearance Time	8.5	10.2	10.5	7.6	7.7
	2010				
Average Response Time	15.6	11.3	12.7	14.8	14.9
Average Clearance Time	9.5	9.4	9.4	7.8	7.8
	2011				
Average Response Time	19.2	12.4	14.7	17.9	17.5
Average Clearance Time	11.3	9.2	9.4	9.7	9.9
	2012				
Average Response Time	18.9	11.4	13.6	17	17.3
Average Clearance Time	**10.5**	**7.4**	**9.5**	9.7	9.6
	2013				
Average Response Time	20.6	12.9	15.6	18.7	17.8
Average Clearance Time	12.5	9.6	9.8	12.4	12

Table A-3: 2009-2013 WMTOC Incidents by Type

WMTOC Incidents by Type	2009	2010	2011	2012	2013
Abandoned Vehicle	5%	17%	10%	11%	8%
Disabled Vehicle	39%	42%	31%	29%	29%
Debris	1%	2%	2%	2%	2%
Crashes	53%	37%	58%	57%	61%
Other	1%	1%	1%	1%	1%
Total	606	1192	1015	1373	1477

Appendix 3: MDOT ITS Cost Data

Table A-4: WMTOC Costs

		Previously installed devices	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Construction Phase Costs	Construction Contract for ITS Devices		$2,815,258	$-	$982,454	$836,209	$439,494	$9,240,291	$-	$1,056,827
	DMS Cost (statewide procurement contract)		$-	$-	$-	$-	$-	$-	$-	$53,000
	Supporting Infrastructure Construction Cost		$ -	$-	$-	$-	$-	$845,741	$-	$-
	New CCTV Quantity	10	7	0	0	6	3	41	0	0
	New MVDS Quantity	0	0	0	42	0	0	78	0	0
	New DMS Quantity	7	3	0	0	1	1	15	0	0
	Estimated Design Cost		$408,212	$-	$142,456	$121,250	$63,727	$1,462,475	$-	$160,925
	Estimated System Manager Cost		$239,297	$-	$83,509	$71,078	$37,357	$857,313	$-	$94,335
Maintenance & Operations Costs	Maintenance Contract Cost / As-Needed System Manager Cost		$45,000	$45,000	$81,000	$113,833	$97,520	$60,112	$363,702	$329,370
	TOC Operations Contract Cost		$166,376	$332,752	$326,903	$357,602	$370,444	$399,665	$527,662	$472,141
	Utility Cost (power)	$21,352	$33,933	$33,933	$38,289	$47,118	$52,154	$130,736	$130,736	$130,736
	Utility Cost (communication)	$16,402	$27,199	$27,199	$42,319	$51,009	$55,533	$145,929	$145,929	$145,929
	MDOT Staff Cost (3 full-time)		$225,000	$225,000	$225,000	$225,000	$225,000	$225,000	$225,000	$225,000

Table A-5: SEMTOC Costs

		Previously installed devices	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Construction Phase Costs	Construction Contract for ITS Devices		$-	$461,854	$-	$8,452,901	$5,317,751	$11,464,490	$10,210,048	$8,443,289
	DMS Cost (statewide procurement contract)		$-	$-	$-	$-	$-	$636,000	$-	$742,000
	Supporting Infrastructure Construction Cost		$-	$-	$-	$-	$499,288	$2,897,817	$5,594,083	$3,380,763
	New CCTV Quantity	92	0	14	0	34	7	22	17	30
	New MVDS Quantity	52	0	0	0	56	17	67	49	33
	New DMS Quantity	48	0	0	0	14	7	12	6	11
	New TTS Quantity	0	0	0	0	0	0	0	0	1
	Estimated Design Cost		$-	$66,969	$-	$1,225,671	$843,471	$2,174,755	$2,291,599	$1,822,078
	Estimated System Manager Cost		$-	$39,258	$-	$718,497	$494,448	$1,274,856	$1,343,351	$1,068,114
Maintenance & Operations Costs	Maintenance Contract Cost		$500,000	$500,000	$613,144	$1,839,432	$2,283,157	$2,329,000	$1,958,571	$1,983,005
	TOC Operations Contract Cost		$1,404,051	$1,197,030	$1,581,544	$1,440,204	$1,728,350	$1,799,884	$1,963,979	$2,022,946
	Utility Cost (power)	$181,419	$181,418.96	$199,116	$199,116	$265,324	$284,646	$334,336	$368,373	$423,510
	Utility Cost (communication)	$163,714	$163,714.03	$183,149	$183,149	$255,547	$273,905	$332,885	$376,284	$434,130
	MDOT Staff Cost (7.5 full-time)		$562,500	$562,500	$562,500	$562,500	$562,500	$562,500	$562,500	$562,500
	Freeway Courtesy Patrol Contract Cost		$1,933,333	$1,933,333	$1,933,333	$1,933,333	$1,933,333	$1,933,333	$1,933,333	$1,933,333

Table A-6: STOC Costs

		Previously installed devices	2006	2007	2008	2009	2010	2011	2012	2013
Construction Phase Costs	Construction Contract for ITS Devices		$-	$453,850	$-	$-	$605,438	$9,386,551	$5,209,444	$3,844,366
	DMS Cost (statewide procurement contract)		$-	$-	$-	$-	$-	$-	$530,000	$477,000
	Supporting Infrastructure Construction Cost		$-	$-	$-	$-	$-	$-	$-	$-
	New CCTV Quantity	0	0	0	0	0	0	19	21	16
	New MVDS Quantity	0	0	0	0	0	0	31	24	10
	New DMS Quantity	0	0	2	0	0	4	16	14	9
	New TTS Quantity	0	0	0	0	0	0	0	3	2
	Estimated Design Cost		$-	$65,808	$-	$-	$87,789	$1,361,050	$832,219	$626,598
	Estimated System Manager Cost		$-	$38,577	$-	$-	$51,462	$797,857	$487,853	$367,316
Maintenance & Operations Costs	Maintenance Contract Cost		$-	$-	$-	$-	$105,547	$220,000	$324,586	$414,211
	TOC Operations Contract Cost		$-	$-	$-	$-	$-	$638,641	$698,043	$883,974
	Utility Cost (power)		$-	$2,489	$2,489	$2,489	$7,466	$54,609	$101,376	$134,045
	Utility Cost (communication)		$-	$720	$720	$720	$2,160	$45,456	$89,368	$119,139
	MDOT Staff Cost (6.25)		$-	$18,750	$18,750	$18,750	$56,250	$468,750	$468,750	$468,750
	Freeway Courtesy Patrol Contract Cost		$-	$-	$-	$-	$-	$-	$-	$366,667

Table A-7: IPO Costs

		2006	2007	2008	2009	2010	2011	2012	2013
MDOT Staff Cost (4.5)		$337,500	$337,500	$337,500	$337,500	$337,500	$337,500	$337,500	$337,500
IPO Support Contract Cost		$250,000	$250,000	$250,000	$250,000	$250,000	$250,000	$250,000	$250,000

