Detroit Freeway Corridor ITS Evaluation

July 2001

Vaishali P. Shah
Dr. Karl Wunderlich

Contract Sponsor: Federal Highway Administration
Contract No.: DTFH61-00-C-0001
Project No.: 0998610D-01
Department: Q020

MTS™ Mitretek Systems
McLean, Virginia

ABSTRACT

This study evaluated the impacts of the Michigan Department of Transportation's ITS systems on congestion in the John C. Lodge corridor of Detroit. ITS systems deployed in Detroit include internet-based pre-trip information, highway advisory radio, ramp metering, and changeable message signs. The analysis was performed primarily using a simulation modeling approach. This study also evaluated the impacts of potential future policy and operational changes, including arterial signal coordination, accident-responsive signal coordination, and ramp metering modifications. This study also addressed a second issue MDOT identified, that of commuters' perceived preference for freeway routes through the Lodge corridor in the presence of shorter (time-based) arterial routes. This preference is termed *freeway bias*.

The team developed a mesoscopic model of the corridor for the 2-hour PM peak period to address the study issues. We compared the impacts of system supply and demand deviation, such a major and minor incidents and directional trip increases, on the existing ITS infrastructure. We analyzed the different levels of benefits for the system with ITS, without ITS, and with potential variants of the existing ITS system.

This evaluation found that commuters who use traveler information via the pre-trip or HAR systems to vary their route benefit significantly in terms of delay reduction when deviations in supply or demand occur. Those not using ITS also at times reduce delay because ITS users' route diversions reduced congestion for the system as a whole. In addition to the benefits to individuals, the existing ITS systems also improve overall system performance (throughput, average speed) when system variability occurs. Measurable increasing flow and speed on the Lodge Freeway north as well as decrease the number of vehicle stops per mile were observed with the existing set of ITS systems compared to a simulated "No ITS" scenario.

Statistical analyses of field data used in developing the mesoscopic model proved no presence of recurrent freeway bias; thus, it was not further addressed in the simulation efforts. The field data did not demonstrate driver preference for congested freeways over better (shorter time) arterial routes. Drivers do have a have a preference for the freeway, but primarily during periods when the freeway is in fact a faster route than the arterials.

Based on the evaluation of potential future operational modifications via simulation, the authors suggest that further evaluation/modification of the ramp metering strategy might provide the largest benefits for corridor performance, followed by implementation of accident-responsive signal coordination. Because route diversions are primarily freeway-to-freeway, arterial signal coordination based on the current level of demand provides only highly localized benefits that are not statistically significant at the corridor level. Current signalization in the corridor showed minimal queue delays for north/south progression; thus re-coordination of signals is not be necessary until significant demand changes occur.

KEY WORDS: Intelligent Transportation Systems, Federal Highway Administration, Detroit, Michigan, Lodge Freeway, benefits, simulation, modeling, Advanced Traveler Information Systems, Advanced Traffic Management Systems, speed, flow, throughput, travel time.

ACKNOWLEGEMENTS

The authors wish to acknowledge numerous colleagues for their contributions to this study:

In the Federal Highway Administration (FHWA): Joe Peters, the sponsor of this work at the Joint Program Office, for his comments and support.

Colleagues from the Michigan Department of Transportation: Kunwar Rajendra, Tom Mullin, Veena Jasuja, and Ray Klucent.

Colleagues from Michigan State University, Bill Taylor and Mousa F. Abbasi.

Colleagues at Mitretek who contributed to the study: Steve Mitchell, Donald Roberts.

TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

LIST OF TABLES

EXECUTIVE SUMMARY

The Michigan Department of Transportation (MDOT) has deployed Intelligent Transportation Systems (ITS) technologies on many of the freeways in metropolitan Detroit. The metropolitan Detroit ITS infrastructure includes ramp metering, changeable message signs (CMS), highway advisory radio (HAR), and pre-trip internet-based information. While these technologies benefit both roadway users and the roadway system, how much benefit and under what conditions this benefit accrues was not well understood. MDOT identified simulation models as a viable way to generate estimates of the range of impacts from the deployed ITS system. It was hoped that such models could also be used to analyze potential future modifications to the transportation system that might potentially improve system performance. In October 1996, MDOT generated an internal proposal for the "Detroit Freeway Corridor Congestion Relief Project." The objectives of this project were to address issues regarding:

- the benefits from their existing ITS facilities,
- the extent of the perceived motorists' preference for congested freeway travel over travel on the surrounding underutilized arterial grid (termed *freeway bias*), and
- the potential for improved transportation systems performance.

MDOT's need to evaluate local ITS impacts was complemented by a federal interest in identifying and disseminating information on quantitative impacts of ITS implementation. Specifically, the Federal Highway Intelligent Transportation Systems Joint Programs Office (ITS JPO) has an ongoing interest in cataloging the benefits of ITS from a variety of operational metropolitan ITS systems. The ITS JPO perceived a unique opportunity to validate simulation tool outputs if a field implementation and monitoring component was added to the Detroit Project.

Based on this convergence of state and federal interests, the Detroit Corridor Study was initiated in June 1997 by MDOT, the Federal Highway Intelligent Transportation Systems Joint Program Office (ITS JPO), and Mitretek Systems. The role of Mitretek in this project was to evaluate the performance of ITS systems/subsystems within a Detroit corridor and to define opportunities to improve the efficiency of travel through the selected corridor.

The following section outlines the evaluation approach and describes the corridor. The next two sections present detailed outcomes from the evaluation of the Existing ITS system and from the evaluation of a prospective operations shift to enable accident signal coordination. The final section highlights study results and discusses the outcomes of the study. Following these overview sections and summary information, the methodology and the results are presented in detail.

Evaluation Approach

This project addressed the benefits of ITS through simulation modeling for a subset of the Detroit region. While the scope of the project was a corridor in Detroit, the results are directly relevant to the national issues of ITS effectiveness in promoting a more efficient transportation system. The simulation modeling approach was selected for its cost-effectiveness compared to extensive field experimentation, as well as for its ability to measure both system and user impacts.

Simulation was particularly valuable for modeling the "No ITS" scenario because MDOT does not have sufficiently detailed data regarding traffic conditions prior to ITS implementation that would allow an appropriate comparison to transportation system performance with ITS implementation. Figure A shows the principal activities (in rectangles) of this study: corridor selection, simulation model selection, model calibration, and alternatives/scenario simulation.

Of nine corridors initially proposed by MDOT for this study, the M-10 corridor was selected because of its concentration of ITS technologies and its relatively greater number of alternative paths compared to other corridors. The alternatives for M-10 include another freeway (the Chrysler Freeway). The study corridor

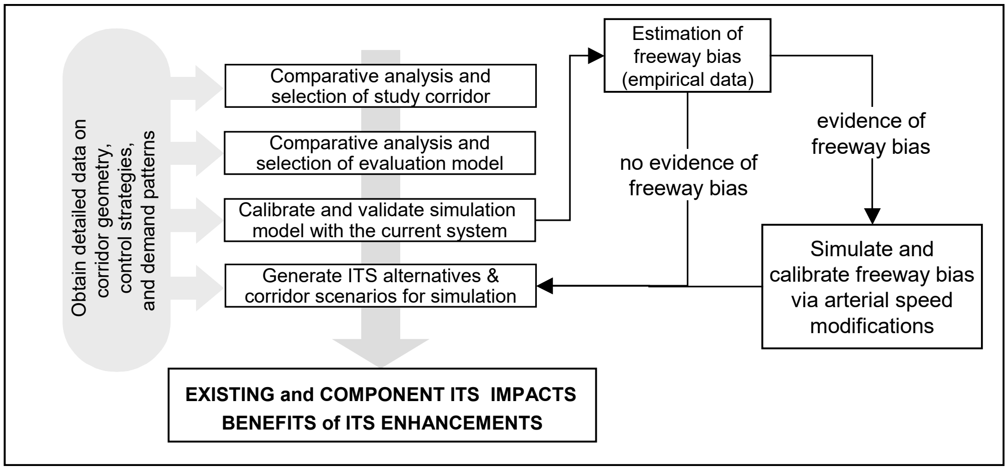

Figure A. Overview of the Study Evaluation Methodology

(Figure B) is located 2.5 km north and west of the Detroit Central Business District (CBD). It is approximately rectangular, 8 km long by 4 km wide, bordered on the east by the Chrysler Freeway and on the west by Linwood Avenue. McNichols Street and Forest Avenue form its northern and southern boundaries, respectively. The study area encompasses two north/south freeways, the Lodge (M-10) and Chrysler (I-75), and two east/west freeways, the Ford (I-94) and Davison. Roughly 40,000-50,000 vehicles travel through this corridor per hour during the morning and evening rush hours.

The INTEGRATION mesoscopic simulation model was selected for analyses. Several simulation modeling tools were evaluated; INTEGRATION's modeling functionalities and output metrics represented the best fit for this study. Freeway bias was analyzed through statistical evaluation of data on arterial and freeway speeds and capacities. The model was calibrated using observed archival data on flow and speed. It was tested for accuracy (validated) and found to be satisfactory. Average flow in simulation was within 5% of observed average flow on freeway facilities and within 10% of observed flow on arterial facilities. Time variance calibration of flow on the Lodge freeway was also within 5% of observed flow. Time variance of minor facilities in simulation was comparable to observed data.

After building the model and testing it, the team used the model to evaluate benefits under different scenarios. The set of alternatives considered were all of the "no-build" variety in the traditional Major Investment Study sense. The alternatives involved three retrospective evaluations, an existing ITS evaluation, and two prospective evaluations. The retrospective evaluations were evaluations of the system with isolated ITS technologies (rather than the current system with multiple technologies). The Existing ITS alternative was compared to the retrospective evaluations of No ITS, Only Ramp Metering, and Only CMS alternatives to gauge the impacts of the current system and component contributions of the current ITS subsystems. The prospective alternatives included a No Ramp Metering alternative, so that the team could assesses the impacts of limiting ramp metering operation, and an Accident-Responsive Signal Coordination alternative that evaluated the benefit of coordinated signals along a detour route during incidents.

Four demand and four supply conditions were considered in the evaluation. These variations were selected to evaluate how ITS technologies work under varying conditons. The four demands modeled in our study include an average demand and three variations on the average demand:

- Average PM peak demand from 4:00-6:00 p.m.,
- Average demand with a 10% increase in trips from the CBD region to the Detroit suburbs via the Lodge freeway
- Average demand with a 25% increase in trips from 4:30 – 5:00 pm from the CBD region to the Detroit suburbs via the Lodge freeway.
- A global trip increase of 5% from all origins to all destinations representing a regional traffic increase.

Figure B. Detroit Study Corridor Roadway and ITS Infrastructure

The four supply variations were selected on the basis of historical incident location and frequency data provided by MDOT. The modeled supply variations include:

- No incidents in the corridor
- Major incident on Lodge Northbound (3 lanes) before the exit for Davison East. The incident lasts from 4:15 to 5:15 pm, effectively reducing capacity by 66% for the first half hour and reducing capacity by 33% for the second half hour.
- Major incident on Lodge Northbound (3 lanes) before the exit for I-94 East. The incident lasts from 4:45 to 5:00 pm, effectively reducing capacity by 100% for the first 15 minutes and 66% for the next 15 minutes. In addition, a minor incident occurs on Lodge Northbound (3 lanes) before the Webb St. exit from 4:30 to 5:30 pm, effectively reducing capacity by 33%.
- Two minor incidents occur. The first occurs on Lodge Northbound (4 lanes) before the Linwood exit, effectively reducing freeway capacity by 25% from 4:15 to 4:45 pm. The second occurs on Lodge Northbound (3 lanes) before the Webb exit, effectively reducing freeway capacity by 33% from 4:15 to 4:30 pm.

The supply and demand conditions were combined to produce *scenarios*. There is a set of scenarios for each alternative (ITS, No ITS, proposed variations in ITS deployment, etc). The set of possible scenarios for each alternative is 16 (four demand variations mapped to four supply variations). The scenario of average demand and no incidents in the corridor is referred to as the *non-event scenario*. All other scenarios are referred to *as event scenarios*.

Each alternative except for the Accident-Responsive Signal Coordination alternative was evaluated for all possible combinations of demand and supply conditions. The Existing ITS with Accident-Responsive Signal Coordination alternative was evaluated for one scenario, that of average demand and one supply variation (an incident). In total, over 80 simulation alternative-scenarios were evaluated with each scenario simulated six times with different random number streams. The large number of scenarios allowed the team to pinpoint the specific conditions under which ITS benefits accrue.

Simulation Outcomes: Existing ITS Versus NO ITS

Table A lists the Existing ITS metrics for all scenarios at the corridor level. The corridor throughput (completed trips per hour) speed, and average trip time for the Existing ITS non-event scenario were 48,050, 36.3 mph and 5.7 minutes respectively. The differences between these values and parallel values of the retrospective alternatives (No ITS, Only Ramp Metering, Only Changeable Message Signs) were not statistically significant. Therefore we concluded that existing ITS infrastructure neither helps nor harms system or individual trip performance at the corridor level when traffic demand is average and no incidents or other supply variations occur.

For event scenarios, corridor throughput ranges from 46,530 to 50,050, corridor speed ranges from 35.5 to 36.2 mph and trip time ranges from 5.9 to 8.6 minutes. Delays between the No ITS and Existing ITS event scenarios are significantly different. Delay reductions attributed to ITS are most significant in scenarios with a major incident on Lodge north at Davison. For scenarios with this major incident, existing ITS technologies and information use reduce delay by 0.18 to 0.22 minutes per trip. This is a 320-vehicle hour aggregate reduction in delay during the pm peak period for major incident scenarios.

Existing ITS Alternative: Corridor Metrics

Incident Occurrence		Throughput		Speed			
	Demand Occurrence	finished trips/hour	%Δ	miles/ hour	%Δ	Trip Time (minutes)	Delay** (min.)
None	Average Demand	48052		36.34		5.7	
None	10% increase CLS*	48253	0.4%	36.19	-0.4%	5.9	0.24
None	25% 1/2 hour inc. CLS	48252	0.4%	36.22	-0.3%	5.9	0.22
None	5% Global increase	50049	4.2%	36.08	-0.7%	6.1	0.40
Lodge N at Davison (major)	Average Demand	46593	-3.0%	35.67	-1.8%	8.1	2.38
Lodge N at Davison (major)	10% increase CLS	46522	-3.2%	35.60	-2.0%	8.5	2.78
Lodge N at Davison (major)	25% 1/2 hour inc. CLS	46534	-3.2%	35.63	-2.0%	8.5	2.75
Lodge N at Davison (major)	5% Global increase	48314	0.5%	35.48	-2.4%	8.6	2.85
Lodge N major and minor	Average Demand	47043	-2.1%	35.98	-1.0%	6.9	1.22
Lodge N major and minor	10% increase CLS	47035	-2.1%	35.88	-1.3%	7.2	1.53
Lodge N major and minor	25% 1/2 hour inc. CLS	46998	-2.2%	35.89	-1.2%	7.3	1.57
Lodge N major and minor	5% Global increase	48827	1.6%	35.77	-1.6%	7.4	1.66
Lodge N Two Minor	Average Demand	48047	0.0%	36.19	-0.4%	6.0	0.30
Lodge N Two Minor	10% increase CLS	48112	0.1%	36.05	-0.8%	6.3	0.61
Lodge N Two Minor	25% 1/2 hour inc. CLS	48085	0.1%	36.05	-0.8%	6.3	0.62
Lodge N Two Minor	5% Global increase	49899	3.8%	35.94	-1.1%	6.5	0.78

* CLS = CBD to Lodge Suburbs

** Delay = trip time$_{\text{event scenario}}$ - trip time$_{\text{Non-event scenario}}$

%Δ = (Event Scenario - Non-Event Scenario)/Non-Event Scenario

Table A. Existing ITS Alternative: Corridor Metrics

Table B presents the average delay for trips in the corridor by commuter type for the Existing ITS and No ITS alternatives. ITS non-users in the Existing ITS alternative's event scenarios often have delays that are lower than in the No ITS alternative. In three of 15 Existing ITS scenarios, ITS non-user delays are slightly higher than parallel No ITS scenarios, but never higher than 0.02 minutes on average. This suggests that negative impacts on ITS non-users at the corridor level usually do not occur, and are very small when such impacts do occur. ITS users reduce anywhere from 35% or more of the delay that commuters in the No ITS alternative incur during event scenarios. Commuters using pre-trip or HAR information reap the greatest benefits in terms of delay reduction. These commuters incur at most 16% of the delay incurred by the No ITS commuter for any scenario aggregated at the corridor level.

Existing ITS v. No ITS Alternatives: Corridor Delay By Commuter Type

Incident Occurrence		Demand Occurrence	No ITS Altern. delay* (min)	Existing ITS Alternative: ITS non-user delay**	ITS non-user %Δ	CMS user delay**	CMS user %Δ	Pre-trip user delay**	Pre-trip user %Δ	HAR user delay**	HAR user %Δ
Incident Occurrence	None	Average Demand									
		10% increase CLS*	0.3	0.3	-2%	-0.1		-0.1		-0.1	
		25% 1/2 hour inc. CLS	0.2	0.2	1%	-0.1		-0.2		-0.1	
		5% Global increase	0.4	0.4	-3%	0.0	92%	0.0	98%	0.1	84%
	Lodge N at Davison (major)	Average Demand	2.6	2.5	3%	1.6	36%	0.2	91%	0.2	93%
		10% increase CLS	3.0	2.9	3%	1.9	36%	0.3	89%	0.2	92%
		25% 1/2 hour inc. CLS	2.9	2.9	2%	1.9	35%	0.3	91%	0.2	93%
		5% Global increase	3.1	3.0	3%	1.9	38%	0.5	82%	0.4	86%
	Lodge N major and minor	Average Demand	1.3	1.3	-2%	0.7	46%	0.0		-0.1	
		10% increase CLS	1.6	1.6	0%	0.9	44%	0.1	94%	0.0	98%
		25% 1/2 hour inc. CLS	1.6	1.6	0%	0.9	43%	0.1	96%	0.1	97%
		5% Global increase	1.7	1.7	0%	1.0	44%	0.2	86%	0.2	86%
	Lodge N Two Minor	Average Demand	0.4	0.3	11%	0.0		-0.1		-0.1	
		10% increase CLS	0.7	0.7	9%	0.2	77%	-0.1		-0.1	
		25% 1/2 hour inc. CLS	0.7	0.7	7%	0.2	75%	-0.1		-0.1	
		5% Global increase	0.9	0.8	7%	0.3	66%	0.1	89%	0.1	88%

note: negativ delay results when scenario event trip time for the commuter type is less than the non-event scenario trip time averaged across all commuters.

* CLS = CBD to Lodge Suburbs

**delay = $(\text{trip time}_{\text{event scenario}} - \text{trip time}_{\text{non-event scenario all commuters)}}$ within Alternative

$\%\Delta = (\text{delay}_{\text{Existing ITS scenario}} - \text{delay}_{\text{No ITS scenario}})/\text{delay}_{\text{No ITS scenario}}$

Table B. Existing ITS Versus No ITS Alternatives: Corridor Delay by Commuter Type

Table C lists the Lodge Freeway north metrics of flow, speed, trip time, and delay for the 16 scenarios modeled in the Existing ITS alternative. These metrics are based on all links in the corridor that are a component of Lodge north as well as trips that traverse the entire length of Lodge north. For the Existing ITS non-event scenario, average flow, speed, vehicle stops per mile, and trip time on Lodge north are 5140 vph, 59.6 mph, 680 stops per mile, and 7.8 minutes respectively. Metrics for this Existing ITS non-event scenario are not statistically different from the No ITS alternative's non-event scenario. Again, in the absence of incidents or increased demand, ITS technologies do not provide significant benefit.

ITS benefits are statistically and practically very significant on Lodge north when variations in traffic occur. For event scenarios flow, speed, stops per mile, and delay range from 4540 to 5430 vph, 39 to 56 mph, 870 to 2520 stops per mile, and 1.7 to 20.4 minutes, respectively. These ranges compared to the No ITS alternative represent as high as a 250 vph and 5.4 mph increase on Lodge north. These ranges also constitute as much as a 610 stops per mile and 4.6-minute trip delay reduction for Lodge north compared to the No ITS alternative. For Existing ITS scenarios with the minor incidents, however, ITS prompts marginally more diversion than needed causing slightly lower flows on Lodge northbound in the Existing ITS alternative than in the No ITS alternative. This does; however, improve Lodge speeds and reduce the stops per mile on Lodge significantly. Across the 15 scenarios, average benefits on Lodge north from the Existing ITS technologies and current market penetration include a 2% increase in flow, a 7% increase in speed, a 13% decrease in stops per kilometer, and an 18% decrease in delay.

Existing ITS Alternative: Lodge North Metrics

Incident Occurrence		Demand Occurrence	Flow veh. / hour	Flow %Δ	Speed miles / hour	Speed %Δ	Stops / Mile number	Stops / Mile %Δ	Trip Time (min.)	Delay ** (min.)
Incident Occurrence	None	Average Demand	5141		60		679		8	
		10% increase CLS*	5432	6%	55	-7%	925	36%	10	1.9
		25% 1/2 hour inc. CLS	5333	4%	56	-6%	873	29%	10	1.7
		5% Global increase	5360	4%	56	-7%	887	31%	10	1.7
	Lodge N at Davison (major)	Average Demand	4540	-12%	43	-27%	2139	215%	25	17.5
		10% increase CLS	4636	-10%	39	-34%	2522	272%	28	19.8
		25% 1/2 hour inc. CLS	4600	-11%	40	-33%	2491	267%	28	20.4
		5% Global increase	4615	-10%	40	-32%	2406	254%	27	19.3
	Lodge N major and minor	Average Demand	4741	-8%	51	-14%	1395	106%	17	8.8
		10% increase CLS	4900	-5%	49	-18%	1691	149%	19	11.1
		25% 1/2 hour inc. CLS	4830	-6%	49	-18%	1688	149%	20	11.8
		5% Global increase	4855	-6%	49	-17%	1602	136%	18	10.5
	Lodge N Two Minor	Average Demand	5101	-1%	55	-7%	922	36%	10	2.6
		10% increase CLS	5300	3%	52	-12%	1178	74%	12	4.5
		25% 1/2 hour inc. CLS	5226	2%	53	-12%	1130	66%	12	4.3
		5% Global increase	5231	2%	53	-12%	1135	67%	12	4.2

* CLS = CBD to Lodge Suburbs

** Delay = trip time$_{\text{event scenario}}$ - trip time$_{\text{Non-event scenario}}$

%Δ = (Event Scenario - Non-Event Scenario)/Non-Event Scenario

Table C. Existing ITS: Lodge North Metrics

Both ITS users and non-users traversing the entire stretch of Lodge Freeway north benefit from the ITS infrastructure; however, most of the benefits go to those using pre-trip or HAR information. Table D presents the delay metrics for commuters traversing the entire length of Lodge north in both the No ITS and Existing ITS alternatives by commuter type. For this non-event 7.7-minute Lodge North trip, the range of commuter delay for those using HAR is 1.0 to 2.2 minutes across the event scenarios. This range is 1.0 to 3.0 minutes for pre-trip users, 1.4 to 19.9 minutes for CMS users, and 1.5 to 20.6 minutes for ITS non-users.

Across all trips in the corridor Changeable Message Signs perform rather well in reducing delay; but, for this particular trip from the central business district to the end of Lodge northbound CMS users actually perform slightly poorer that those not using information in half of the event scenarios. This is because (1) the severity of the incident caused congestion did not warrant diversion at that point in the network, or (2) the arterials are significantly more congested along the diversion route. When there is no clearly relevant message to put on the CMS, the CMS provides limited to no benefit. Also, sometimes the diversion route is slower than the freeway, particularly in the case of relatively minor incidents.

Existing ITS Versus No ITS Alternatives: Lodge North Delay by Commuter Type										
		No ITS delay* (min)	Existing ITS Alternative							
			ITS non-user		CMS user		Pre-trip user		HAR user	
Incident Occurrence	Demand Occurrence		delay*	%Δ	delay*	%Δ	delay*	%Δ	delay*	%Δ
None	Average Demand									
	10% increase CLS*	1.9	1.7	12%	1.8	10%	1.3	32%	1.4	27%
	25% 1/2 hour inc. CLS	1.9	1.6	18%	1.4	27%	1.0	49%	1.0	49%
	5% Global increase	1.7	1.5	13%	1.5	16%	1.3	25%	1.3	26%
Lodge N at Davison (major)	Average Demand	21.5	17.6	18%	17.6	18%	2.6	88%	2.0	91%
	10% increase CLS	24.4	20.0	18%	19.9	19%	2.6	89%	2.2	91%
	25% 1/2 hour inc. CLS	24.5	20.6	16%	19.9	19%	2.4	90%	1.9	92%
	5% Global increase	23.8	19.4	18%	19.2	19%	3.0	87%	2.1	91%
Lodge N major and minor	Average Demand	11.5	8.8	23%	9.0	22%	1.5	87%	1.1	90%
	10% increase CLS	13.9	11.1	21%	11.2	20%	1.9	86%	1.2	91%
	25% 1/2 hour inc. CLS	14.7	11.8	20%	11.3	24%	1.8	88%	1.1	93%
	5% Global increase	13.5	10.5	22%	10.6	22%	2.0	85%	1.2	91%
Lodge N Two Minor	Average Demand	3.1	2.4	22%	2.4	21%	1.5	50%	1.3	58%
	10% increase CLS	5.9	4.4	26%	4.4	26%	1.6	73%	1.2	79%
	25% 1/2 hour inc. CLS	6.1	4.2	31%	3.9	35%	1.5	75%	1.2	81%
	5% Global increase	5.4	4.0	25%	3.9	27%	1.8	67%	1.3	76%

* CLS = CBD to Lodge Suburbs

*delay = (trip time$_{\text{event scenario}}$ - trip time$_{\text{non-event scenario all commuters}}$) within Alternative

%Δ = (delay$_{\text{Existing ITS scenario}}$ - delay$_{\text{No ITS scenario}}$)/delay$_{\text{No ITS scenario}}$

Table D. Existing ITS versus NO ITS: Lodge North Delay by Commuter Type

Simulation Outcomes: Accident-Responsive Signal Control

Based on the outcomes of the retrospective and Existing ITS alternatives, we found that route diversion predominantly occurs onto other major highways. Benefits from CMS were minimal for the scenarios evaluated. In addition, an analysis of queue lengths on the arterials to be considered for route diversion indicated that signals are already relatively well timed for northbound progression. As such, the expectation for potential benefit from accident-responsive signal coordination was low and the number of simulations conducted to evaluate potential benefits was limited to six random trials of one option. This single trial was based on average demand conditions, and the two minor incident supply variation. Major incident supply variations were not considered because diversions for those events were almost exclusively onto highway paths. ITS technologies in the scenario included the Existing ITS and real time coordination of signals along a primary detour route.

For this single trial, an incident occurs on Lodge northbound prior to the exit for Webb Avenue that reduces lane capacity by 33%. In the Existing ITS alternative, this capacity reduction causes traffic to slow to 10 – 28 mph from the incident back as far as Grand Boulevard as compared to the non-event scenario. A second minor incident on Lodge northbound prior to the exit for Linwood Avenue reduces lane capacity by 25%. Due to the bottleneck prior to Webb Avenue, however, speeds are compromised no more than 10 mph through the incident.

Under the Existing ITS alternative for this event option, detours made by ITS users predominantly take the freeway exit for Chicago Avenue, travel shortly on Hamilton, make a left onto Chicago and a right onto the onramp for Lodge north. This detour eliminates having to travel on 0.5 miles of freeway that performs at speed ranging from 10-15 mph due to the incident prior to the exit for Webb Avenue. For the Existing

ITS alternative, approximately 80 vehicles per hour utilize the aforementioned detour. Commuters detouring do not continue on Hamilton and enter Lodge north via the Webb Avenue onramp. This is because this possible detour requires 25% longer travel through three additional signalized intersections on urban arterials having travel speeds of 20-30 mph.

By implementing signal progression favoring northbound and left turning traffic on both the utilized detour route as well as the unutilized one, the number of detours increased to 120 vehicles per hour. At a corridor or Lodge freeway facility level, the impact of accident signal coordination on Lodge north speed, flow, or stops per kilometer is not statistically significant. However, focusing specifically on the short detoured segment of Lodge northbound, speed increase by 2mph for the hour of greatest incident based congestion. Flow also increases on the mainline segment detoured by 55 vph during the peak hour of accident-based congestion. Speed northbound on Hamilton, the detour route, increases by 3 mph as well. Speed south on Hamilton, however decreases and queues are 50% greater than in the Existing ITS alternative because green phasing time was taken to provide left and through movement for northbound Hamilton. Commuters (ITS users) making the detour reduced their delay by 20% on average whereas mainline users reduced their delay by approximately 2% on average for the PM peak period.

Summary of Findings

The purpose of this study was to provide MDOT with ranges of quantified benefits of their existing ITS infrastructure, to measure the extent of freeway bias and its impact on corridor performance, and to measure the benefits of potential changes in operations or policy intended to improve corridor performance. The results of this study, which specific to Detroit, are relevant to the national discussion of the benefits of ITS. Through a statistical analysis of various data and simulation of over 80 scenarios, we successfully addressed each of the issues identified in the initial project objectives. This section responds to the following five issues presented in project objectives subsection:

Query 1. Is there measurable freeway bias in the corridor and what is the system impact of the bias?
Query 2. How does the existing ITS infrastructure affect the system and facility performance?
Query 3. Under what conditions do the existing ITS systems prove most beneficial?
Query 4. How do ITS impacts vary among those who use and do not use ITS information?
Query 5. What potential policy /operations changes considered by MDOT would enhance user and system performance?

With regard to measurable freeway bias in the corridor, we found through statistical analysis that speeds during the entire evening peak on freeways are significantly higher than on arterials. Therefore, freeway bias, at least in the sense of an irrational preference for congested freeways over free-flowing arterials, simply does not exist during average traffic conditions. Data was not available to evaluate whether freeway bias is present during major incidents. Freeway bias was not present for average PM traffic conditions in the corridor and therefore no freeway bias was incorporated in the simulation modeling effort.

With regard to the system and facility level performance of the existing ITS infrastructure Mitretek identified ITS impacts through modeling and comparison of four alternatives: No ITS, Ramp Metering (only), CMS (only), and Existing ITS. The Existing ITS system proved very beneficial in improving flow and speed on Lodge Freeway, particularly when incidents occur. The Existing ITS technologies contributed to as high as a 250 vph and 5.4 mph increase on Lodge north over the case modeled of No ITS technologies. The Existing ITS technologies also constitute as much as a 610 stops per mile and 4.6-minute trip delay reduction for Lodge north compared to the No ITS alternative.

Overall, benefits from the Existing ITS system are significant at the corridor level for commuters and the system during the pm peak when significant changes in corridor demand and supply occur. The greatest benefit is in commuter delay reduction. The current ITS system mitigates delay across the corridor by as much as 22% among the scenarios modeled. Corridor speed and throughput are also at times marginally improved.

The ITS systems proved most beneficial under conditions of significant supply variations such as incidents. For demand variations ITS benefits are also realized, but to a lesser extent. Ramp metering and pre-trip/HAR information proved equally valuable tools at reducing commuter delay and improving facility metrics in response to major incidents. In response to demand variations, pre-trip/HAR information proved most effective. Changeable (variable) message signs do benefit commuters in terms of awareness of traffic activities. In terms of delay reductions; however, commuters acting upon CMS signs' messages of delay found little benefit, and at times also increased delay by diverting. Moreover, CMS proved no benefit to facility operation in terms of flow or speed. Also, ramp metering, although effective during major incident events, proved questionable in the absence of incidents or when minor incidents occurred.

ITS benefited all commuters in terms of delay reduction, but most of the benefits were realized by those using pre-trip or HAR information. Pre-trip and HAR ITS users realized delay reduction of over 80%, mainly through freeway-to-freeway route diversions. Although arterial signals are already relatively well timed, arterial route diversions are relatively unattractive to commuters given the availability of freeways at much higher speeds.

Potential future operational enhancements considered in this study included retiming of arterials for signal progression, providing operational functionality for real time signal coordination to promote diversion around a freeway incident, and deactivating ramp metering.

Because a queue analysis of arterial signals indicated minimal queue formation at signals as well as relatively good signal progression, retiming for corridor progression was found not be necessary. The team conducted a single scenario evaluation for accident signal coordination because predominantly, route diversion occurs freeway to freeway. This single evaluation proved significant benefits from coordination at the local level but not at the corridor level. The most promising operational change found to improve corridor performance is deactivating ramp metering for average conditions and when perturbations to the freeway facility are minor. During these conditions on Lodge north, freeway speeds are still equal or better than arterial speeds. By making this operational shift of turning off metered ramps in the absence of major events, delay on ramps and arterials leading to ramps proved in simulation to be significantly less without harming mainline operations.

Overall, through conduct of this study, the following summarizes characteristics of the corridor, benefits from ITS in this corridor, and operational/policy shifts that should be further considered by MDOT:

- The corridor evaluated has relatively minimal recurrent PM peak-period congestion and therefore parallel freeways serve as most favorable diversion routes. Arterials, although relatively well timed for signal progression in the corridor, are not attractive route alternatives.
- Freeway bias was not evident in the data available.
- In terms of ITS Benefits for this system, pre-trip and HAR information proved most effective at reducing commuter delay while ramp metering proved very effective at improving facility performance when major incidents occur. Delay reductions of as much as 22% throughout the corridor were realized while flow and speed improvements of as much as 250 vph and 5mph on Lodge north were realized compared to a system without any ITS.

The strategy of signal coordination should be considered when and if demand changes from those modeled in this study occur or if demand significantly increases in the corridor. Based on the current system and demand evaluated, accident-responsive signal coordination provided benefit at the local level, but until arterial diversions become more attractive, benefits will not be significant at the corridor level. The MDOT ramp metering strategy should be evaluated and ramp metering should be considered for modified operation on a selective basis.

The remainder of this report consists of detailed information on the methodology and results covered in this overview material.

1.0 INTRODUCTION

The Michigan Department of Transportation (MDOT) has Intelligent Transportation Systems (ITS) technologies deployed on many of the freeways in metropolitan Detroit. While these technologies benefit both roadway users and the roadway system, how much benefit and under what conditions this benefit accrues was not well understood. The metropolitan Detroit ITS infrastructure includes ramp metering, changeable message signs, highway advisory radio, and pre-trip internet-based information. MDOT identified simulation models as a viable way to generate estimates of the range of impacts from the deployed ITS system. Moreover, such models could be applied to pinpoint potential modifications to the transportation system that might potentially improve system performance. In October 1996, MDOT generated an internal proposal for the “Detroit Freeway Corridor Congestion Relief Project.” The objectives of this project were to address issues regarding:

- the benefits from their existing ITS facilities,
- the extent of motorists’ perceived preference for congested freeway travel over travel on the surrounding underutilized arterial grid (termed *freeway bias*), and
- the potential for improved transportation systems performance.