Table A-8: WMTOC Project Costs

Year	MDOT Project Number	Project Description	DMS	CCTV	MVDS	Smart Sign	RWIS	Final Construction Cost
2006	72044	Implementation of WMTOC and ITS Installation along I-96, I-196	3	7	0			$2,815,258.29
		Subtotal	**3**	**7**	**0**	**0**	**0**	
2007								
		Subtotal	**0**	**0**	**0**	**0**	**0**	
2008	87663	Grand Rapids Detector	0	0	42			$982,453.87
		Subtotal	**0**	**0**	**42**	**0**	**0**	
2009	87662	ITS Repairs along US-131, I-96, I-196	1	6				$836,209.08
		Subtotal	**1**	**6**	**0**	**0**	**0**	
2010	100377	ITS Installation along US-31	1	3				$439,493.54
		Subtotal	**1**	**3**	**0**	**0**	**0**	
2011	100492	GVMC ITS Expansion	6	41	78			$6,952,319.35
	105798	Fiber Installation along I-96, M-6						$845,740.78
	105799	ITS Installation on I-96, I-196, M-6	9					$2,287,971.83
		Subtotal	**15**	**41**	**78**	**0**	**0**	
2013	106328	DMS replacement & repair along US-131, I-96, I-196	1					$690,464.11
	109687	NB Auxiliary Lane from Leonard to Ann	-1	0	0			$366,362.83
		Subtotal	**0**	**0**	**0**	**0**	**0**	
		Grand Total	**20**	**57**	**120**	**0**	**0**	

Table A-9: SEMTOC Project Costs

Year	MDOT Project Number	Project Description	DMS	CCTV	MVDS	Smart Sign	RWIS	Final Construction Cost (ITS only, where applicable)
2006								
		Subtotal	**0**	**0**	**0**	**0**	**0**	
2007	86518	ITS Improvements along M-10	0	14	0			$461,853.84
		Subtotal	**0**	**14**	**0**	**0**	**0**	
2008								
		Subtotal	**0**	**0**	**0**	**0**	**0**	
2009	47171	ITS Portion of I-96, I-696 Freeway Reconstruction	1	0	23			$2,146,314.23
	59637	ITS Installation along I-69, I-94, I-96, I-275	13	34	33			$6,306,586.38
		Subtotal	**14**	**34**	**56**	**0**	**0**	
2010	51492	ITS Portion of M-10 Freeway Reconstruction	0		2			$364,296.73
	88401	ITS Communications Upgrade on I-94, I-75, and I-696						$499,288.09
	55850	ITS Portion of M-59 Freeway Reconstruction	2	5	6			$1,447,495.80
	100535	Speed Warning Systems	5	2	9			$1,698,464.90
	101266	DMS Replacement along I-75, I-94, I-375, I-696 and M-10	0					$1,807,493.77
		Subtotal	**7**	**7**	**17**	**0**	**0**	

Year	MDOT Project Number	Project Description	DMS	CCTV	MVDS	Smart Sign	RWIS	Final Construction Cost (ITS only, where applicable)
2011	59196	ITS Installation along I-94	0	4	7			$2,776,474.45
	55663	ITS Portion of I-75 Freeway Reconstruction			3			$270,296.31
	103457	ITS Communication Tower Replacement along I-696						$2,897,816.95
	100725	ITS Installation along I-94	5	14	32			$3,533,767.39
	108732	ITS Upgrades along I-75, I-275, I-696, M-10			13			$1,214,881.98
	76901	ITS Portion of M-8 Freeway Reconstruction	1	2	3			$1,107,173.82
	76902	ITS Portion of M-39 Freeway Reconstruction	6	2	9			$2,561,896.41
		Subtotal	**12**	**22**	**67**	**0**	**0**	
2012	37795	ITS Portion of I-75, I-96 Freeway Reconstruction	0	1	1			$1,180,406.08
	83143	ITS Portion of I-696 Freeway Reconstruction			4			$119,138.68
	86516	ITS Communication Upgrades along I-96	2	9	33			$4,309,014.77
	102639	ITS Communication Towers along I-696						$1,765,793.59
	84570	9 Mile Rd Curve Warning System	4	3	8			$2,151,111.03
	87981	ITS Installation along I-75		4	3			$507,862.85
	111903	ITS Communication Tower Reconstruction						$3,828,289.58
	87828	ITS Installation in Metro Region	0					$1,942,515.00
		Subtotal	**6**	**17**	**49**	**0**	**0**	

Year	MDOT Project Number	Project Description	DMS	CCTV	MVDS	Smart Sign	RWIS	Final Construction Cost (ITS only, where applicable)
2013	106649	Metro I-75 ITS	6	13	7			$2,080,389.96
	107609	ITS Fiber Installation along M-10		2				$624,369.76
	111643	ITS Installation along I-275, I-94	5	15	26			$5,676,057.77
	110938	Fiber Installation along M-10, I-75, I-94		0	0			$3,380,763.09
	106682	Triangle Phase I	0	0		1		$62,471.25
		Subtotal	**11**	**30**	**33**	**1**	**0**	
		Grand Total	**50**	**124**	**222**	**1**	**0**	

Table A-10: STOC Project Costs

Year	MDOT Project Number	Project Description	DMS	CCTV	MVDS	Smart Sign	RWIS	Final Construction Cost
2006								
		Subtotal	**0**	**0**	**0**	**0**	**0**	
2007	**86806**	ITS Installation along I-75	2					$453,850.16
		Subtotal	**2**	**0**	**0**	**0**	**0**	
2008								
		Subtotal	**0**	**0**	**0**	**0**	**0**	
2009								
		Subtotal	**0**	**0**	**0**	**0**	**0**	
2010	**104021**	ITS Installation along M-28, US-2	4					$605,438.26
		Subtotal	**4**	**0**	**0**	**0**	**0**	
2011	**87775**	Genesee Phase I	2	2	18			$2,684,629.65
	88138	Brighton ITS	7	10	5			$2,525,017.40
	100523	ITS Installation along I-75, I-675	3	7	8			$1,845,515.27
	105846	ITS Installation In Superior Region	4				~~12~~	$2,331,388.34
		Subtotal	**16**	**19**	**31**	**0**	**0**	

Year	**MDOT Project Number**	**Project Description**	**DMS**	**CCTV**	**MVDS**	**Smart Sign**	**RWIS**	**Final Construction Cost**
2012	**102169**	Southwest Region ITS Expansion	4	10	5			$1,819,684.73
	102226	DMS in North/Superior Region	5					N/A
	105741	RWIS stations in North Region			6		~~11~~	$608,872.55
	107039	ITS Installation along US-127, US-10	2					$262,593.21
	107179	Ann Arbor ITS	8	11	13	3		$2,518,293.59
		Subtotal	**14**	**21**	**24**	**3**	**0**	
2013	**106682**	Triangle Phase I	2	10		2		$1,157,556.75
	109707	SW 4 DMS	4		4			$708,333.92
	110762	Lansing ITS	3	6	6			$2,047,415.86
		Subtotal	**9**	**16**	**10**	**2**	**0**	
		Grand Total	**45**	**56**	**65**	**5**	**0**	

Table A-11: Construction Costs by Device Type and TOC

	WMTOC	**SEMTOC**	**STOC**	**Total**
New CCTV Quantity	57	124	56	237
New MVDS Quantity	120	222	65	407
New DMS Quantity	20	50	45	115
New TTS Quantity	0	1	5	6
Total	**197**	**397**	**171**	**765**
ITS Construction Cost	$15,423,533	$45,728,333	$20,506,649	$81,658,515
Supporting Infrastructure Construction Cost	$845,741	$12,371,951	$-	$13,217,692
Estimated Design Cost	$2,359,045	$8,424,541	$2,973,464	$13,757,050
Estimated System Manager Cost	$1,382,888	$4,938,524	$1,743,065	$8,064,478
Total Construction Cost	**$20,011,207**	**$71,463,350**	**$25,223,178**	**$116,697,735**
Average Construction Cost per Device	**$101,580**	**$180,008**	**$147,504**	**$152,546**
Average Construction Cost per CCTV	**$102,226**	**$195,197**	**$141,945**	**$160,254**
Average Construction Cost per MVDS	**$79,420**	**$128,126**	**$45,853**	**$100,626**
Average Construction Cost per DMS	**$232,694**	**$373,512**	**$307,037**	**$323,010**
Average Construction Cost per TTS	**n/a**	**$139,304**	**$95,422**	**$102,736**