MDOT’s need to evaluate local ITS impacts was complemented by a federal interest in identifying and disseminating information on quantitative impacts from ITS implementation. Specifically, the Federal Highway Intelligent Transportation Systems Joint Programs Office (ITS JPO) has an ongoing interest in cataloging the benefits of ITS from a variety of operational metropolitan ITS systems. The ITS JPO also perceived a unique opportunity to validate simulation tool outputs if a field implementation and monitoring component was added to the Detroit Project.

Based on this convergence of state and federal interests, the Detroit Corridor Study was initiated in June 1997 by MDOT, the Federal Highway Intelligent Transportation Systems Joint Programs Office (ITS JPO), and Mitretek Systems. The role of Mitretek in this project was to evaluate the performance of ITS systems/subsystems within a Detroit corridor and to define opportunities to improve the efficiency of travel through the selected corridor. The role of MDOT was to supply data relevant to Mitretek’s analysis, to implement strategies defined by Mitretek to improve corridor efficiency and to subsequently monitor the system for changes in system performance. Mitretek would then compare the field outcomes to simulation outcomes to validate simulation tool outputs. The field implementation and model validation components of the project were subsequently dropped due to the outcomes of the simulation study and a shift in MDOT requirements. In summary, the objectives of this project included measuring the level of freeway bias within a corridor of Detroit, quantifying the range of benefits from MDOT’s existing ITS infrastructure, and investigating the options for promoting better use of freeway and arterial facilities using advanced traffic management and traveler information strategies.

This report, prepared by Mitretek Systems, describes the project background and objectives, the study approach, the corridor analyzed, and results of the Mitretek evaluation. Section 1 sets the context of this study and defines specific goals of the analysis. Section 2 describes the methodological approach. Here we outline the criteria and constraints related to selecting the study corridor and evaluation model, and calibrating and validating the model. We also discuss the role of various factors in the realization of ITS benefits and the process by which to capture inherent commuter preferences for certain routes. The methodology section concludes with a discussion on data needs and study constraints. The evaluation methodology pertaining to field implementation and model calibration is not a part of this document because these parts of the initial study plan were dropped.

Section 3 describes the study corridor and data obtained to conduct this study. Section 4 describes the simulation model and how accurately the model represents congestion conditions observed in the corridor. Section 5 details the alternatives and scenarios generated for evaluation. Also addressed in this section is the issue of freeway bias. Section 6 presents the outcomes of the alternatives analysis from this study and details the relative contribution of ITS components. The final section (Section 7) summarizes the key findings and addresses the extent to which project objectives were met.

1.1 Context Setting

Advanced traffic management systems (ATMS) and advanced traveler information systems (ATIS) are being deployed worldwide to mitigate recurrent and non-recurrent congestion through real-time modifications in system capacity and efficient distribution of motorist demand. ATMS technologies are used to identify unexpected traffic conditions such as incidents, and can subsequently modify ramp metering and signal coordination to meet corridor capacity requirements. ATIS technologies can be used to notify motorists of atypical delays, advising motorists to modify their routes, modes, or departure times to utilize efficient alternatives. Through this process, queues are reduced and overall corridor throughput is improved. In addition, motorists benefit in the form of more predictable travel times and lower stress.

The 1997 the Detroit Metropolitan ITS system included 32 miles of freeway managed by a traffic monitoring system of 11 closed circuit television cameras, 14 changeable message signs (CMS), 49 ramp meters, 4 highway advisory radio (HAR) stations, and over 1200 inductive vehicle detectors [1]. Significant expansions have been made to extend the 1997 ITS system. Figure 1 presents the location of existing and proposed ATMS/ATIS facilities within the Detroit metropolitan region as of 1998.

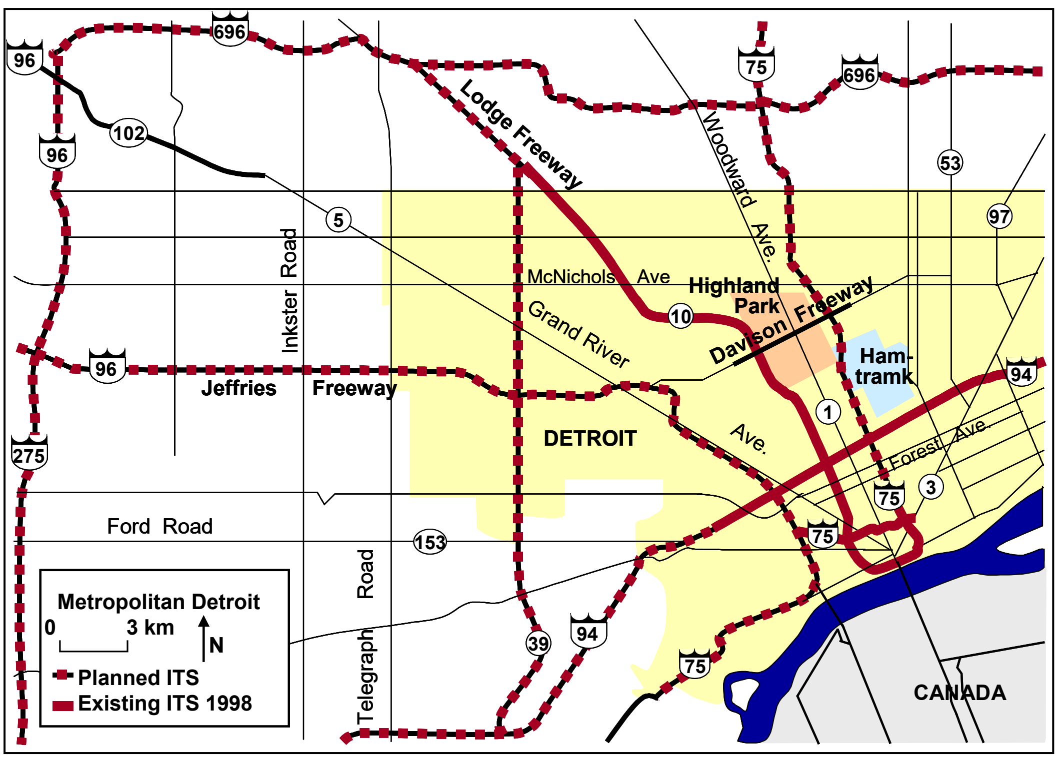

Figure 1. Detroit Metropolitan Road Infrastructure

There are approximately 20 major arterial roadways that parallel ITS-equipped freeway facilities within the Detroit metropolitan area. MDOT staff have observed over the years of ITS deployment that the current ITS system has prompted some level of route diversions; however, they theorized that additional diversion would improve overall system performance. MDOT hypothesized that during the peak morning and evening traffic periods "freeways are excessively crowded … while the major surface streets are greatly under used" [7] because of motorists resolute preference for freeways regardless of better time-based path alternatives. The resolute preference by motorists toward freeway travel was termed 'freeway bias.' MDOT also hypothesized that operations improvements such as signal progression, accident-responsive signal coordination, or ramp metering modifications might improve corridor performance and reduce freeway bias.

This project addressed these issues through simulation modeling for a subset of the Detroit region, and indirectly addressed the national issue of ITS effectiveness in promoting a more efficient transportation system. The simulation modeling approach was selected for its cost-effectiveness compared to extensive field experimentation, as well as its ability to measure both system and user impacts. In addition, MDOT did not have the appropriate data regarding traffic conditions prior to ITS implementation that would provide for a sufficient comparison to transportation system performance with ITS implementation. In simulation, this could be overcome by representing the existing transportation system and conducting alternatives analyses with or without specific ITS components.

1.2 Project Objectives

The goals of this project were to calculate the range of impacts from the existing ITS system/subsystems, to identify the impacts of any existing freeway bias, and to identify strategies for improved corridor performance. Specific issues addressed by this project related to ITS impacts are listed below.

Query 1. Is there measurable freeway bias in the corridor and what is the system impact of the bias?
Query 2. How does the existing ITS infrastructure affect the system and facility performance?
Query 3. Under what conditions do the existing ITS systems prove most beneficial?
Query 4. How do ITS impacts vary among those who use and do not use ITS information?
Query 5. What potential policy /operations changes considered by MDOT would enhance user and system performance?

Metrics of overall system performance included statistics on flow, speed, and variability in flow. User performance metrics from the simulation evaluation include trip-based statistics on travel time and delay.

2.0 METHODOLOGY

Figure 2 shows the principal activities (in rectangles) of the methodology. The following 4 subsections describe the principal activities and how freeway bias was measured. The final subsection outlines data sources and study constraints. Application of the methodology and its outcome is presented in Section 3.

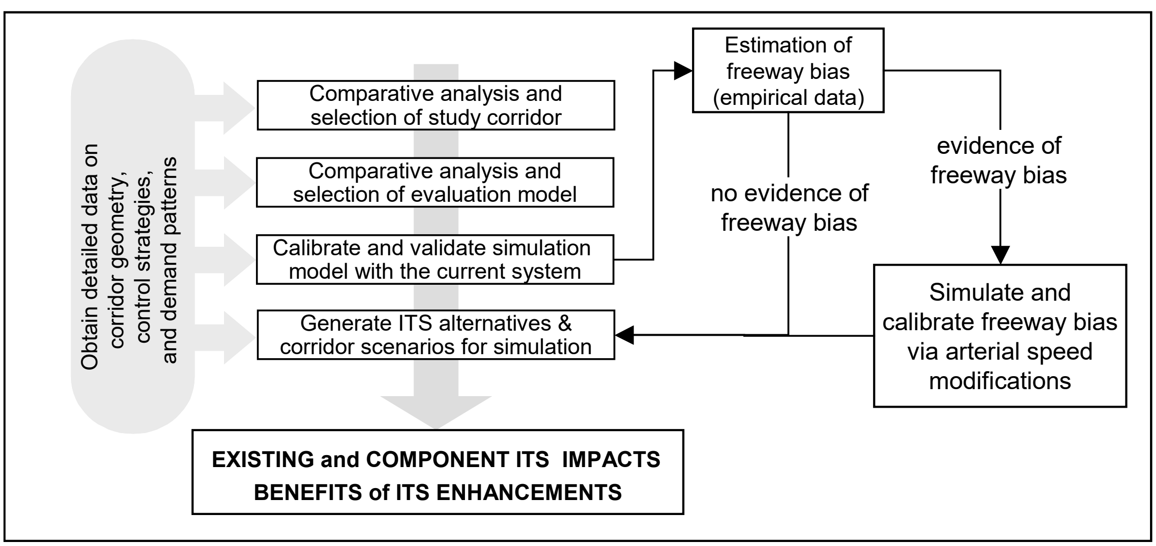

Figure 2. Overview of the Study Evaluation Methodology

There are significant advantages to the simulation evaluation approach, as highlighted in the previous section. Through simulation of an ITS corridor, the benefits from the existing ITS can be estimated for a variety of corridor capacity and demand scenarios. This was accomplished by validating model performance for an 'average' scenario with the existing ITS and then running the model for the same scenario, but in the absence of or with modifications to ITS components. Comparison of output parameters from these sets provided the estimate of ITS impact. This estimate could not be obtained through field research because corridor data prior to ITS implementation was not available, and because removal of ITS system to measure the reduction in benefits was not practical. The impact of ITS across a variety of corridor conditions and by specific ITS component could also be evaluated via simulation. The use of a simulation model also provided an opportunity to 'game out' proposed implementations and fine-tune strategies to increase ITS effectiveness in the corridor.

2.1 Corridor Selection Criteria

The ITS deployment in the Detroit metro area is intended to improve system efficiency primarily through real-time freeway route diversion. The four essential conditions for real-time freeway diversion include the need for route diversion, the existence of viable alternate routes, the capabilities for corridor monitoring, and the ability to inform motorists of road conditions and alternative routes. In order for these conditions to occur, there must be some freeway congestion, alternate routes that are less congested, and real-time traffic monitoring and information distribution systems. The candidate corridor must meet these four conditions to in order to recognize transportation and environmental benefits from ITS. For example, if the freeway is not congested, information on alternate routes will not be relevant or provide much benefit. One of the first tasks of the team was to pick an appropriate corridor.

In the selection process, a simple cumulative scoring scheme was developed to identify freeway corridor options. For each freeway alternative, four scores were assigned, each associated with one of the necessary attributes for real-time freeway diversion benefits. Scores ranged in magnitude from 3, 2, 1, and 0 corresponding to 'significant,' 'moderate,' 'minimal,' and 'none.' The four scores were summed for each freeway alternative. The three alternatives with highest cumulative score and no single criteria score less than one were identified as acceptable choices for the project. The final selection among acceptable alternatives was made as a joint decision among project partners.

Once the team had a good idea of appropriate freeways, they also had to select corridor study boundaries. The corridor size was constrained by the capabilities of the modeling tool, project resource limitations, and data availability. Criteria for boundary selection included the location of freeway diversion opportunities, location of alternate routes, location of motorist advisory information, and resource constraints (time, data collection costs, etc.). Corridor boundaries were selected to include 'natural' points of freeway diversion choice, and locations where motorist information would be received. Details on the corridor selection process and its results are presented in Section 3.

2.2 Evaluation Model Selection Criteria

In selecting the appropriate simulation model, three model review documents were surveyed (7,8,9). Specific simulation capability requirements included:

- modeling arterial and freeway facility interactions;
- modeling dynamic traffic management problems caused by incidents and atypical events;
- modeling adaptive/coordinated traffic signal controls;
- representing traffic phenomenon such as queue spill-back; and
- modeling dynamic route guidance, ramp metering, surveillance methods, and highway advisory radio technologies.

Simulation output requirements included time-based link, vehicle, origin-destination, and system measures of performance including speed, travel time, throughput, number of stops, and queue length. Simulation model suitability was also a function of network size, in terms of model building capabilities and computation time. Other factors in model selection were the operating platform, technical support, and the data requirements of the model.

In a modeling approach, developing a representative model is critical to generating accurate measures of impact. Three primary tasks are necessary to ensure that the model is representative of the corridor system: representing the physical and operational structures of the system, calibrating the system demand and reaction components, and confirming that model outcomes represent observed outcomes. These tasks are described in further detail below.

Representing the physical components of the corridor requires that the simulation tool accurately represents the physical characteristics of roadway, traffic control, and ITS infrastructure such as road length, number of lanes, and location of traffic/ITS controls. The simulation tool must also account for the operational components of the corridor such as traffic movement restrictions, signal phasing and coordination, and ITS reliability and update speed.

Model calibration is required to validate that the simulation model properly represents the behavioral and demand characteristics of motorists traversing the corridor. Behavioral factors include acceleration, gap acceptance, car following, and lane changing sensitivities as well as adherence to motorist information. Motorist demand pertains to identification of demand generators and attractors, and representation of corridor time-based demand volume for travel from each generator (origin) to each attractor (destination).

We confirm that model outcomes represent observed outcomes by comparing simulated and observed traffic flow and speed in the corridor. Comparisons are unlikely to match exactly because of variances in demand by day and time of day as well as data inaccuracies. We, therefore, develop a threshold measure based on observed day-to-day variation in speed or flow. Figure 3 illustrates the threshold concept for confirming model outcomes, where σ is a measure of standard deviation in the metric by time of day. When the number of observations to calculate standard deviation is too low, the threshold measure does not caputre the true variability in traffic by day. In such circumstances, thresholds are set as a percentage of the observed mean or an absolute amount difference from the mean. If the physical structure, behavioral components, demand patterns, and flow or speed observations of the simulation model match the corridor system components, one can then have confidence in the outcomes of the model.

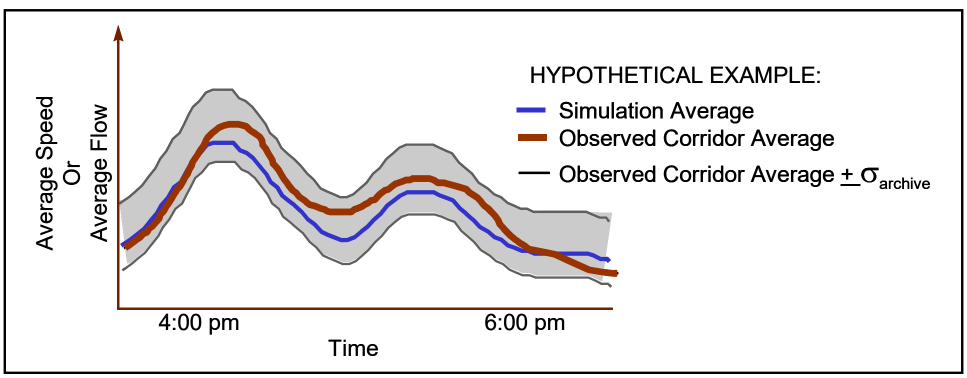

Figure 3. Model Validation through Thresholds

2.3 Freeway Bias

A corridor is defined to be at user equilibrium when no motorist can achieve a better travel time through the corridor by changing to an alternate route. In the absence of unusual travel demand or system capacity changes, a corridor system is expected to exist near user equilibrium. This is because seasoned motorists are expected to have tested feasible paths for their commute and have selected alternatives with minimal travel time for an average day of traffic. Under certain circumstances, however, a motorist population may have preferences for a path despite the existence of alternate shorter time-based paths.