Table A-12: Operations & Maintenance Costs by Device Type and TOC

	WMTOC	SEMTOC	STOC	Total
Total CCTV Quantity	301	1162	115	1578
Total MVDS Quantity	486	1096	151	1733
Total DMS Quantity	134	541	115	790
Total TTS Quantity	0	1	8	9
Total (Device-Year)	921	2800	389	4110
Maintenance Contract Cost	$1,135,537	$12,006,309	$1,064,344	$14,206,190
TOC Operations Cost	$2,953,545	$13,137,988	$2,220,658	$18,312,191
Utility Cost (power)	$597,636	$2,255,840	$304,964	$3,158,440
Utility Cost (communication)	$641,047	$2,202,764	$258,283	$3,102,093
MDOT Staff Cost	$1,800,000	$4,500,000	$1,518,750	$7,818,750
IPO Cost (MDOT + Support Contract)	$1,566,667	$1,566,667	$1,566,667	$4,700,000
Total O&M Cost	$8,694,432	$35,669,568	$6,933,664	$51,297,664
Average O&M Cost per Device	$9,440	$12,739	$17,824	$12,481
Freeway Courtesy Patrol Cost	$-	$15,466,667	$366,667	$15,833,333

Appendix 4: Simulation Corridor Data

Table A-13: Simulation Study Site 2013 Characteristics

Study Site	Site Characteristics																				
	Corridor Length	Network Length	ITS Deployment					Crash Summary						Incident Summary		Assist Summary		Avg. AADT	Avg % Comm. Veh.
			DMS	CCTV	TTS	MVDS	FCP	Total	K	A,B,C	PDO	On DMS Seg.	On Other ITS Seg.	Total	Average Duration	Total	Average Duration		
SEMTOC SS1	5.25	20.755	8	3	0	15	YES	1111	2	253	856	370	650	654	48.19	1886	20.18	70407	5%
SEMTOC SS2	3.3	10.104	5	6	0	10	YES	360	1	75	284	91	186	274	43.11	682	25.31	52883	8%
SEMTOC SS3	7	33.503	3	10	0	23	YES	1054	0	171	883	151	561	604	49.67	800	24.67	68564	6%
WMTOC SS4	4.9	15.031	5	10	0	25	NO	826	1	171	654	194	241	369	44.67	0	0	46815	6%
WMTOC SS5	5.7	22.193	4	9	0	32	NO	710	2	136	572	132	539	333	43.04	0	0	34480	5%
STOC SS6	6.75	28.178	2	5	0	3	YES	305	0	46	259	55	148	33	39.76	367	17.58	33475	6%
STOC SS	4.8	26.744	1	1	0	4	NO	259	0	47	212	26	79	20	82.85	7	100	27791	6%