Freeway bias can be shown to exist when an arterial route provides a significantly better travel time than a parallel freeway route whose performance is degraded by recurrent congestion. This bias may be attributed to the complexity of arterial paths, greater variability in arterial travel time, commuter unfamiliarity with arterial paths, or safety concerns related to arterial environments. Figure 4 demonstrates what freeway bias would look like in a generic system. Note in Figure 4 that around 5:00 pm the example freeway facility is at or exceeds capacity and travel time using the freeway facility is greater than travel time using the 'arterial 2' facility. At the same time the volume of traffic on the 'arterial 2' facility is well below capacity. If this were a recurrent relationship, then one can conclude the presence of freeway bias for this example corridor.

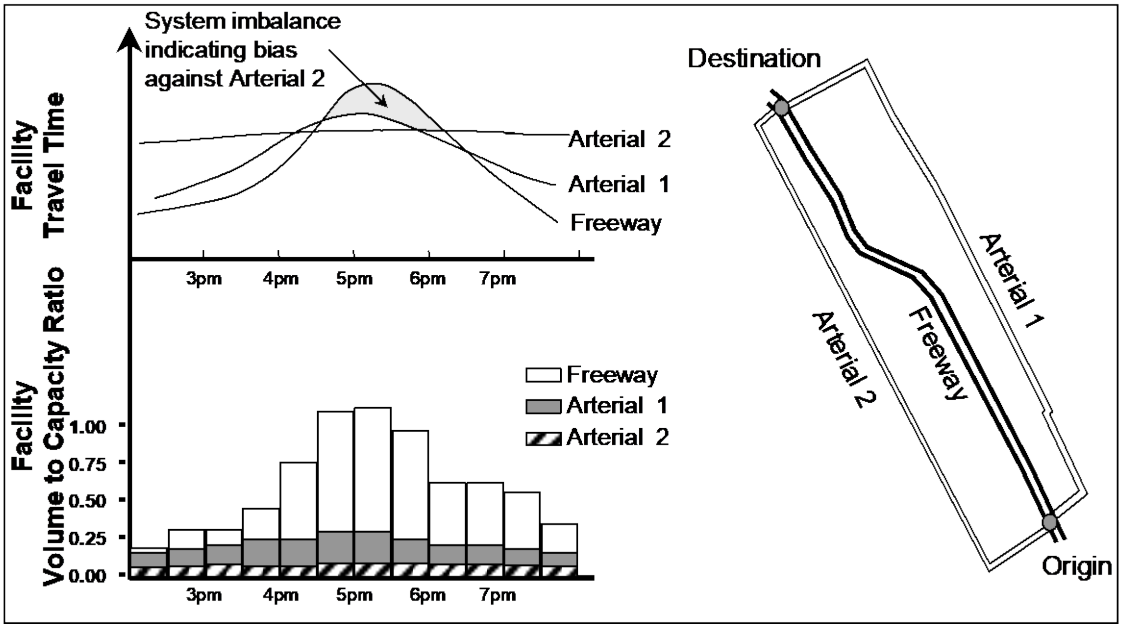

Figure 4. Occupancy and Traversal Time Relationship for Freeway Biased Facilities

Freeway bias can also be observed during capacity reducing events on the freeway. For example, during queue spillback resulting from a freeway incident, motorists may choose to remain on the queued freeway rather than divert to a parallel arterial with lower travel time.

The team addressed the MDOT hypothesis that Detroit commuters have a bias toward freeways first by a statistical analysis of field data, with the intention to follow up with simulation modeling if the statistical analysis identified bias. Assuming the existence of freeway bias, a commuter would select a freeway route although another route may provide a better travel time. A comparison of field data on travel time for the freeway and any parallel arterial during expected traffic conditions would reveal the existence and magnitude of recurrent freeway bias. For these comparisons, a two-tailed t-test for means and differences was performed.

After identifying bias, simulation modeling could quantify the degradation in performance resulting from the freeway bias for a range of corridor demand and capacity characteristics by adjusting facility speed conditions. In the event of freeway bias, simulation path choice would neglect any existing freeway bias. By lowering arterial link speeds in simulation, path assignment would favor freeway use and therefore reflect freeway bias present in the corridor. The quantity by which arterial speeds are reduced would reflect the magnitude of freeway bias.

2.4 Alternative and Scenario Formation

ITS technologies are expected to be most effective for high-variability conditions with moderate levels of ITS market penetration. The effectiveness of each ITS strategy (referred to as an alternative) is related to the source of system variability (referred to as a scenario). Different strategies may be effective for different scenarios. For example, a CMS may be more effective than ramp metering in reducing freeway traffic for a planned construction event. Similarly, ramp metering may be more effective than a CMS in smoothing the flow of freeway traffic during incident-based congestion.

The objective in scenario definition was to select a manageable set of representative events that would reflect the varying conditions and differences in each alternative's effectiveness. The constraints to the scenario set size included computation power, data storage and staff effort. Factors causing variability in corridor performance could be attributed to two categories: supply and demand changes. Supply changes included events such as poor weather, incidents, and construction closures. Figure 5 presents these factors in a two-dimensional coordinate area. The center is representative of average demand, good weather, and minor or no incidents, generating typical corridor performance. Although the occurrence of an atypical (shown by stars in Figure 5) event is infrequent, a significant portion of ITS benefit may be derived from mitigating the single extreme event.

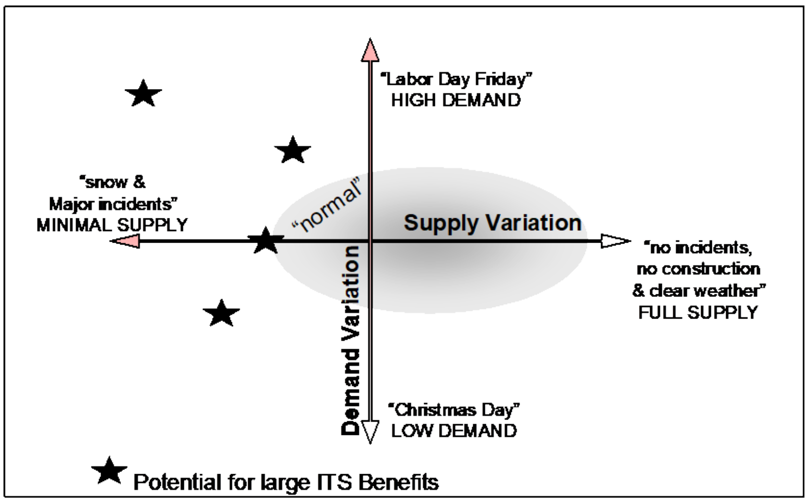

Figure 5. Sources of Transportation System Variability

Other factors that may affect the level of ITS impact is the market penetration of ITS technologies and the geographic distribution of ITS users. The expectation is that at low market penetrations, ITS use would benefit users with minimal impacts on non-users on ITS diversionary routes. If only a few people have superior information on congestion and alternative routes, their route diversions will provide significant benefits to those users while moderately improving overall system performance. At higher market penetrations, however, ITS user benefits may decrease as the alternative routes become congested. Due to the lack of specific information on the market penetration and geographic distribution of ITS use in the Detroit metropolitan region, this study evaluated ITS impacts at a simulated level of market penetration and assumed equal geographic distribution of ITS use.

Annual impact, or measure of effectiveness, for an alternative would be derived from aggregating weighted scenario impacts. The scenario weight would represent the probability of occurrence of that scenario over a one year time period. However, the team did not generate annualized benefits estimates because this represented a significant effort outside the agreed scope of the projects. Impacts are presented by un-weighted scenario type. Weighted benefits would be a good topic for future research.

2.5 Data Needs

Data on transportation capacity, motorist demand, and travel behavior is required to properly represent any corridor via a simulation model. Transportation capacity data was acquired from MDOT, the City of Detroit, the City of Highland Park, South East Michigan Council of Governments (SEMCOG), Etak Inc., and field observation. This included geometric configuration, signal operation, turning restriction, speed limits, and ITS operation.

The regional planning model origin-destination (OD) matrix was unavailable at the required level of detail, and prohibitively costly to acquire. Therefore, a synthetic OD generation technique was used to estimate motorist demand. The accuracy of synthetic generation techniques is a function of the quantity and quality of input data. For this study, real-time measurements of flow for a subset of freeway and arterial facilities were obtained from inductive vehicle loop detectors and tube counters. Year 1995 annual counts of residential and employment volumes for zones within the corridor were also used in estimating the OD matrix.

Resource and time constraints precluded the measurement of travel behavior characteristics specific to the Detroit region; thus, parameters based on observed macroscopic traffic flow relationships were employed in the simulation. Specifically, loop detector data on speed, flow, and occupancy coupled with the Highway Capacity Manual standards were inputs to the simulation model. Acceleration, car following and lane changing behavior in the model was designed to be consistent with macroscopic observed traffic flow conditions.

3.0 Corridor Selection and Description

Nine alternative freeway corridors within the Detroit metropolitan region were introduced in the MDOT *Freeway Relief Corridors Discussion Paper* [8] and were considered for selection in this study. Table 1 lists these nine alternatives and their individual and cumulative scores regarding the conditions needed to achieve ITS benefits. Scores in each case were provided by engineers at the Michigan Intelligent Transportation Systems (MITS) Center, the center of the Detroit Metropolitan area ITS operations. Upon a review of the top three alternatives (I-94, M-10, and I-75) the M-10 alternative was selected for its relatively greater number of alternative paths, which included a freeway facility (Chrysler Freeway). The Edsel Ford Freeway scored high on the criteria, but it was not appropriate for this study because long-term facility construction and rehabilitation plans would interfere in performance measurements.

	Gauge of Freeway Corridor Acceptability for Study				
Freeway Alternatives	Congestion Presence	Uncongested Alternative(s)	Corridor Surveillance	Motorist Information	TOTAL SCORE
Edsel Ford Freeway (I-94)	3	1	3	2	9
John C. Lodge Freeway (M-10)	2	3	2	2	9
Fisher Freeway (I-75)	3	2	1	2	8
Chrysler Freeway (I-75/I-375)	3	2	1(3)	1(3)	6
I-275 Freeway	3	2	0(1)	0(2)	5
Reuther Freeway (I-696)	3	2	0(2)	0(2)	5
Jeffries Freeway (I-96)	2	2	0(2)	0(2)	4
Southfield Freeway (M-39)	2	1	0 (1)	0(2)	3
Davison Freeway (M-8)	0	2	0	0	2

cell entry options/scores: 3 = significant 1 = minimal
2 = moderate 0 =none
Number in brackets is expected conditions upon ATMS/ATIS expansion.

Table 1. Corridor Options and Attractiveness Rating

At the same time as the team was researching the freeway candidates, they were also selecting the corridor boundaries. Definition of corridor boundaries was based on the aforementioned factors and MDOT requirements. Boundaries include McNichols Avenue to the north, Chrysler Freeway to the east, Forest Avenue to the south, and Linwood Avenue to the west. The following section describes the selected corridor.

3.1 Location and Land Use

The study corridor (Figure 6) is located 2.5 km north and west of the Detroit Central Business District (CBD). It is approximately rectangular, 8 km long by 4 km wide, bordered on the east by the Chrysler Freeway and on the west by Linwood Avenue. McNichols Street and Forest Avenue form its northern and southern boundaries, respectively. As mentioned earlier, data availability and simulation constraints affect the size of the corridor model. A number of potential alternate arterials to the west of Linwood were not included.

Figure 6. Detroit Study Corridor Roadway and ITS Infrastructure

The study area encompasses two north/south freeways, the Lodge (M-10) and Chrysler (I-75), and two east/west freeways, the Ford (I-94) and Davison. The Lodge, Chrysler, and Ford Freeways link the Detroit suburbs with the CBD. Parallel to Lodge and Chrysler are a number of arterial streets that provide alternative access to the downtown areas. Woodward Avenue, the primary arterial, is a 4-lane undivided facility midway between the Lodge and Chrysler Freeways. To the west of the Lodge Freeway is Linwood Avenue, which is 4-lane street through most of the corridor, and links to Grand River for access to the downtown area. In addition, there are a number of one-way arterial pairs that could serve as alternatives to both Lodge and Chrysler through the corridor section. These are (west to east): 14th/Rosa Parks (12th) Avenues, 3rd/2nd Avenues, and John R/Brush Avenues. In addition, Hamilton and Oakland Avenues provide partial alternatives to Lodge and Chrysler respectively.

Land use throughout the corridor is light industrial, small business and office, and residential. Business and office space, along with museums and Wayne State University, occupy the southern portion of the corridor (south of West Grand Boulevard), while residential areas and a few automotive plants dominate the northern section.

Figure 7 presents the residential and employment presence by zone. The data is based on 1995 SEMCOG estimates. The estimates provide a guideline for trip generation and attraction potential by zone as well as the location of trip origin and destination nodes.

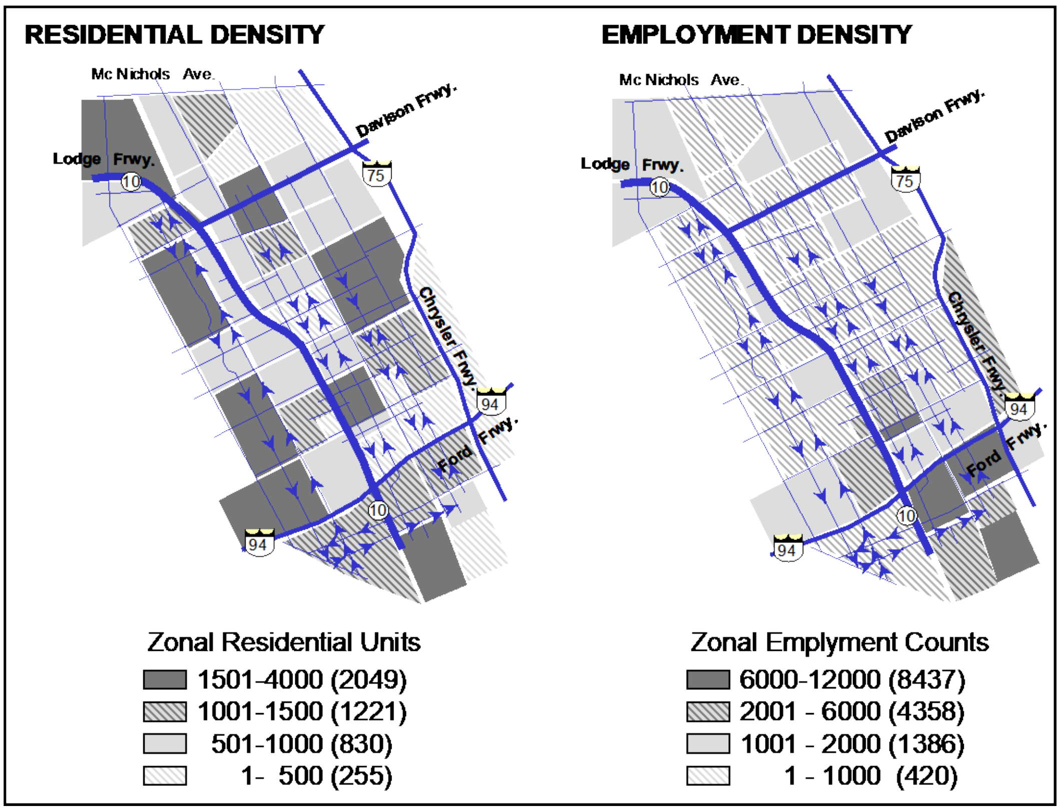

Figure 7. Residential and Employment Densities

3.2 Conventional Traffic and ITS Elements

Within the study area are approximately 230 signalized and 30 unsignalized intersections. Signals are operated by one of three jurisdictions: City of Detroit, City of Highland Park, and City of Hamtramk. There is no centralized traffic control system. Signal timing is predominantly fixed-time, operating in a.m., p.m., and off-peak plans. Most intersections are 2-phase operations, though a number of locations implement protected or protected/permitted phasing. Many signals are coordinated for corridor progression. Signal timing plans were obtained from the City of Detroit, the City of Highland Park, and from MDOT. In 1998, the Woodward corridor signals were calibrated for northbound progression. This upgrade was included in the simulation.

Deployed ITS elements within the Detroit study area include ramp metering, CMS, HAR, CCTV, and mainline detectors. Ramp metering is operated Monday to Friday from 6 a.m. to 10 a.m. and from 3 p.m. to 7 p.m. on the Lodge and Ford Freeways. Ramp metering is also operated in the off-peak time periods during major incidents. The metering rate is determined by a demand responsive system using main line loop detectors to activate/deactivate meters when thresholds are met. Metering signals operate at a step-wise rate with a minimum of 10 vehicles per minute and a maximum rate of 15 vehicles per minute. The rate increase from a minimum rate is triggered by an occupancy value of 20%. Sixteen ramps within the study area are metered. Motorist information systems in the corridor include five CMS within study boundaries, and two just outside the southern boundary. In addition, a CMS is located along the Lodge Freeway five miles northwest of the corridor. An HAR and an Internet site also transmit traveler information. The location of ramp meters, CMS, and HAR are shown in Figure 6.

Corridor freeway surveillance includes a series of detector stations and CCTV cameras along the Chrysler, Lodge, and Ford freeways. The detector stations consist of magnetic loops in each lane at an interval of approximately 0.50 miles along the Lodge and Ford freeways. These stations collect volume, occupancy, and speed data in 30-second blocks, and transmit the data to the MITS center in Detroit.

3.3 Traffic Flow and Speed Characteristics

Travel demand in this corridor is primarily through-travel between Detroit suburbs (north and west of the corridor) and the CBD (south of the corridor). Morning peak period demand is predominantly southbound with relatively equal demand in the east and west directions. Morning congestion starts at 7:00 a.m. and subsides by 9:00 am, with demand peaking between 7:30 to 8:00 a.m. Approximately 40,000 motorists per hour traverse the corridor during the morning period.

The evening peak period from 4:00 pm to 6:00 pm and has significantly greater level of traffic. Evening demand is northbound with relatively equal demand in the east and west directions. Over 75% of the demand is through traffic during the evening period. Evening congestion starts at 3:00 PM and subsides by 7:00 PM. Approximately 100,000 motorists traverse the corridor from 4:00 to 6:00 PM. Demand estimates are scaled for the 1997-1998 year and are based on observed flow and SEMCOG planning data.

Michigan State University (MSU) provided most of freeway data used in this study. The data was filtered volume and speed measurements at minute intervals from freeway loop detectors during 1996 and 1997. MSU had filtered raw loop detectors counts to eliminate measurements during incident events or faulty loop detector performance. The Michigan ITS (MITS) Center of MDOT sent Mitretek volume and speed measurements for a two-month period in 1998. The values of flow combine the MSU data and the loop detector data collected by MITS specifically for this study.

The greatest flow during the evening peak is in the northbound Lodge Freeway and I-75. The Lodge Freeway and I-75 carry about equivalent northbound volumes during the evening peak period. The speed limit is 65 mph. The average speed on Lodge northbound during the PM peak period is 60.0 miles per hour (mph). Point speed measurements along Lodge northbound ranged from 42 to 76 mph on average during the PM peak. Speed on Lodge southbound and other major freeway facilities averaged 65.1 mph with a standard deviation among point speeds of 10 mph. Freeway observed measurements are presented in greater detail in the subsequent section under model calibration.

MDOT also collected arterial data using tube counters at approximately 70 directed arterial locations for a period of two to four days (based on location). Table 2 lists the location, direction, average flow (4:00 pm - 6:00 pm), and the number of observations of lane counts made by MDOT.

PM AVERAGE VEHICLES PER HOUR FROM LANE COUNTS

North/South Arterial Count Locations	Flow* (# Obs.) N	Flow* (# Obs.) S
12th @ N of Lasalle Gardens	626 (3)	124 (4)
12th @ N of Warren	269 (2)	
12th @ S of Grand	413 (2)	
12th @ S of Webb		477 (2)
12th @ N of Glendale	347 (4)	
12th @ S of Canfield	89 (2)	
14th @ N of Euclid		225 (2)
14th @ S of EB 1-94 SD		188 (2)
14th St @ S of Davison		241 (3)
2nd @ S of Chicago	255 (4)	
2nd @ S of Seward	706 (2)	
2nd @ S of Webb	329 (2)	
3rd @ N of Grand	134 (2)	604 (2)
3rd @ N of Webb		64 (2)
3rd @ N of Pallister		132 (2)
3rd @ S of Chicago		112 (2)
Anthony Wayne @ S of Palmer	564 (3)	350 (3)
Anthony Wayne @ S of Warren	376 (3)	634 (3)
Brush @ N. of I-94	343 (2)	
Brush @ S of Holbrook	89 (3)	
Hamilton @ N of McNichols	553 (2)	267 (2)
Hamilton @ S of Oakman	914 (2)	522 (2)
Hamilton @ N of Chicago	417 (4)	124 (4)
Hamilton @ S of Chicago	375 (2)	504 (2)
John R. @ N of Canfield	453 (3)	153 (3)
John R. @ S of Baltimore		291 (2)
John R. @ S of Holbrook		154 (3)
Linwood @ N of Grand	258 (3)	228 (3)
Linwood @ N of Glendale	552 (4)	382 (4)
Oakland @ N of Davison	199 (3)	395 (3)
Oakland @ N of Grand	436 (3)	
Woodward @ N of Glendale	1299 (2)	821 (2)
Woodward @ N of Grand	1394 (2)	747 (3)
Woodward @ N of Manchester		1174 (2)
Woodward @ N of Warren	1409 (2)	881 (2)
Woodward @ S of Warren	1515 (2)	

East/West Arterial Count Locations	Flow* (# Obs.) E	Flow* (# Obs.) W
Caniff @ E of I-75		584 (3)
Chicago @ W of 14th	246 (4)	682 (4)
Chicago @ W of Hamilton	260 (2)	679 (2)
Davison @ W of 14th	1580 (3)	1726 (3)
Davison @ W of Conant	2059 (2)	1505 (3)
Davison @ W of Woodrow Wil.	1846 (4)	
Forest @ E of 3rd	627 (2)	
Forest @ E of Lodge	855 (3)	441 (3)
Forest @ E of Woodward	503 (2)	
Forest @ W of 12th	336 (2)	
Forest @ W of Lodge	570 (3)	
Forest @ W of Woodward	233 (2)	
Grand @ E of 12th		1398 (4)
Grand @ E of Russell	613 (4)	287 (4)
Grand @ E of Woodward	934 (3)	823 (3)
Grand @ W of 14th	581 (4)	1154 (4)
Grand @ W of Linwood	626 (4)	1226 (3)
Grand @ W of Woodward	965 (3)	754 (3)
Grand River @ E of Linwood	238 (2)	528 (2)
Grand River @ N of 12th	258 (2)	477 (2)
Grand River @ S of 12th	198 (2)	459 (2)
Mc Nichols @ W of Woodward		650 (2)
Mc Nichols @ E of Woodward	690 (6)	
Mc Nichols @ W of I-75	828 (3)	781 (4)
Mc Nichols @ W of Linwood	574 (3)	828 (3)
Warren @ W of I-96(Grand Riv.)	329 (3)	742 (3)
Warren @ E of 12th		716 (3)
Warren @ E of Woodward	952 (3)	1370 (2)
Warren @ W of I-75	1509 (3)	1532 (3)
Warren @ W of Russell	960 (3)	760 (3)
Warren @ W of Woodward	750 (2)	1188 (2)

*flow in vehicles per hour
data based on lane counter measures from 4:00 pm - 6:00 pm

Table 2. Location of Tube Counts

Current arterial speed data was not available; therefore, Mitretek conducted a limited number of data collection travel runs along northbound arterial routes considered as alternatives to Lodge northbound traffic. Two to four travel runs each were performed on five north/south facilities in October 1998. The outcomes of these travel runs are shown in Table 3. Mitretek also traveled other east-west and north-south routes and made qualitative assessments of speed characteristics by macro zones. Based on these qualitative assessments, Mitretek sectioned the corridor into seven macro-zones shown in Figure 8 and characterized each zone either as congested, moderate, or free flow. These qualitative values are also shown in Figure 8.

The macro zones are the regions by which system metrics of speed and queues were calculated in simulation. These values were also compared with the qualitative assessments to confirm that simulation model outcomes accurately represented qualitative assessments. Macro zones also provide a first level indicator of shifts in traffic patterns.

AVERAGE SPEED FROM MITRETEK RUNS				
FACILITY/DIRECTION	From	To	Average Speed	Runs
Linwood South	McNichols	Forest	26.8	3
Linwood North	Forest	Mc Nichols	28.5	4
14th St. South	Oakman	Forest	26.9	2
12th St. (Rosa Parks) North	Forest	Oakmon/Linwood	24.8	4
Hamilton South	McNichols	Lodge South	29.6	2
Hamilton North	Lodge North	Mc Nichols	26.3	2
Woodward South	McNichols	Forest	22.8	4
Woodward North	Forest	Mc Nichols	21.9	6

Table 3. Arterial Speed Profiles based on 1998 Data

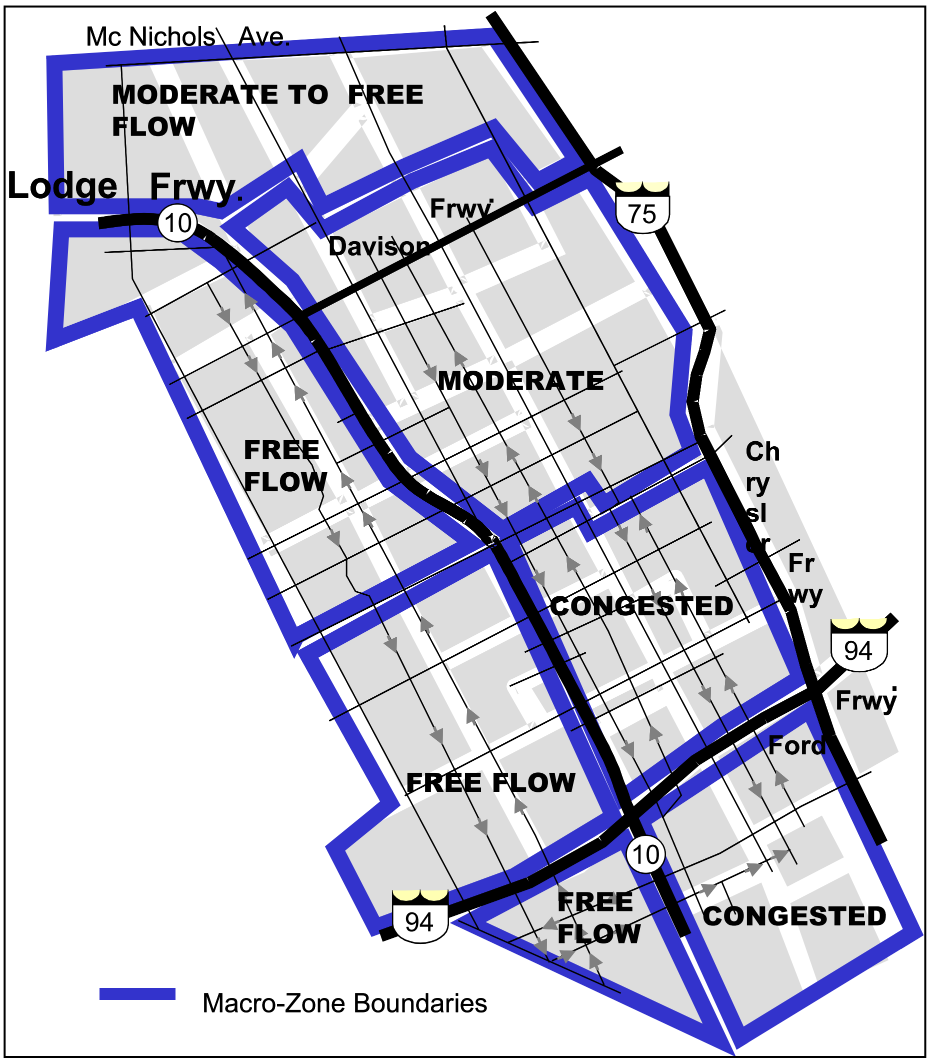

Figure 8. Qualitative Congestion Levels by Macro-Zones

4.0 Simulation Model Selection, Description, and Calibration

A review of commercially available simulation models identified a small set with the ability to both quantify the benefits of ITS technologies and represent urban/freeway networks. These tools included INTEGRATION, AIMSUM2, FLEXSYT II, PARAMICS, and VISSIM. Of these, INTEGRATION was identified as most widely used. [9] Moreover, it was the only one with the ability to model networks of the size required by this project, and support the simulation platforms available for the study. Therefore, INTEGRATION Version 2.0 was initially selected for the simulation task.

INTEGRATION models the progress of individual vehicles as they traverse a network of links from various origins to destinations. An aggregate time-variant demand matrix externally specifies the number of vehicles from each origin to each destination. The aggregate demand is parsed into a series of individual vehicles that enter the network when the simulation clock reaches the vehicle's scheduled departure time. The desired travel speed of the vehicle is determined by the characteristics of the link upon which it is traveling. The actual speed of the vehicle when it enters the network is based on the distance headway between it and the vehicle immediately preceding it. Lane changing decisions and speed updates are performed every 0.10 seconds for each vehicle in this micro-simulation model.

Ini INTEGRATION, a vehicle's decision to traverse one of many links is based on a path table that indicates the appropriate next link, given that vehicle's present location and final destination. Various path tables are created and periodically updated based on historical or prevailing network conditions. Each path table corresponds to a specific vehicle class. Through this process, the INTEGRATION model provides for static and dynamic multi-path routing. A vehicle's progress toward its specified destination is a result of its desired speed, as well as network controls or constraints such as traffic signals, ramp meters, speed limits, and queue formation.

In addition to the demand matrix specification, input on network composition is required to effectively utilize INTEGRATION. The primary network input components include node, link, lane striping, signal control, and incident files. Nodes can be of an origin and/or destination type, or of a link connector type. A link is specified to be a segment of roadway characterized by homogeneity in factors such as the number of lanes, roadway geometry, speed limit, capacity, and lane restrictions. The lane striping file indicates what turning movements are acceptable from each lane. The signal control file specifies the existing signal timing plans of all signalized intersections within the network as well as cycle length boundaries for signal optimization search processes. The incident file lists location, duration, and severity of incidents to be modeled through simulation.

Outputs generated by the INTEGRATION model include vehicle statistics on trip time, trip distance, and number of stops. Link statistics on total flow, average travel time, maximum queue size, maximum vehicle density, average speed, average occupancy, average volume to capacity ratio, and average effective green duration can also be generated.

As with most micro-simulation models, INTEGRATION uses random number streams in its modules. The simulation should be executed for an array of random number streams to verify that differences in alternatives are not attributed to the random stream. The random number stream introduces variability in the vehicle path and time trajectory; therefore, precise agreement between the micro-simulation model and real world data is unlikely. Validation of the model should be based on similarities in mean and variance of field observed and modeled characteristics. Two outputs that can be easily compared with field data are link flow and trip time.

When calibrating the micro-simulation model, the team recognized that a significant activity within the corridor was not well replicated with the model. Within the selected corridor, significant interchange weaving and short length on/off ramp weaving occurs. This could not be properly replicated in the micro-simulation model, which generated unrealistically intense congestion in particular interchange geometries. In addition, the range of parameters within the model overseeing merging and weaving operations could not be adjusted to represent the observed flows in the corridor. Therefore, the team decided to use INTEGRATION Version 1.5, a mesoscopic simulation model similar to the microscopic model. By transitioning to this model, the project team lost the ability to model detailed lane-based weaving and merging activities and detailed signalization related to turning and queuing. With this transition, freeway-to-freeway merge issues were dissipated, but at the expense of detailed signalization and ramp metering modeling. In the mesoscopic model, the time interval of vehicle decision-making increased from 0.1 seconds to 1.0 seconds, reducing detail with which vehicle reactions to signals and ramp meters could modeled. The available traffic metrics generated by both models are overwhelmingly similar.

A significant consideration for the simulation approach is the inability of the simulation model to explicitly represent changes in trip timing choices of commuters that occur due to the introduction of the ITS. Also, the study area precludes representation of trip-segments outside the network. Thus, route changes that modify corridor entry point, exit point, or bypass the corridor entirely may be overlooked in our study. These issues were outside the scope of the project, and may be good topics for future research.

The physical and operational characteristics of the corridor, along with the demand characteristics of the region in terms of trip origins, destinations, and frequencies were represented using an array of data sources and processes. The following three subsections describe the tasks in model development.

4.1 Physical and Operational Representation

Network geometry data defines the connectivity and right of way for vehicle progression. Types of geometric and right of way data accounted in the simulation model include nodal coordinate (x, y) values, road lengths, number of lanes per segment, free flow and congested density speeds per segment, lane prohibited movements, facility or lane use restrictions, directionality restrictions, ramp length and configuration, signal locations, signal controller type, signal cycle length and phase operation, ramp meter location, ramp meter hours of operation, ramp meter control type, and stop and yield sign locations. These data were obtained through the following sources:

- Etak, Inc --Latitude and longitudinal coordinates of roadways profiles with a resolution of 0.05 miles. Data were transformed to generate node coordinates and link lengths.

- Michigan DOT Plans of Proposed Traffic Signals for the City of Detroit & Highland Park – Intersection layout plan views with lane striping (1997).

- Michigan DOT Detroit Area Freeway Surveillance, Control & Driver Information System General Plans -Loop detector location, ramp merge profiles, and number of lanes (1980).

- City of Detroit, Department of Transportation Signal Timing Plans –Signal cycle, phase, and offset data for existing signal operation (1952-1998).

- City of Highland Park, Department of Transportation Signal Timing Plans –Signal cycle, phase, and offset data for existing signal operation (1952-1998).

- GPS Odograph Roadway Profiles --Arterial and freeway speed and travel time profiles conducted by Mitretek Systems (1997-1998).

- Mitretek Roadway Observation – Arterial and freeway physical lane, signage, and signalization observations conducted by Mitretek Systems (1997-1998).

From these data sources, a physical network of approximately 950 nodes, 2000 links, 230 signals, and 16ramp meters, was generated.

4.2 Demand Estimation

The creation of the OD distributions for the PM peak hours required a series of tasks to extract the needed INTEGRATION inputs from available data. A number of sources of data were utilized to approximate OD distributions within the study corridor and to transform the distribution into INTEGRATION-specific demand data. 1995 planning data was downloaded from the SEMCOG website. This data showed household, population and employment figures for planning zones throughout the study corridor. Based on these zones and their figures, INTEGRATION network OD locations were added or moved to more accurately reflect origin and destination distributions. 1995 average daily traffic (ADT) planning volume data for many links within the study corridor was downloaded from the SEMCOG website.