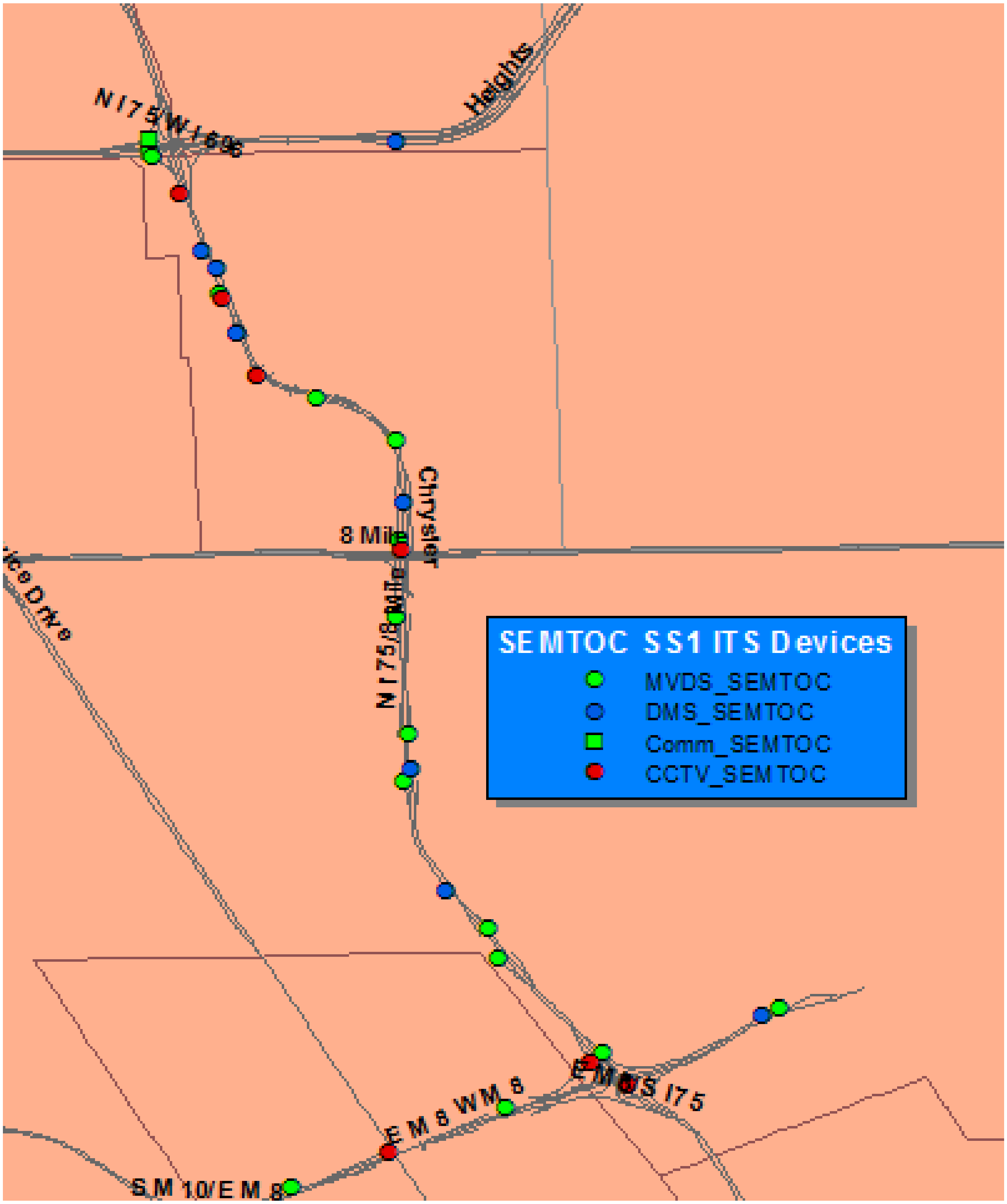

Figure A-1: 2013 SEMTOC SS1 ITS Devices

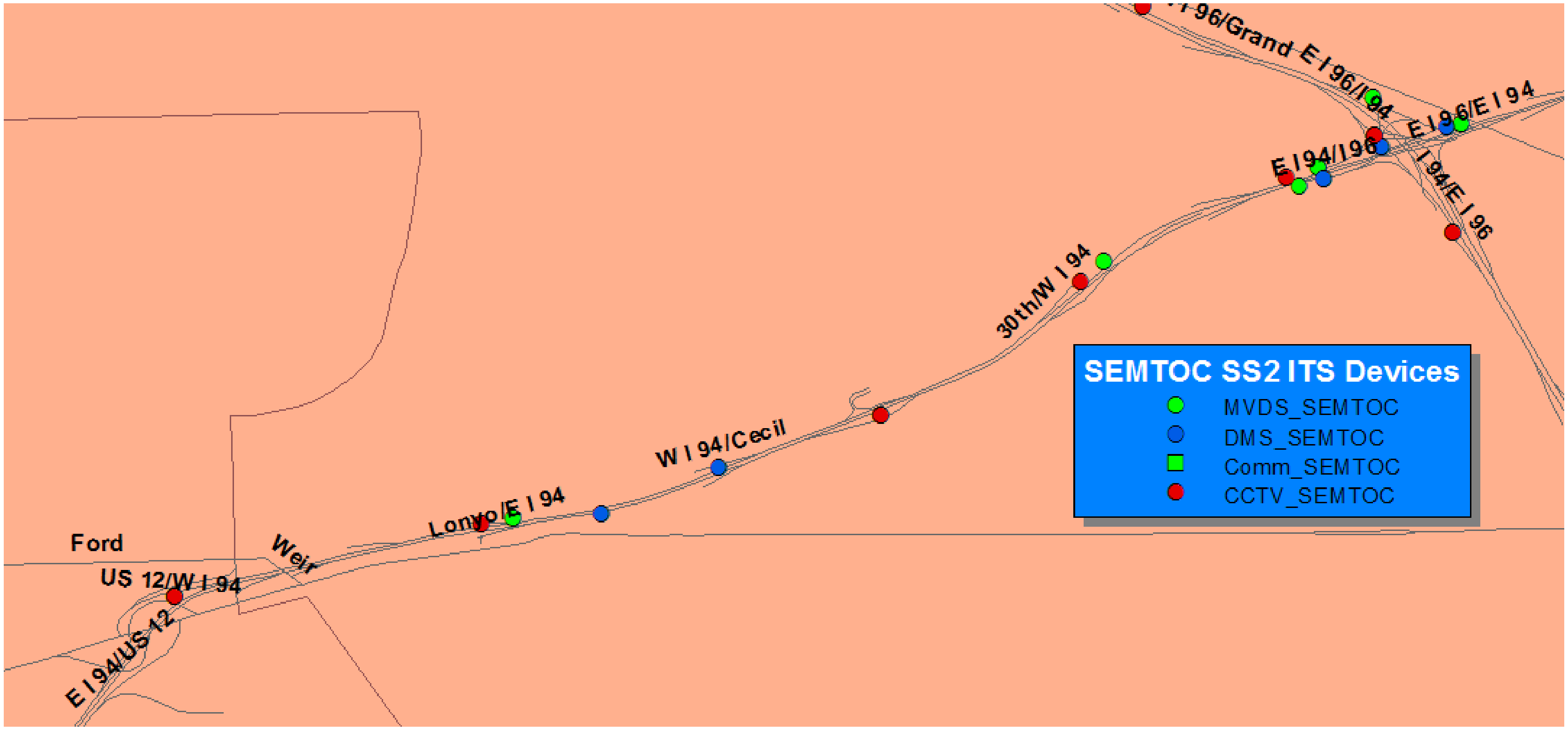

Figure A-2: 2013 SEMTOC SS2 ITS Devices

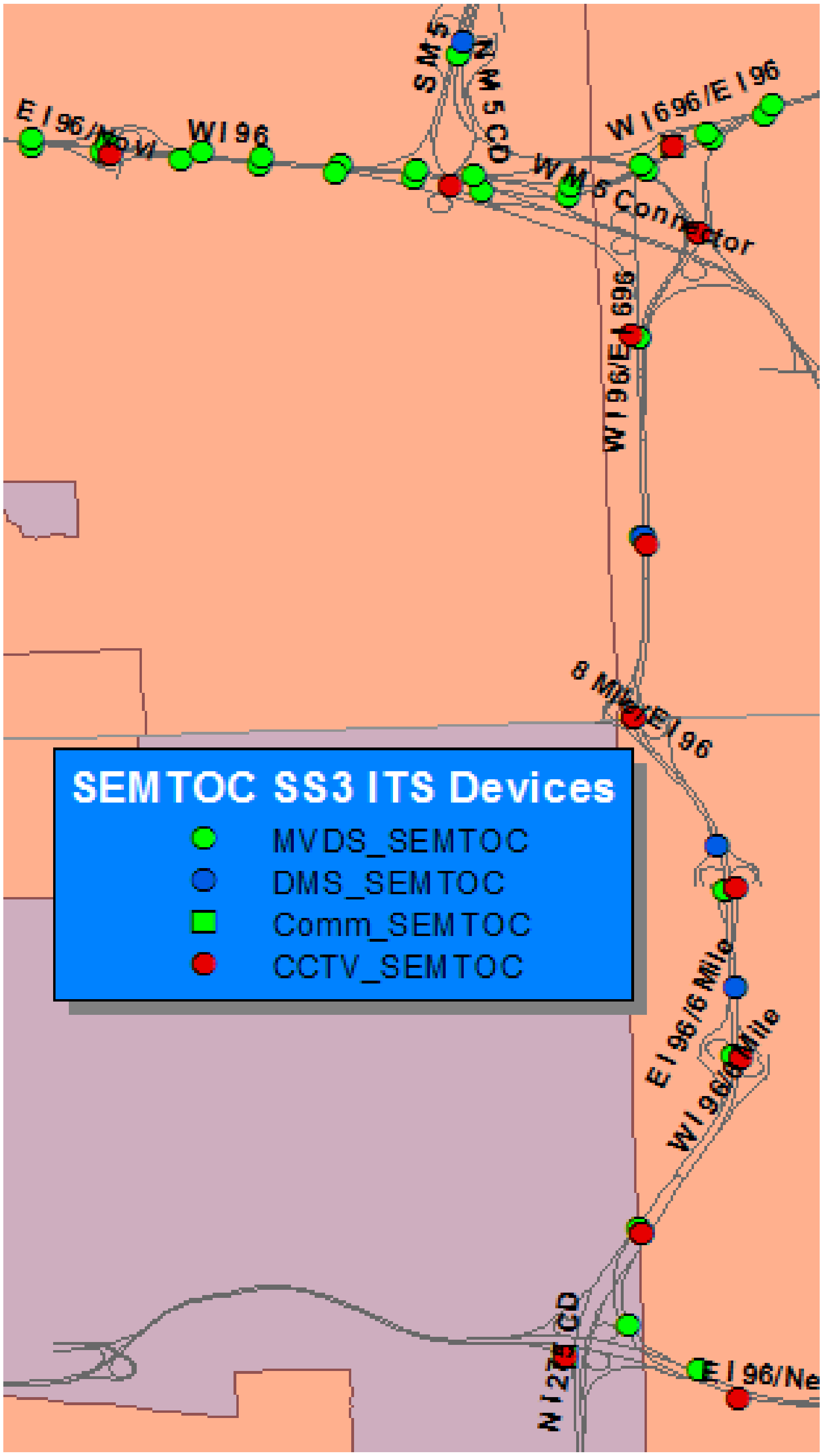

Figure A-3: 2013 SEMTOC SS3 ITS Devices

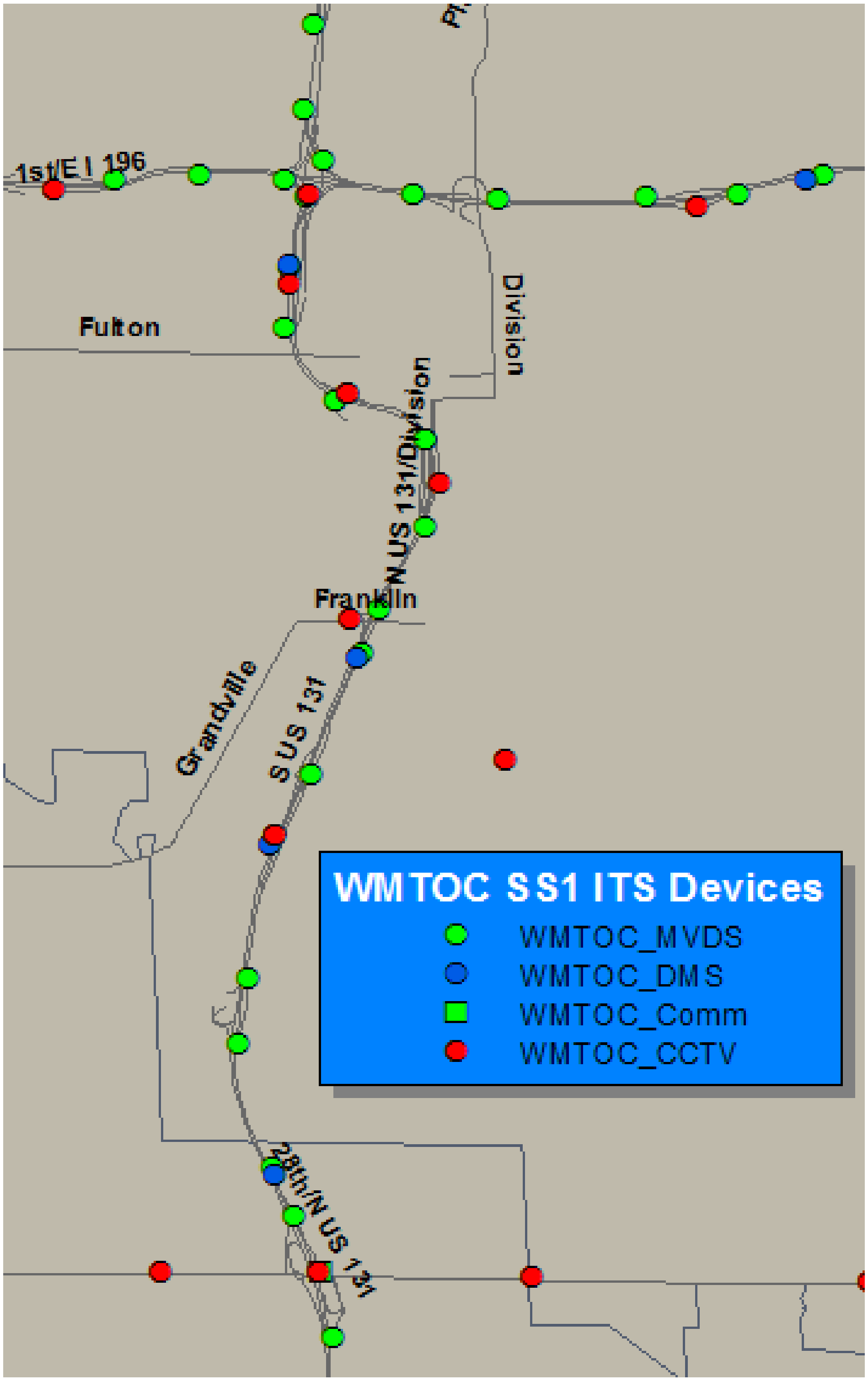

Figure A-4: 2013 WMTOC SS4 ITS Devices

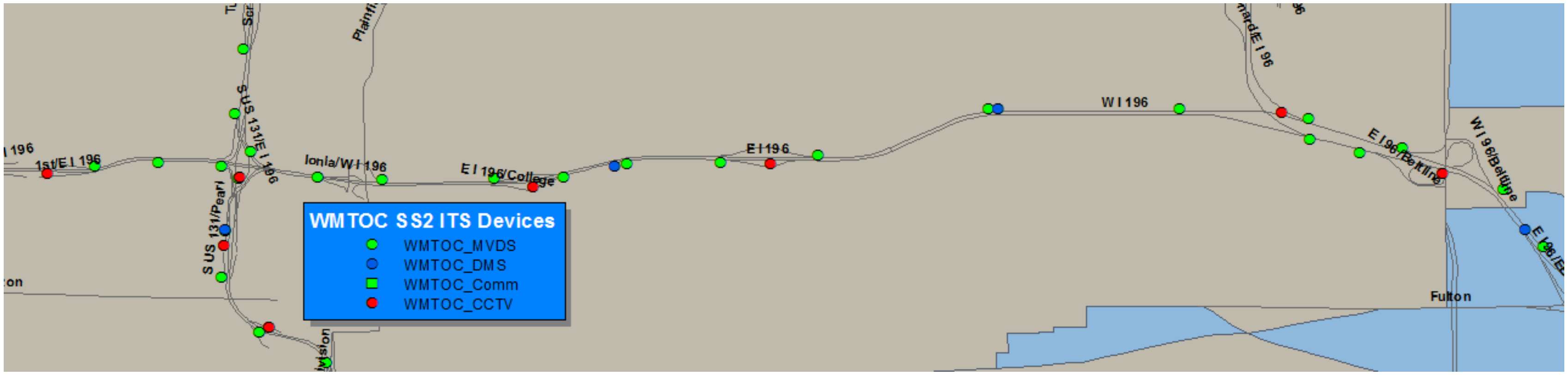

Figure A-5: 2013 WMTOC SS5 ITS Devices

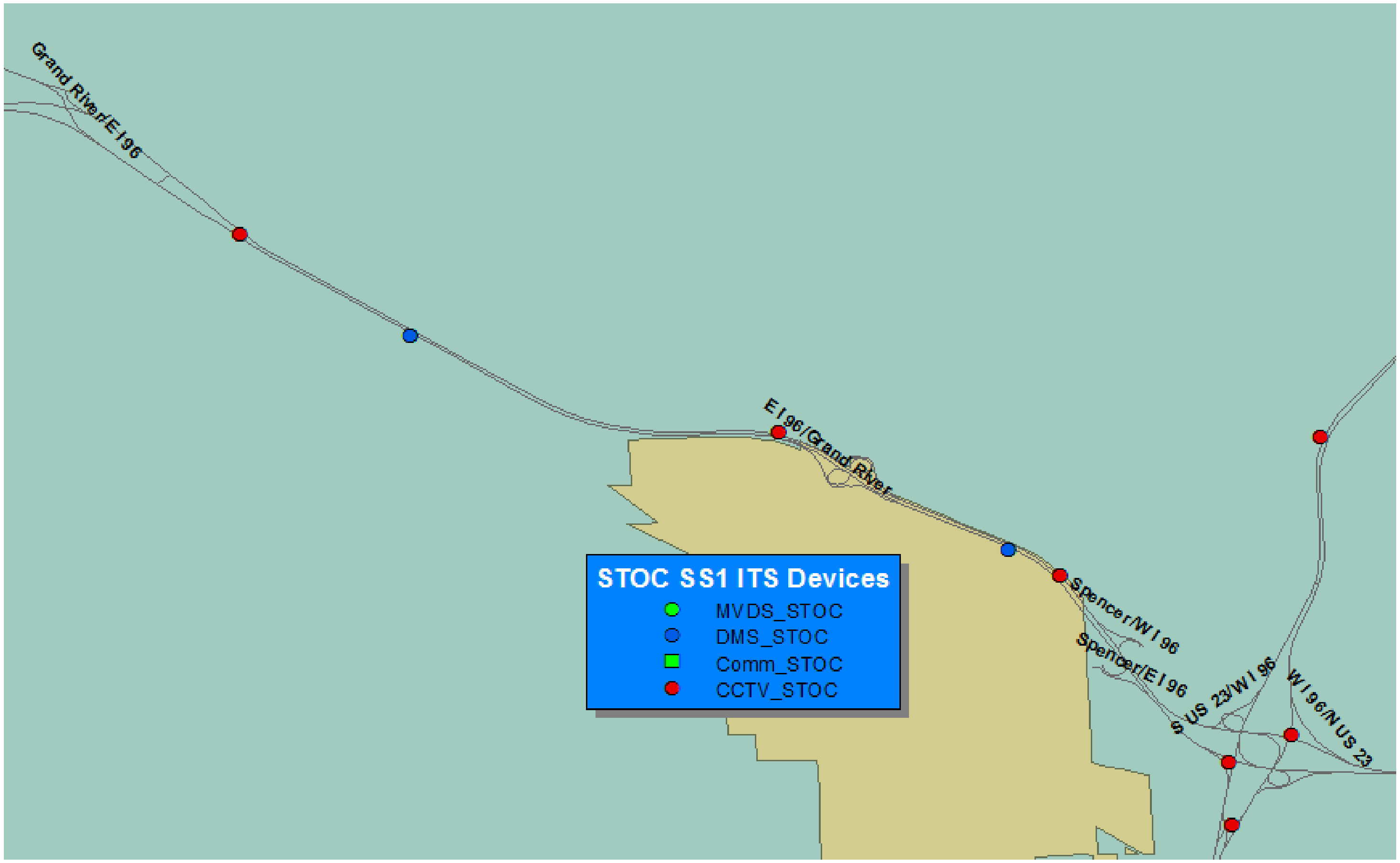

Figure A-6: 2013 STOC SS6 ITS Devices

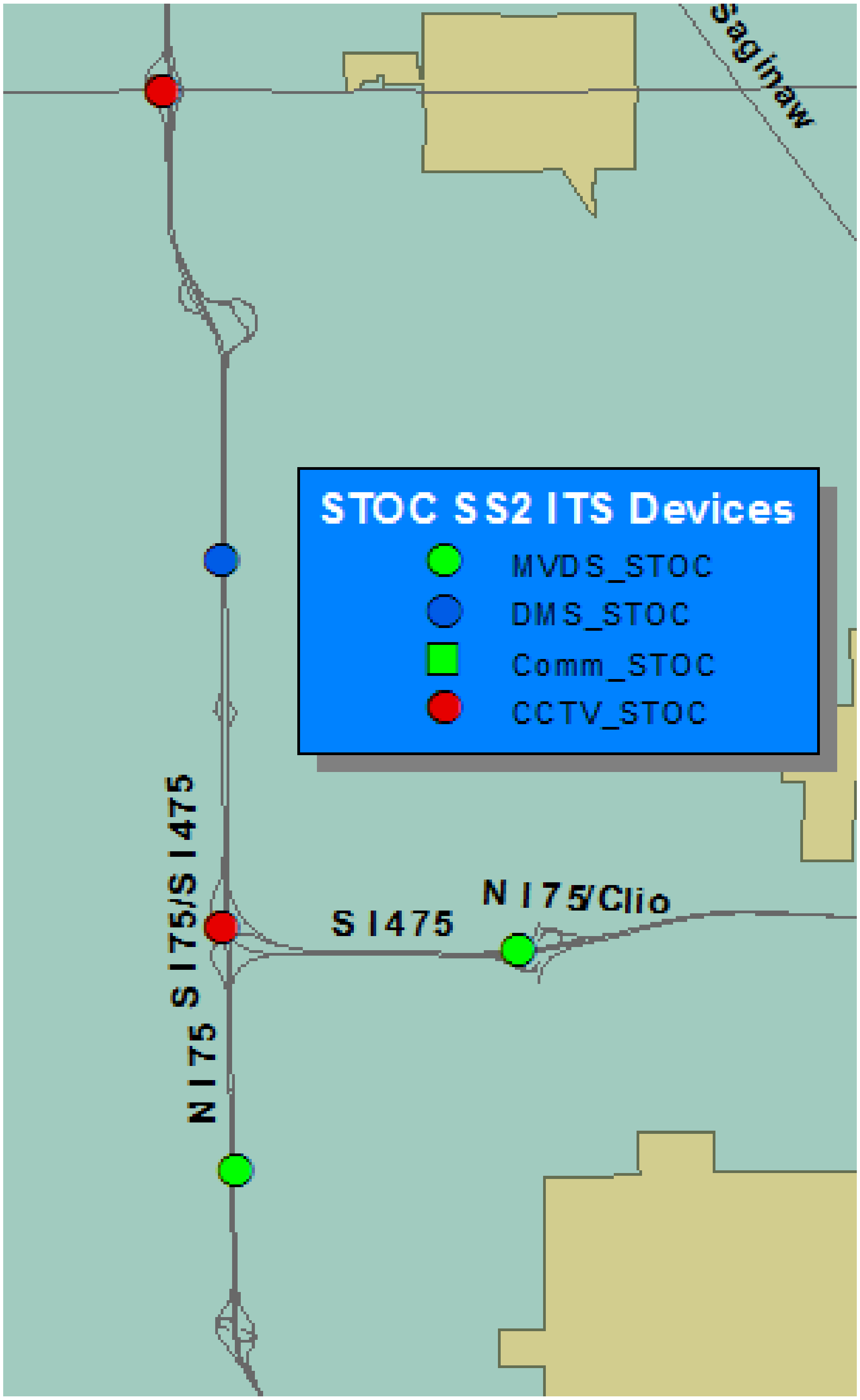

Figure A-7: 2013 STOC SS7 ITS Devices

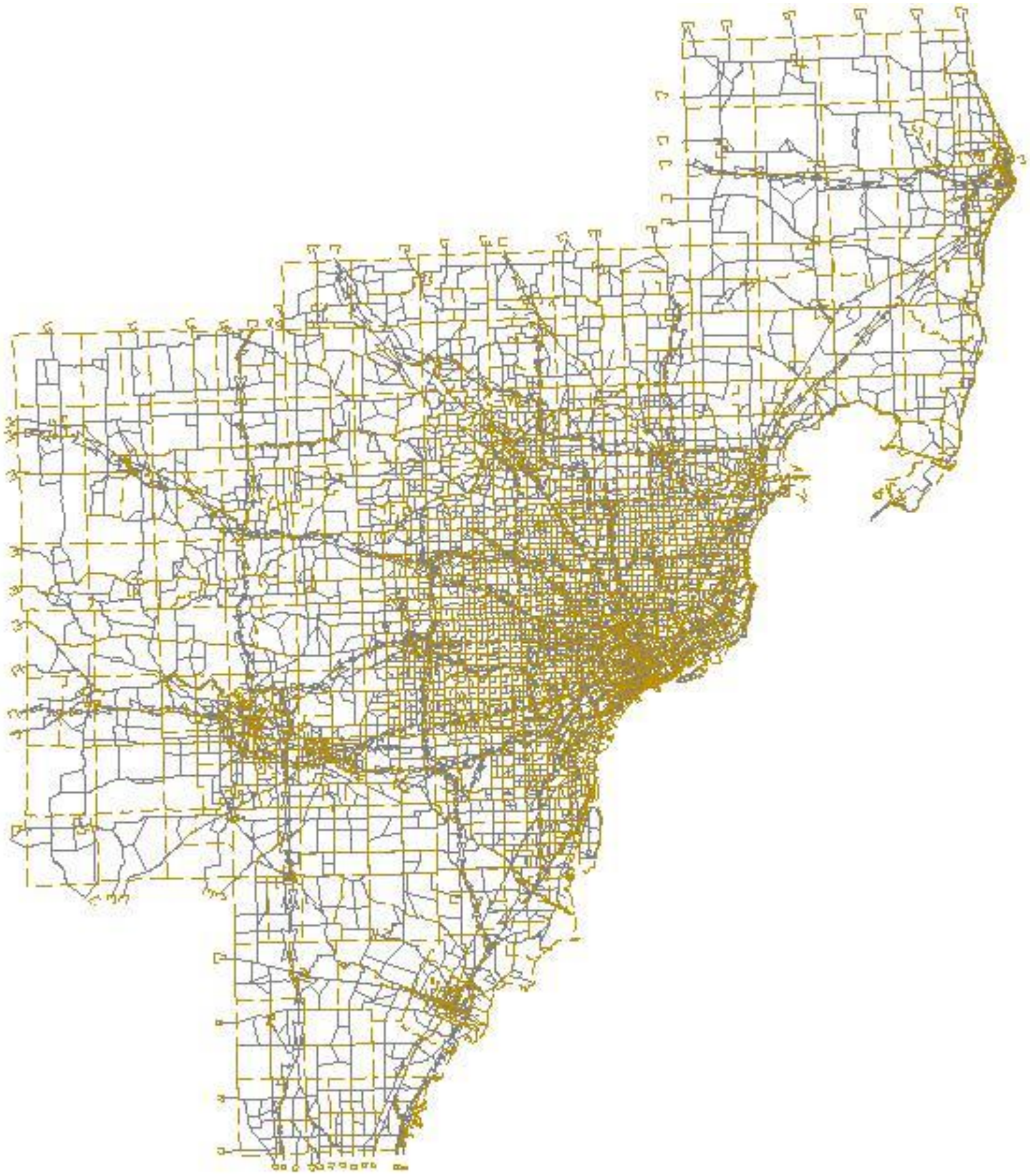

Figure A-8: SEMCOG TransCAD Model

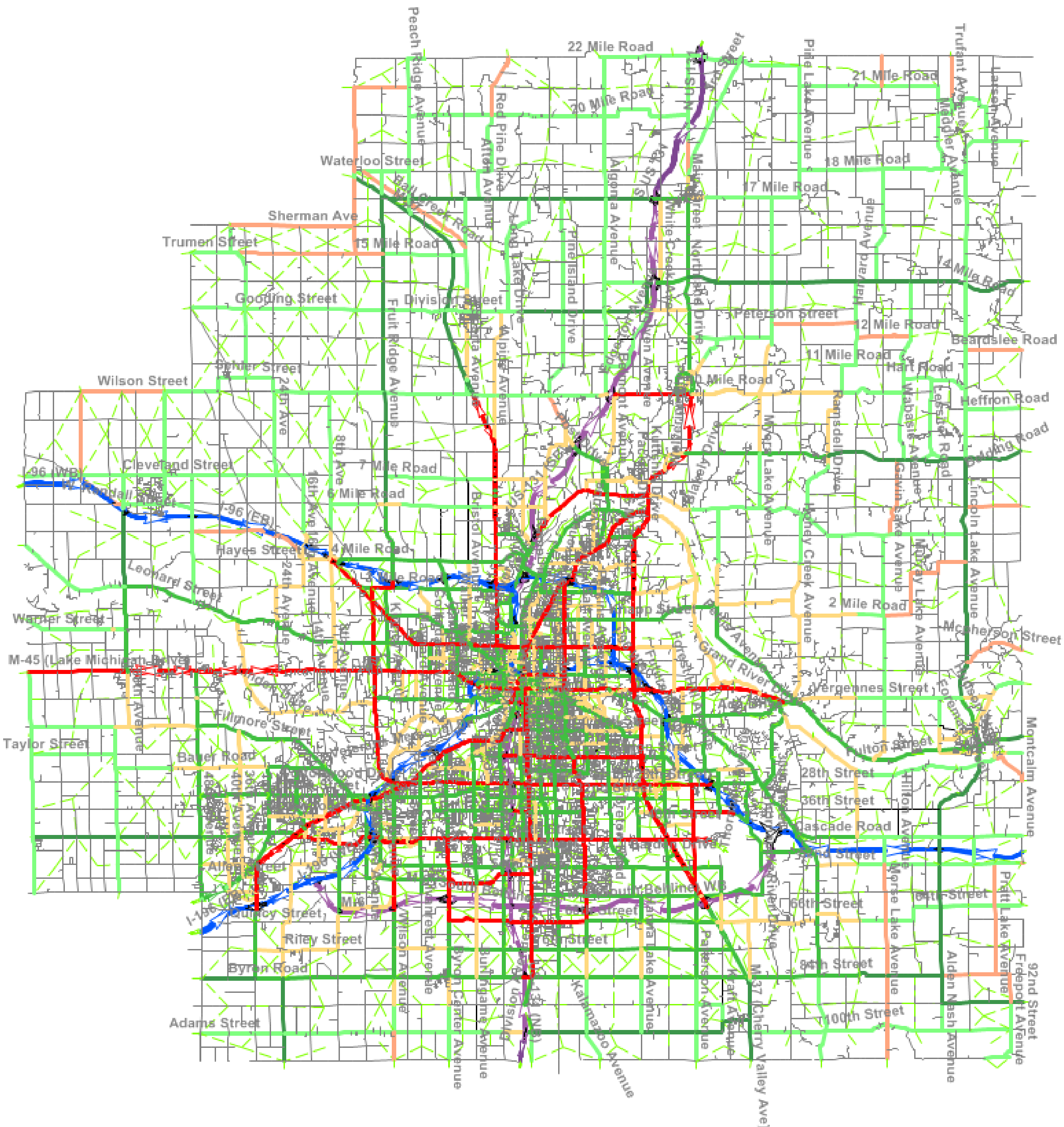

Figure A-9: GVMC TransCAD Model

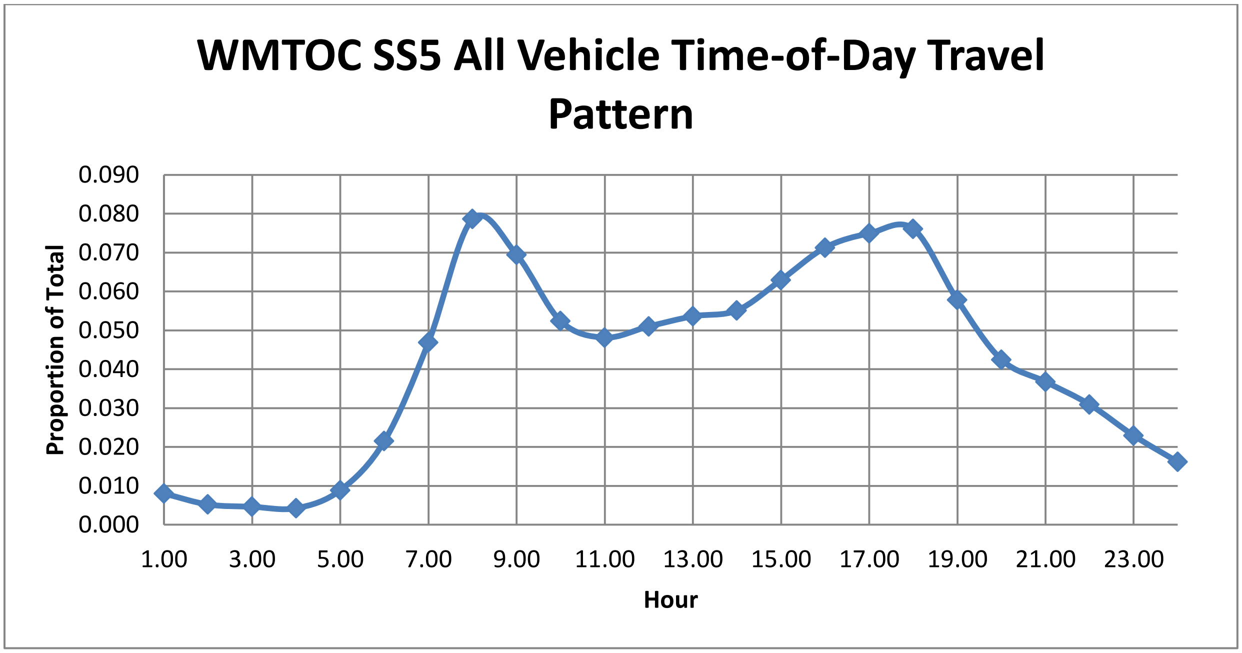

Figure A-10: WMTOC SS5 ToD Travel Pattern

Appendix 5: Candidate ITS Corridors

PR	LENGTH	BPT	EPT	SEG_BEG	SEG_END	CRASHES_13	AADT_13	Crash_Mi
992703	0.547	28003525	28002929	13.259	13.806	47	25775	85.9
993209	0.157	28001897	28001937	0.995	1.152	17	29441	108.3
1431003	0.267	81004953	81004597	0.752	1.019	14	32500	52.4
935105	0.63	47015068	47015150	22.998	23.628	20	45700	31.7
1427301	0.99	81019910	81019519	11.56	12.55	41	27554	41.4
1426109	0.582	81016772	81024409	28.609	29.191	27	53200	46.4
992703	1.591	28004546	28003525	11.668	13.259	83	26921	52.2
993610	0.744	28002057	28002030	3.95	4.694	90	34178	121.0
1427301	0.326	81018143	81017946	16.802	17.128	20	30297	61.3
994002	1.108	28003098	28003316	1.824	2.932	48	25505	43.3
4300001	0.321	58007669	58007225	16.38	16.701	40	30011	124.6
1427301	0.664	81018473	81018143	16.138	16.802	72	26536	108.4
355110	0.137	33005281	33005223	0.984	1.121	7	25100	51.1
1426109	0.517	81024409	81016280	29.191	29.708	21	50700	40.6
992703	0.857	28002929	28002058	13.806	14.663	88	25212	102.7
1427301	0.729	81018861	81018473	15.409	16.138	63	25204	86.4
355110	0.781	33005584	33006764	5.015	5.796	32	30650	41.0
935207	0.794	47014812	47015127	23.002	23.796	27	45700	34.0
767610	0.5	9006883	9006065	4.362	4.862	31	26578	62.0
1501502	0.361	25012034	25025580	10.241	10.602	35	30803	97.0
767610	0.228	9007240	9006883	4.134	4.362	21	26986	92.1
1427706	1.046	81013119	81013703	3.586	4.632	80	25553	76.5
1427706	0.157	81013035	81013119	3.429	3.586	30	25553	191.1
349805	0.11	33003181	33002997	1.32	1.43	7	34427	63.6
349804	0.254	33004535	33004119	0.583	0.837	14	34427	55.1
1494107	1.182	25014265	25014187	7.909	9.091	90	28623	76.1
349804	0.103	33003183	33003003	1.338	1.441	5	34427	48.5
335601	0.498	33004696	33004970	5.554	6.052	37	28806	74.3
567503	0.342	23001568	23010720	19.111	19.453	25	25062	73.1
21502	0.957	39005469	39005428	4.286	5.243	48	26136	50.2
567503	1.015	23001548	23001531	21.105	22.12	72	25952	70.9