The planning data showed households and employment figures for all zones within the corridor, but it did not break them down into periods by time of day. The following steps and assumptions were applied to derive approximate OD numbers for the 4:00 pm – 6:00 pm peak period:

- Assume each household contributes a single vehicle to the "supply pool" on a daily basis.
- Assume a 10% reduction in this number for inner-OD travel or unemployment.
- Assume that of the remaining households, 50% work/travel on a first-shift basis, and therefore would contribute to PM peak traffic. This factor is applied to both household and employment values.
- On a gross basis, for zones containing multiple model OD locations, assume the both the household and employment totals are evenly distributed among the ODs.
- Examine each OD for what it represents, and modify its supply and demand accordingly. For example, parking garages were assumed to be generators only, having no demand during the PM peak, as were factories specifically represented by OD nodes.

Since supply and demand for the network should balance, variable destination values were uniformly adjusted for each period until demand equaled supply. Once each origin and destination value was determined, an OD matrix could be developed to approximate travel patterns within the corridor. For Detroit, this was a 120 X 120 matrix. A linear program was created in Excel to distribute volumes within the matrix. Origin and destination estimates were used as constraints to the program, as were various assumptions applied to certain OD pairs. For example, through traffic on Lodge from the CBD was assumed to be a certain percentage of the total for the corresponding origin and destination. In addition, no vehicles were assumed destined for parking garages and factories. A number of proximate external origins and destinations were assumed to have no traffic interaction. Some non-proximate origins and destinations with more viable alternate routes external to the network also were assumed to not interact.

Once these assumptions were in place, the program was run on an iterative basis to distribute volumes. An iteration consisted of two steps: first distribute volume from each origin to each destination based on the level of demand at the destination, then modify these values for each destination based on its surplus/deficit resulting from the origin estimates. Theoretically this process would converge until all origins and destinations had no surplus or deficit volume; however, for large matrices this convergence could take a significant amount of time. Therefore, distributions were considered reasonable after five iterations, and then remainders were randomly distributed in pairs (one origin to another at the same destination) until all volumes balanced. Once complete, this matrix was exported to a format compatible with INTEGRATION.

The network simulation was designed to analyze time-variant traffic demand; thus, most OD matrix required some form of reduction before it could be input to the model. Review of time-variant data indicated rather flat variation of flow during the PM peak period. Moreover, for arterial facilities, time-variance of flow could be established only on the basis of two to four days of data. Therefore, demand predominantly on arterial facilities was maintained constant where demand predominantly on freeway facilities was modified to impose time variance in flow observed on Lodge Freeway. This further step broke the PM-peak OD matrix into time-variant periods to input to the model.

4.3 Flow Calibration

The demand matrix developed for this study reflects zonal relationships between trip origins and destinations. The distribution of trips within a zone was based on the assumption of equal demand and generation of trips through out the zone. This assumption was removed in the flow calibration phase of the model. Clearly, flows provide greater detail as to which roads within a zone carry greater vehicle traffic. This information was used to adjust the distribution of demand within zones to better represent observed flow values. Values of free-flow speeds, congestion density and speed at capacity were also adjusted to represent the flow/speed conditions on freeway and arterial facilities. The study highlighted the outcomes of the calibration process first in terms of flow on freeways, followed by flow on arterial facilities and speed on both freeway and arterial facilities.

All this calibration achieved the goal of ensuring that the model accurately represented reality. Based on the physical, operational, demand, and flow calibrations made, simulation flows along major freeways were within 5% of observed flows. For the Lodge freeway facility, average simulation flow was within 2% of observed flow. Figure 9 charts the observed versus simulation flow along the Lodge freeway averaged over the peak period of analysis. The time and location-based average flow is 5450 vph for Lodge north and 3500 vph for Lodge south. For Lodge northbound, flow and consequently congestion generally increases from I-94 to the north-most end of Lodge, corresponding to commuters entering the freeway to reach their destinations outside the study region via Lodge freeway.

As compared to the average flow along the Lodge facility shown in Figure 9, Figure 10 presents the flow on the Lodge Freeway by time during the PM peak period and averaged across the facility. Flow on Lodge does vary throughout the PM-peak period; however, the variance in flow along the freeway was much greater than the variance of flow by time during the PM-peak period. As with the calibration of average flow on various freeway facilities, time-variance of flow along Lodge was within 2% of observed time-variance. Simulation time-variance on I-94 was within 5% of observed time variance. Time variance on I-75 could not be evaluated due to the unavailability of such data.

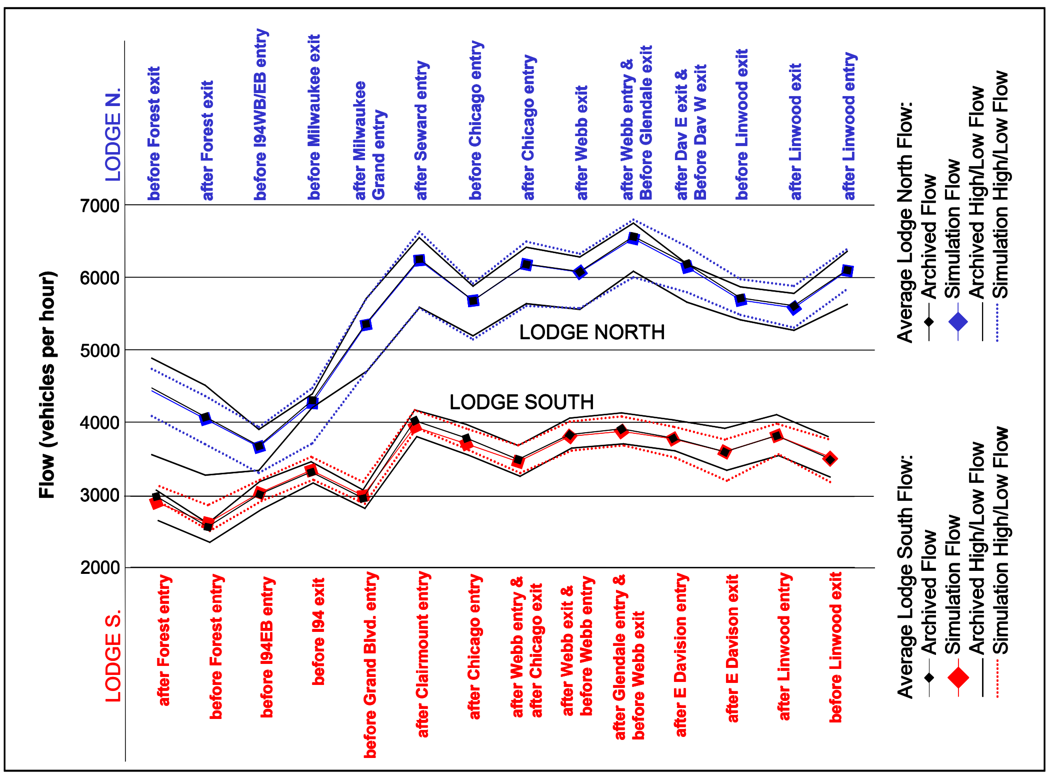

Figure 9. PM Average Observed versus Simulation Flow Along Lodge Freeway

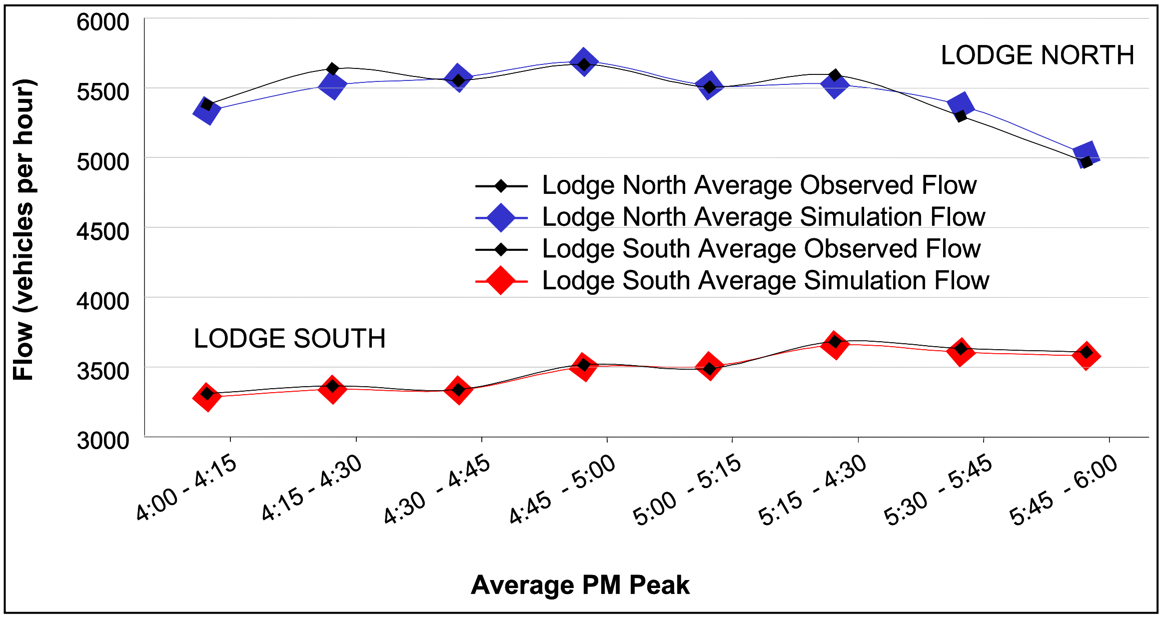

Figure 10. Facility Average Observed versus Simulation Flow on Lodge over PM-Peak

Arterial flows for north/south facilities in the simulation were overwhelmingly within 10% of observed flow values. Where flow observations were more than 10% different from simulation, the difference in terms of vehicles per hour (vph) was less than 50vph. The limited number of observations for time-variance of flow, ranging from one to four, for arterial locations precluded the conduct of time-variance calibration.

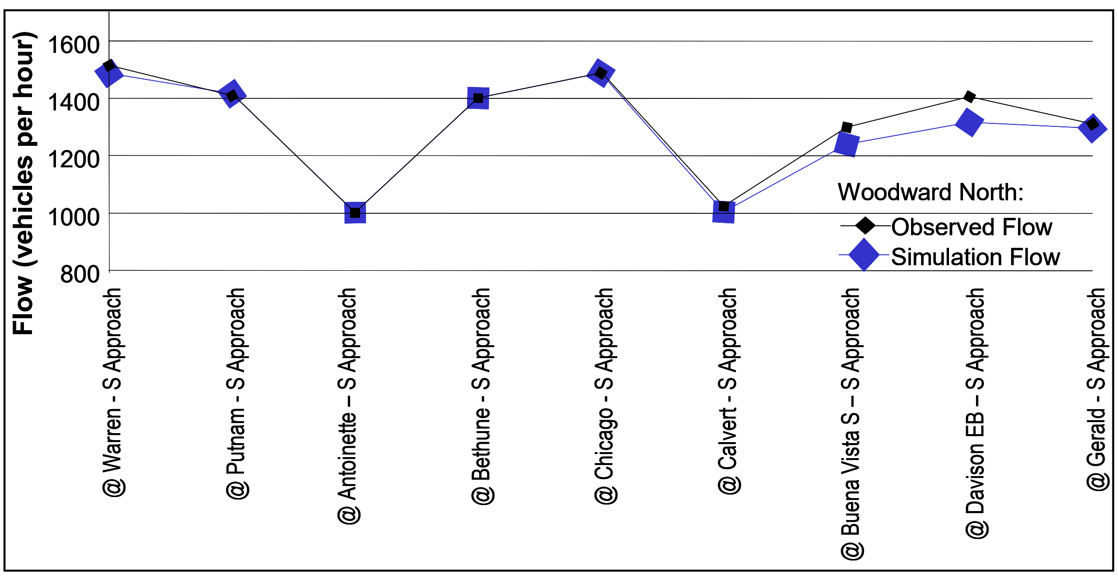

Figure 11. Woodward North Average Observed versus Simulation Flow

The average speeds on freeway and arterial facilities were within 5% of observed average speeds. The average simulation speed along Lodge Freeway is 59.6 mph whereas the observed average speed was 60.0 mph. In simulation, the range of peak period average link speeds for Lodge Freeway is 42 – 68 mph. The observed range of average point speeds along Lodge Freeway was 42 – 71 mph. Link speeds on Linwood, Rosa Parks, Woodward, and Hamilton ranged from 15 – 36 mph with an average of 28 mph in simulation. Observed speed traversing these facilities also averaged 28 mph.

5.0 Simulation Alternatives and Scenarios

By comparing simulation runs of existing ITS with simulation runs without ITS or with component ITS, the performance of the corridor ITS infrastructure could be gauged. The task was to identify and evaluate a number of alternative ITS solutions or strategies (referred to as alternatives) that could address recurrent or non-recurrent congestion. The effectiveness of specific alternatives is related to the source of system variability, be it an accident, or a demand change (referred to as scenarios). Each simulation option was modeled six times corresponding to different random number streams to verify that differences in output were attributable to the option modeled rather than the random number stream used.

The alternatives analysis was also affected by the level of market penetration of specific ITS technologies and on the level of bias against the Lodge Freeway's arterial alternatives. In the absence of market penetration information, we evaluated all technologies assuming a 2% market penetration with homogeneous geographic penetration. The following subsection details the outcome of the freeway bias issue and its implications on simulation. The next subsections detail the alternatives and scenarios evaluated in this study.

5.1 Freeway Bias Evaluation

As stated previously, freeway bias can be shown to exist when an arterial route provides a significantly better travel time than a parallel freeway route whose performance is degraded by recurrent congestion, but motorists choose the freeway. In order to first statistically analyze whether speed characteristics of the corridor imply the potential for freeway bias, we required estimates of travel time on arterial and freeway facilities. To conduct more detailed statistical analyses, travel time estimates during freeway incident conditions on both the freeway and parallel arterial facilities would also be required.

Michigan State University (MSU) had point speed estimates from 1996 and 1997 along the Lodge and I-94 freeway facilities. Also MDOT provided point speed estimates for two months in 1998 along the Lodge freeway. These freeway data were not sufficient to conduct more detailed statistical analyses. Based on MSU data, travel on Lodge northbound from 4:00pm to 6:00pm is at speeds of 61mph with a standard deviation of 10 mph. Based on the two months of MDOT data, travel on Lodge northbound from 4:00pm to 6:00pm is at a speed of about 58 mph.

MDOT did not have point speed or travel time estimates on arterial facilities. Therefore, Mitretek Systems conducted limited travel time studies on the major northbound arterials within the corridor. Travel time northbound along Linwood Ave., Rosa Parks Ave., Hamilton Ave., Woodward Ave., and I-75 were measured during the 4:00 pm to 6:00 pm period for three consecutive days in February 1998. Conversion of travel time to travel speed along the arterial facilities yielded speed ranges from 20 mph (Woodward Ave.) to 30 mph (Hamilton Ave.). Travel speed on I-75 northbound averaged 63 mph.

Based on the set of available arterial and freeway speed data, Mitretek concluded that during average conditions, freeways provide the better alternative for northbound travel. Because MDOT was unable to provide data during incident conditions, Mitretek cannot evaluate whether freeway bias does occur during atypically congested freeway conditions. As such, the queries pertaining to freeway bias were not carried over to the simulation phase of the analyses.

5.2 Alternatives

The set of alternatives considered were all of the "no-build" variety in the traditional Major Investment Study sense. However, the alternatives included a retrospective evaluation of isolated components of the currently installed systems and proposed improvements to the currently installed ITS system. The system improvements modeled would not require geometric modifications such as additional lanes or left-turn bays. Following are the five classes of alternatives that are evaluated through simulation:

Existing ITS --This is the baseline scenario. It models the current transportation systems, infrastructure, and services within the corridor, and is calibrated to approximate existing traffic patterns. The corridor currently has ITS elements that are included in this alternative. These include CMS signs, HAR coverage over the entire network, pre-trip informational available and updated real-time, and active ramp meters. The market penetration of use of the CMS, HAR, and pre-trip information is assumed at 6% for the population with a breakout of 2% adherence to each technology.

No ITS --This is one of three retrospective alternatives. The No ITS alternative models the current corridor with current demand but without current ITS infrastructure or operations. In this alternative we removed the ramp meters, as well as CMS, HAR, and pre-trip information. In this way we isolated the beneficial impact of ITS (Existing ITS alternative) when compared to this alternative.

Only Ramp Metering --This a retrospective alternative to evaluate the impacts of the installed ramp meters in the absence of traveler information services.

Only CMS --This a retrospective alternative to evaluate the impacts of the installed CMS signs in the absence of the other two traveler information services and in the absence of ramp meters.

No Ramp Metering –This is a prospective future system alternative that explores the option of turning off the ramp meters for the 'existing' ITS scenario. CMS, HAR, and pre-trip information are modeled in this alternative, and ramp meters are removed.

Existing ITS with Accident-Responsive Signal Coordination –Currently, the signals within the corridor are coordinated on a local basis; i.e. little consideration has been given to signal timing impacts relative to overall network performance. In addition, no consideration has been given to signal optimization in circumstances of additional freeway diversion. Successful diversion strategies will require optimized coordination along the surface arterials. In this alternative we re-timed signals along Hamilton Avenue for an incident scenario. The basis for selecting Hamilton Avenue is discussed in detail in the results section pertaining to this alternative.

Initially, alternatives involving retiming of signals along major northbound arterials for normal peak conditions were also considered. These, however, were dropped after an initial evaluation of the current ITS system showed minimal/non-existent queue spillback along the alternate arterials of Linwood, Rosa Parks, and Hamilton.