335601	0.304	33004526	33004696	5.25	5.554	25	28806	82.2
1497008	0.172	25012968	25012635	7.333	7.505	15	25656	87.2
466004	0.683	73007654	73007639	16.011	16.694	23	25864	33.7
335601	0.529	33004310	33004526	4.721	5.25	64	26677	121.0

21502	0.751	39005316	39005340	6.244	6.995	35	30420	46.6
567503	0.306	23001560	23001556	19.799	20.105	25	26464	81.7
21502	0.212	39005313	39005316	6.032	6.244	29	28808	136.8
335601	1.038	33004970	33005522	6.052	7.09	43	25794	41.4
567503	0.346	23010720	23001560	19.453	19.799	35	25062	101.2
21502	0.789	39005428	39005313	5.243	6.032	72	25058	91.3
352303	0.518	33008088	33007533	3.709	4.227	33	25846	63.7
460105	0.499	73002311	73001895	2.738	3.237	27	26086	54.1
459605	0.822	73005073	73005086	2.71	3.532	69	31540	83.9
459605	0.752	73005086	73005100	3.532	4.284	28	27461	37.2
460105	0.994	73003346	73002311	1.744	2.738	54	25291	54.3
7405	0.641	39005599	39005569	0.628	1.269	56	25494	87.4