5.3 Scenarios

Each alternative was evaluated under a variety of traffic demand and supply scenarios. Specifically, four demand and four supply conditions are considered in the evaluation. These variations were selected to evaluate the impacts of ITS technologies on the northbound flow of traffic along Lodge freeway. The four demands modeled in our study include an average demand and three variations on the average demand:

- Average PM peak demand from 4:00-6:00 p.m.,
- Average demand with a 10% increase in trips from the CBD region to the Detroit suburbs via the Lodge freeway
- Average demand with a 25% increase in trips from 4:30 – 5:00 pm from the CBD region to the Detroit suburbs via the Lodge freeway.
- A Global trip increase of 5% from all origins to all destinations representing a regional traffic increase.

The four supply variations were selected on the basis of historical frequency data on incident location provided by MDOT. Figure 12 provides a histogram of incident frequency along the Lodge freeway based on years 1993 to 1997. The modeled incidents were selected to represent a range of events that are relatively common and would yield a spatial, temporal, and magnitude variation in impact. The modeled supply variations include:

- No incidents in the corridor
- Major incident on Lodge Northbound (3 lanes) before the exit for Davison East. The incident lasts from 4:15 to 5:15 pm, effectively reducing capacity by 66% for the first half hour and reducing capacity by 33% for the second half hour.
- Major incident on Lodge Northbound (3 lanes) before the exit for I-94 East. The incident lasts from 4:45 to 5:00 pm, effectively reducing capacity by 100% for the first 15 minutes and 66% for the next 15 minutes. In addition, a minor incident occurs on Lodge Northbound (3 lanes) before the Webb St. exit from 4:30 to 5:30 pm, effectively reducing capacity by 33%.
- Two minor incidents occur. The first occurs on Lodge Northbound (4 lanes) before the Linwood exit, effectively reducing freeway capacity by 25% from 4:15 to 4:45 pm. The second occurs on Lodge Northbound (3 lanes) before the Webb exit, effectively reducing freeway capacity by 33% from 4:15 to 4:30 pm.

A combination of a specific demand and supply is referred to as a scenario. The set of possible scenarios for each alternative is 16. The scenario of average demand and no incidents in the corridor is referred to as the non-event scenario. All other scenarios are referred to as event scenarios.

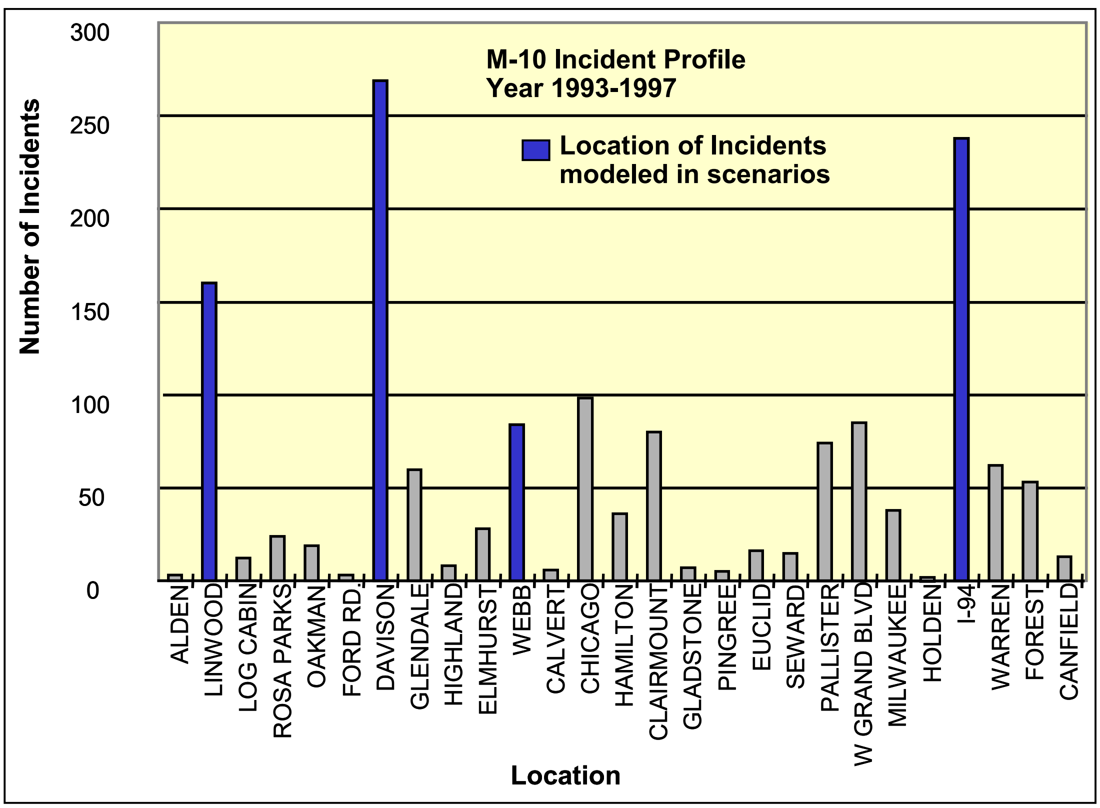

Figure 12. Frequency of Incidents along Lodge Freeway from 1993-1997

6.0 Results

Each alternative except for the Accident Signal Coordination alternative was evaluated for each possible combination of demand and supply conditions. The Existing ITS with Accident-Responsive Signal Coordination alternative was evaluated for one scenario, that of average demand and one supply variation (an incident). In total, over 80 simulation alternative-scenarios were evaluated with each scenario simulated six times with different random number streams. This section presents the outcomes of these simulations.

Figure 13 presents the comparisons among and within alternatives explored in this section. The numbered triangles in Figure 13 are referenced throughout this section to clarify what scenarios and alternatives are being compared. The team first analyzed the No ITS alternative *corridor level* outcomes for the average demand and no incident scenario (called the *non-event* scenario). We then compared at the corridor level the No ITS alternative scenarios (where either demand varied from the average or incidents occurred) to the non-event scenario. The event and non-event outcomes were then explored for the No ITS alternative at the *facility level*, specifically for Lodge north.

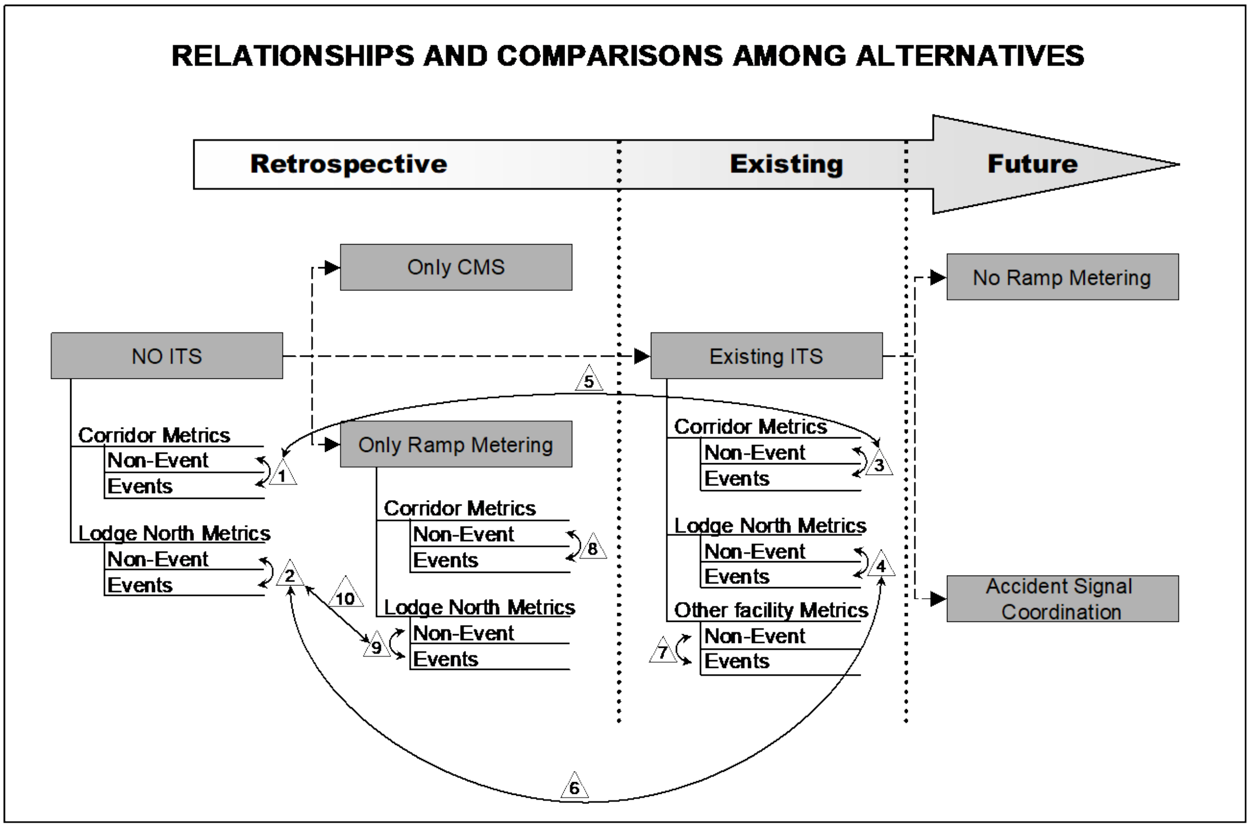

Figure 13. Schema for Exploring Simulation Outcomes

After discussing results for the No ITS alternative, this document presents results for the Existing ITS alternative. Here, comparisons were also made between the Existing ITS scenarios' outcomes and comparable outcomes in the No ITS scenarios. These comparisons highlight the impacts of the existing ITS technologies under a range of potential transportation system realities. In this section, benefits by commuter type (those adhering to or not using various ITS services) are explored. Significant impacts from the existing ITS infrastructure on arterials providing access to Lodge north or other facilities are presented. To conclude the exploration of the Existing ITS alternative, outcomes are compared for the Existing ITS scenario with average demand a major incident on Lodge north prior to Davison to the Existing ITS non-event and the No ITS parallel event scenarios.

The next section explores the two retrospective, isolated component ITS alternatives: Only Ramp Metering and Only CMS. These analyses reveal which ATIS components yield the greatest benefits and how benefits vary by traffic conditions. Analyses where outcomes are statistically and practically significant are presented. For these alternatives, comparisons are also made between the alternative's outcome and comparable outcomes in the No ITS and Existing ITS alternatives.

The final subsection presents the analysis of the No Ramp Metering and the Accident Signal Coordination alternatives. These are prospective, or future, alternatives that evaluate the implications of operational changes. Comparisons are made between the prospective and the Existing ITS alternatives.

6.1 No ITS Alternative

Table 4 lists the corridor metrics of throughput, speed, trip time, and delay for the 16 scenarios modeled for this alternative. Comparisons made in this paragraph are represented in Figure 13 by $\triangle$. Corridor throughput, measured by the number of completed trips per hour, is 48,080 for the non-event scenario. Link averaged speed and average trip time in the corridor for the non-event scenario are 36.4 miles per hour (mph) and 5.7 minutes. For event scenarios, corridor throughput ranges from 46,490 to 50,070, average speed ranges from 35.6 to 36.3 mph, and average trip time ranges from 5.9 to 8.8 minutes. The average delay for trips in the corridor ranged from 0.25 to 3.0 minutes for event scenarios compared to the non-event scenario trip time.

The worst incident scenario reduces corridor throughput by 3.3% and causes average travel time to increase by 53% for all trips in the corridor for the PM peak period modeled. The differences between each event scenario and the non-event scenario in terms of speed, trip time, and delay are statistically significant. Throughput differences are also statistically significant for all except for the three scenarios. Throughput differences were not statistically significant in scenarios where minor incidents occur with either average, or when there is an increase in Lodge mainline demand.

No ITS Alternative: Corridor Metrics

Incident Occurrence		Demand Occurrence	Throughput: finished trips/hour	Throughput: %Δ	Speed: miles/hour	Speed: %Δ	Trip Time (minutes)	Delay (min.)
	None	Average Demand	48081		36.41		5.7	
		10% increase CLS*	48266	0.4%	36.25	-0.4%	5.9	0.25
		25% 1/2 hour inc. CLS	48248	0.3%	36.27	-0.4%	5.9	0.24
		5% Global increase	50070	4.1%	36.15	-0.7%	6.1	0.41
	Lodge N at Davison (major)	Average Demand	46581	-3.1%	35.74	-1.8%	8.3	2.56
		10% increase CLS	46490	-3.3%	35.71	-1.9%	8.7	3.00
		25% 1/2 hour inc. CLS	46503	-3.3%	35.72	-1.9%	8.6	2.95
		5% Global increase	48258	0.4%	35.56	-2.3%	8.8	3.07
	Lodge N major and minor	Average Demand	47132	-2.0%	36.01	-1.1%	7.0	1.26
		10% increase CLS	47081	-2.1%	35.94	-1.3%	7.3	1.61
		25% 1/2 hour inc. CLS	47053	-2.1%	35.95	-1.3%	7.3	1.65
		5% Global increase	48888	1.7%	35.81	-1.6%	7.4	1.73
	Lodge N Two Minor	Average Demand	48023	-0.1%	36.24	-0.5%	6.1	0.37
		10% increase CLS	48023	-0.1%	36.09	-0.9%	6.4	0.72
		25% 1/2 hour inc. CLS	48010	-0.1%	36.11	-0.8%	6.4	0.71
		5% Global increase	49824	3.6%	35.98	-1.2%	6.6	0.88

* CLS = CBD to Lodge Suburbs

** Delay = trip $\text{time}_{\text{event scenario}}$ - trip $\text{time}_{\text{Non-event scenario}}$

%Δ = (Event Scenario - Non-Event Scenario)/Non-Event Scenario

Table 4. No ITS Alternative: Corridor Metrics

Table 5 lists the Lodge north metrics of flow, speed, trip time, and delay for the 16 scenarios modeled in this alternative. These metrics are based on all links in the corridor that are a component of Lodge north as well as all trips that for the non-event scenario traverse the entire stretch of Lodge north. Comparisons made in this and the following paragraphs are represented in Figure 13 by Δ. For the non-event scenario, average flow, speed, stops per mile and trip time are 5142 vph, 59.5 mph, 680 stops per mile, and 7.7 minutes respectively. Flow on Lodge north increases by as much as 6% from the non-event scenario, corresponding to a 10% increase in trips on the facility. The increases in flow occur at the expense of speeds decreases, by as much as 9 mph due to overcrowding on the freeways. Flow decreases by as much as 15% from the non-event scenario, corresponding to the major accident at Davison. Moreover, where flow decreases from the non-event scenario due to a major accident, speed decreases by as much as 24 mph over the peak period on Lodge north.

Trip time and stops per mile proved much more sensitive to perturbations in traffic than the other metrics used. Trip time increase by 4 fold in some event scenarios compared to the non-event scenario, and the number of stops per mile increase by as much as 350% compared to the non-event scenario stops per mile.

As expected, facility-level variations in traffic performance, either from increases in demand or from decreases in supply, were more pronounced at the facility level, but also have repercussions that can be observed at the corridor level. The measures of impact we used were more sensitive to modeled supply variations than to demand variations.

No ITS Alternative: Lodge North Metrics

			Flow		Speed		Stops / mile		Trip	
Incident Occurrence		**Demand Occurrence**	veh. / hour	%Δ	miles / hour	%Δ	number	%Δ	Time (min.)	Delay ** (min.)
	None	Average Demand	5142		59		679		8	
		10% increase CLS*	5438	6%	55	-8%	937	38%	10	1.9
		25% 1/2 hour inc. CLS	5352	4%	55	-7%	900	33%	10	1.9
		5% Global increase	5365	4%	55	-7%	899	32%	9	1.7
	Lodge N at Davison (major)	Average Demand	4399	-14%	38	-36%	2695	297%	29	21.5
		10% increase CLS	4395	-15%	35	-41%	3054	350%	32	24.4
		25% 1/2 hour inc. CLS	4373	-15%	36	-40%	3042	348%	32	24.5
		5% Global increase	4367	-15%	36	-40%	3013	344%	31	23.8
	Lodge N major and minor	Average Demand	4709	-8%	48	-19%	1729	155%	19	11.5
		10% increase CLS	4784	-7%	45	-25%	2099	209%	22	13.9
		25% 1/2 hour inc. CLS	4737	-8%	45	-25%	2096	209%	22	14.7
		5% Global increase	4765	-7%	46	-23%	2015	197%	21	13.5
	Lodge N Two Minor	Average Demand	5131	0%	54	-9%	985	45%	11	3.1
		10% increase CLS	5336	4%	50	-15%	1328	95%	14	5.9
		25% 1/2 hour inc. CLS	5263	2%	51	-15%	1298	91%	14	6.1
		5% Global increase	5268	2%	51	-14%	1268	87%	13	5.4

* CLS = CBD to Lodge Suburbs

** Delay = trip time$_{\text{event scenario}}$ - trip time$_{\text{Non-event scenario}}$

%Δ = (Event Scenario - Non-Event Scenario)/Non-Event Scenario

Table 5. No ITS Alternative: Lodge North Metrics

6.2 Existing ITS

In this section we present the results for the Existing ITS alternative parallel to those highlighted for the No ITS alternative in the previous section. Comparisons are also made between the event scenario outcomes of these two sets of alternatives for all commuters and by commuter type. These comparisons are represented in Figure 13 by △5. Commuter type refers to whether the trip employed ITS information or technologies in selecting route

We first explore the aggregate corridor impacts of the Existing ITS alternative for system and user impacts. Next, impacts focused on the Lodge northbound facility are discussed. This section concludes with a detailed outcomes exploration of one scenario compared to the non-event scenario for the Existing ITS alternative and the No ITS alternative.