22207	1.845	39008859	39008151	6.388	8.233	126	27504	68.3
341208	0.548	33003064	33002732	5.086	5.634	32	29366	58.4
1426704	1.125	81007279	81005680	3.658	4.783	62	28582	55.1
341208	0.091	33003137	33003064	4.995	5.086	16	29103	175.8
1427706	0.634	81012727	81013035	2.795	3.429	120	36324	189.3
7405	0.125	39005605	39005599	0.503	0.628	11	25494	88.0
1227004	0.14	58009610	58009438	14.776	14.916	11	25608	78.6
1427706	0.81	81012469	81012727	1.985	2.795	83	33253	102.5
4604878	0.207	81009812	81009933	0.428	0.635	24	27413	115.9
341208	0.619	33002426	33002384	6.171	6.79	28	31352	45.2
1427103	1.067	81007208	81005729	3.668	4.735	41	28582	38.4
4603186	0.671	81008666	81007532	2.187	2.858	46	26940	68.6
932910	0.88	47009806	47010292	15.692	16.572	54	32990	61.4
22207	0.123	39005569	39005557	10.739	10.862	17	26129	138.2
341208	0.537	33002732	33002426	5.634	6.171	21	32860	39.1
932910	0.612	47009580	47009806	15.08	15.692	39	29486	63.7