6.2.1 Corridor Impacts

Table 6 lists the Existing ITS metrics at the corridor level. The corridor throughput (completed trips per hour) speed, and average trip time for the Existing ITS non-event scenario are 48,050, 36.3 mph and 5.7 minutes respectively. The differences between these values and parallel values of the No ITS alternative are not statistically significant. As such, we conclude that existing ITS infrastructure neither helps nor harms system or trip performance at the corridor level when traffic demand is average and no incidents or other supply variations occur. Intuitively, this makes sense: ITS information and flow control devices have limited system-wide benefit when traffic is normal and matches driver expectations.

For event scenarios, corridor throughput ranges from 46,530 to 50,050, corridor speed ranges from 35.5 to 36.2 mph and trip time ranges from 5.9 to 8.6 minutes. Here again corridor level differences are not statistically significant in terms of throughput or speed between the No ITS and Existing ITS alternatives. Delays between the No ITS and Existing ITS event scenarios are different. Delay reductions attributed to ITS are greatest in scenarios with a major incident on Lodge north at Davison. For scenarios with this major incident, existing ITS technologies and information use reduces delay by 0.18 to 0.22 minutes per trip. This is a 320-hour aggregate reduction in delay during the pm peak period for the major incident scenarios. This and the following comparisons related to delay are represented in Figure 13 by △5.

Existing ITS Alternative: Corridor Metrics								
			Throughput		Speed			
Incident Occurrence		Demand Occurrence	finished trips/hour	%Δ3	miles/ hour	%Δ3	Trip Time (minutes)	Delay** (min.)
	None	Average Demand	48052		36.34		5.7	
		10% increase CLS*	48253	0.4%	36.19	-0.4%	5.9	0.24
		25% 1/2 hour inc. CLS	48252	0.4%	36.22	-0.3%	5.9	0.22
		5% Global increase	50049	4.2%	36.08	-0.7%	6.1	0.40
	Lodge N at Davison (major)	Average Demand	46593	-3.0%	35.67	-1.8%	8.1	2.38
		10% increase CLS	46522	-3.2%	35.60	-2.0%	8.5	2.78
		25% 1/2 hour inc. CLS	46534	-3.2%	35.63	-2.0%	8.5	2.75
		5% Global increase	48314	0.5%	35.48	-2.4%	8.6	2.85
	Lodge N major and minor	Average Demand	47043	-2.1%	35.98	-1.0%	6.9	1.22
		10% increase CLS	47035	-2.1%	35.88	-1.3%	7.2	1.53
		25% 1/2 hour inc. CLS	46998	-2.2%	35.89	-1.2%	7.3	1.57
		5% Global increase	48827	1.6%	35.77	-1.6%	7.4	1.66
	Lodge N Two Minor	Average Demand	48047	0.0%	36.19	-0.4%	6.0	0.30
		10% increase CLS	48112	0.1%	36.05	-0.8%	6.3	0.61
		25% 1/2 hour inc. CLS	48085	0.1%	36.05	-0.8%	6.3	0.62
		5% Global increase	49899	3.8%	35.94	-1.1%	6.5	0.78

* CLS = CBD to Lodge Suburbs

** Delay = $\text{trip time}_{\text{event scenario}} - \text{trip time}_{\text{Non-event scenario}}$

%Δ3 = (Event Scenario - Non-Event Scenario)/Non-Event Scenario

Table 6. Existing ITS Alternative: Corridor Metrics

Trip times, and therefore delays, are much smaller for commuters using ITS traveler information services than for those not using traveler information. Under some event scenarios, the TS user may completely eliminate delay or enjoy lower travel times than the non-event scenario. However, ITS users may reduce their own delay by switching routes, but may cause ITS non-users traversing the switched route to incur greater delays. The previous paragraph evaluated the aggregate commuter impact at the corridor level. The following paragraph evaluates impact at the corridor level by the following commuter types:

- ITS non-users ~travelers that do not use any traveler information and maintain their non-event routes,
- CMS users ~travelers that change their route based on CMS information as they cross the CMS,
- Pre-Trip users ~travelers that select shortest time route, based on pre-trip information, and
- HAR users ~ travelers that modify route based on HAR information after trip start.

Table 7 presents the average delay for trips in the corridor by commuter type for the Existing ITS and No ITS alternatives. ITS benefits even non-users, typically lowering their delays. In 12 of 15 scenarios the ITS non-users in the Existing ITS alternative experience a lower delay than ITS non-users in the No ITS alternative. In three of 15 Existing ITS scenarios, ITS non-user delays are slightly higher than parallel No ITS scenarios, but never higher than 0.02 minutes on average. This suggests that impacts on ITS non-users at the corridor level when negative are relatively minimal. ITS users reduce anywhere from 35% or more of the delay that commuters in the No ITS alternative incur during event scenarios. Commuters using pre-trip or HAR information reap the greatest benefits in terms of delay reduction. These commuters incur at most 16% of the delay incurred by the No ITS commuter for any scenario aggregated at the corridor level.

Existing ITS v. No ITS Alternatives: Corridor Delay By Commuter Type

Incident Occurrence	Demand Occurrence	No ITS Altern. delay* (min)	Existing ITS Alternative: ITS non-user delay**	%Δ	CMS user delay**	%Δ	Pre-trip user delay**	%Δ	HAR user delay**	%Δ
None	Average Demand									
	10% increase CLS*	0.3	0.3	-2%	-0.1		-0.1		-0.1	
	25% 1/2 hour inc. CLS	0.2	0.2	1%	-0.1		-0.2		-0.1	
	5% Global increase	0.4	0.4	-3%	0.0	92%	0.0	98%	0.1	84%
Lodge N at Davison (major)	Average Demand	2.6	2.5	3%	1.6	36%	0.2	91%	0.2	93%
	10% increase CLS	3.0	2.9	3%	1.9	36%	0.3	89%	0.2	92%
	25% 1/2 hour inc. CLS	2.9	2.9	2%	1.9	35%	0.3	91%	0.2	93%
	5% Global increase	3.1	3.0	3%	1.9	38%	0.5	82%	0.4	86%
Lodge N major and minor	Average Demand	1.3	1.3	-2%	0.7	46%	0.0		-0.1	
	10% increase CLS	1.6	1.6	0%	0.9	44%	0.1	94%	0.0	98%
	25% 1/2 hour inc. CLS	1.6	1.6	0%	0.9	43%	0.1	96%	0.1	97%
	5% Global increase	1.7	1.7	0%	1.0	44%	0.2	86%	0.2	86%
Lodge N Two Minor	Average Demand	0.4	0.3	11%	0.0		-0.1		-0.1	
	10% increase CLS	0.7	0.7	9%	0.2	77%	-0.1		-0.1	
	25% 1/2 hour inc. CLS	0.7	0.7	7%	0.2	75%	-0.1		-0.1	
	5% Global increase	0.9	0.8	7%	0.3	66%	0.1	89%	0.1	88%

note: negativ delay results when scenario event trip time for the commuter type is less than the non-event scenario trip time averaged across all commuters.

* CLS = CBD to Lodge Suburbs

**delay = (trip time$_{\text{event scenario}}$ - trip time$_{\text{non-event scenario all commuters}}$) within Alternative

%Δ = (delay$_{\text{Existing ITS scenario}}$ - delay$_{\text{No ITS scenario}}$)/delay$_{\text{No ITS scenario}}$

Table 7. Existing ITS Versus No ITS Alternatives: Corridor Delay by Commuter Type

6.2.2 Lodge North and Other Facility Metrics

Table 8 lists the Lodge north metrics of flow, speed, trip time, and delay for the 16 scenarios modeled in the Existing ITS alternative. These metrics are based on all links in the corridor that are a component of Lodge north as well as trips that for the non-event scenario traverse the entire stretch of Lodge north. Comparisons made in the following paragraphs are represented in Figure 13 by Δ4 and Δ6.

For the Existing ITS non-event scenario average flow, speed, vehicle stops per mile, and trip time on Lodge north are 5140 vph, 59.6 mph, 680 stops per mile, and 7.8 minutes respectively. Metrics for this Existing ITS non-event scenario are not statistically different from the No ITS alternative's non-event scenario. ITS doesn't have much impact if there is no incident. The alternatives do differ in non-event scenario facility metrics pertaining to freeway onramps. The average speeds of ramp-metered onramps in the Existing ITS alternative are about 8 mph less than the parallel value in the No ITS alternative. The fact that flow on Lodge is not statistically different between alternatives, and that speed on ramp meters is reduced in the Existing ITS alternative non-event scenario, suggests that ramp metering is not beneficial during the PM period when changes to average traffic do not occur. With the exception of freeway-metered ramps, facility-level metrics for the non-event scenario are not statistically different between the Existing ITS and the No ITS alternatives.

Existing ITS Alternative: Lodge North Metrics

Incident Occurrence		Demand Occurrence	Flow: veh. / hour	Flow: %Δ4	Speed: miles / hour	Speed: %Δ4	Stops / Mile: number	Stops / Mile: %Δ4	Trip Time (min.)	Delay ** (min.)
Incident Occurrence	None	Average Demand	5141		60		679		8	
		10% increase CLS*	5432	6%	55	-7%	925	36%	10	1.9
		25% 1/2 hour inc. CLS	5333	4%	56	-6%	873	29%	10	1.7
		5% Global increase	5360	4%	56	-7%	887	31%	10	1.7
	Lodge N at Davison (major)	Average Demand	4540	-12%	43	-27%	2139	215%	25	17.5
		10% increase CLS	4636	-10%	39	-34%	2522	272%	28	19.8
		25% 1/2 hour inc. CLS	4600	-11%	40	-33%	2491	267%	28	20.4
		5% Global increase	4615	-10%	40	-32%	2406	254%	27	19.3
	Lodge N major and minor	Average Demand	4741	-8%	51	-14%	1395	106%	17	8.8
		10% increase CLS	4900	-5%	49	-18%	1691	149%	19	11.1
		25% 1/2 hour inc. CLS	4830	-6%	49	-18%	1688	149%	20	11.8
		5% Global increase	4855	-6%	49	-17%	1602	136%	18	10.5
	Lodge N Two Minor	Average Demand	5101	-1%	55	-7%	922	36%	10	2.6
		10% increase CLS	5300	3%	52	-12%	1178	74%	12	4.5
		25% 1/2 hour inc. CLS	5226	2%	53	-12%	1130	66%	12	4.3
		5% Global increase	5231	2%	53	-12%	1135	67%	12	4.2

* CLS = CBD to Lodge Suburbs

** Delay = trip time$_{\text{event scenario}}$ - trip time$_{\text{Non-event scenario}}$

%Δ4 = (Event Scenario - Non-Event Scenario)/Non-Event Scenario

Table 8. Existing ITS Alternative: Lodge North Metrics

ITS benefits are statistically and practically very significant on Lodge north when variations in traffic occur. For event scenarios flow, speed, stops per mile, and delay range from 4540 to 5430 vph, 39 to 56 mph, 870 to 2520 stops per mile, and 1.7 to 20.4 minutes, respectively. These ranges compared to the No ITS alternative constitute as high as a 250 vph and 5.4 mph increase on Lodge north. These ranges also constitute as much as a 610 stops per mile and 4.6-minute trip delay reduction for Lodge north compared to the No ITS alternative. For Existing ITS scenarios with the minor incidents, however, ITS prompts marginally more diversion than needed causing slightly lower flows on Lodge northbound in the Existing

ITS alternative than in the No ITS alternative. This does; however, improve Lodge speeds and reduce the stops per mile on Lodge significantly. Across the 15 scenarios average benefits on Lodge north from the Existing ITS technologies and market penetration include a 2% increase in flow, a 7% increase in speed, a 13% decrease in stops per kilometer, and an 18% decrease in delay.

Both ITS users and non-users traversing the entire stretch of Lodge north benefit from the ITS infrastructure; however, benefits are greatest for those using pre-trip or HAR information. Table 9 presents the delay metrics for commuters traversing the entire length of Lodge north in both the No ITS and Existing ITS alternatives by commuter type. For the non-event 7.7-minute Lodge North trip, the range of commuter delay for those using HAR is 1.0 to 2.2 minutes across the event scenarios. This range is 1.0 to 3.0 minutes for pre-trip users, 1.4 to 19.9 minutes for CMS users, and 1.5 to 20.6 minutes for ITS non-users.

Across all corridor trips, CMS performs rather well in reducing delay; but, for this particular trip from the central business district to the end of Lodge northbound CMS users actually perform slightly poorer that those not using information in half of the event scenarios. This is because (1) the severity of the congestion did not warrant diversion at that point in the network, or (2) the arterials were significantly more congested along the diversion route. The next section details the outcome for one of the Existing ITS scenario to illustrate the complete set of detailed impacts by relevant facilities in the corridor.

Existing ITS Versus No ITS Alternatives: Lodge North Delay by Commuter Type

Incident Occurrence		Demand Occurrence	No ITS delay* (min)	Existing ITS Alternative: ITS non-user delay*	%Δ6	CMS user delay*	%Δ6	Pre-trip user delay*	%Δ6	HAR user delay*	%Δ6
	None	Average Demand									
		10% increase CLS*	1.9	1.7	12%	1.8	10%	1.3	32%	1.4	27%
		25% 1/2 hour inc. CLS	1.9	1.6	18%	1.4	27%	1.0	49%	1.0	49%
		5% Global increase	1.7	1.5	13%	1.5	16%	1.3	25%	1.3	26%
	Lodge N at Davison (major)	Average Demand	21.5	17.6	18%	17.6	18%	2.6	88%	2.0	91%
		10% increase CLS	24.4	20.0	18%	19.9	19%	2.6	89%	2.2	91%
		25% 1/2 hour inc. CLS	24.5	20.6	16%	19.9	19%	2.4	90%	1.9	92%
		5% Global increase	23.8	19.4	18%	19.2	19%	3.0	87%	2.1	91%
	Lodge N major and minor	Average Demand	11.5	8.8	23%	9.0	22%	1.5	87%	1.1	90%
		10% increase CLS	13.9	11.1	21%	11.2	20%	1.9	86%	1.2	91%
		25% 1/2 hour inc. CLS	14.7	11.8	20%	11.3	24%	1.8	88%	1.1	93%
		5% Global increase	13.5	10.5	22%	10.6	22%	2.0	85%	1.2	91%
	Lodge N Two Minor	Average Demand	3.1	2.4	22%	2.4	21%	1.5	50%	1.3	58%
		10% increase CLS	5.9	4.4	26%	4.4	26%	1.6	73%	1.2	79%
		25% 1/2 hour inc. CLS	6.1	4.2	31%	3.9	35%	1.5	75%	1.2	81%
		5% Global increase	5.4	4.0	25%	3.9	27%	1.8	67%	1.3	76%

* CLS = CBD to Lodge Suburbs

*delay = (trip $time_{event\ scenario}$ - trip $time_{non\text{-}event\ scenario\ all\ commuters}$) within Alternative

%Δ6 = ($delay_{Existing\ ITS\ scenario}$ - $delay_{No\ ITS\ scenario}$)/$delay_{No\ ITS\ scenario}$

Table 9. Existing ITS versus No ITS Alternatives: Lodge North Delay by Commuter Type

6.2.3 Average Demand, Major Incident on Lodge NB at Davison Scenario

In the No ITS alternative for Lodge north, flow decreases from 5140 vph to 4400 vph, travel speed decreases from 59 mph to 38 mph, and average vehicle stops per mile increases from 680 to 2700 when this event scenario is compared to the non-event scenario (Figure 13, comparison Δ2). With the Existing

ITS infrastructure, flow is increased by 3.2% (140vph), speed is increased by 14.3% (5.4 mph), and the average vehicle stops per mile is reduced by 17% (435) on Lodge Northbound from the aforementioned No ITS scenario levels (Figure 13, comparison △6).

Zonal flows degrade by up to a 6% magnitude (macro-zone 4), and zonal stops increase by 30% (macro-zone 3) from the Existing ITS non-event to this Existing ITS event scenario (Figure 13, comparison △7). Also, on arterials leading to Lodge north, flow is reduced by 4%, speed is reduced by 6%, and stops per mile are increased by 45% from the non-event to this event scenario for Existing ITS.

The arterial/macro-zone degradation occurs because (1) ramp meters limit entry onto the facility, (2) CMS diverts commuters to northbound access roads along congested sections, and (3) HAR and Pre-Trip inform commuters from the CBD use I-75 and Davison freeways to divert a significant stretch of the congested Lodge freeway. Specifically, some commuters from macro-zone 4 choose to use I-75 to reach their destinations, and some commuters from macro-zone 3 who must reach Lodge freeway are forced into long queues to enter Lodge northbound due to ramp meters. The route diversion in the Existing ITS alternative causes flow on I-75 in this scenario to increase from the non-event scenario by approximately 1.5% with minimal degradation to speed or vehicle stops per mile. The non-freeway degradation is significant, but in comparison with Lodge north improvements, the net is a positive. Table 10 presents the facility-level outcomes of this scenario.

6.3 ITS Retrospective Alternatives

The Only Ramp Metering and Only CMS alternatives have similar results to the Existing ITS and No ITS alternatives in the absence of demand or supply changes at both the corridor and facility level. The one exception is onramp performance in Ramp Metering alternative. For the non-event option, speed on metered onramps is reduced by 8 mph lower and stops per mile are 14% higher without significant improvements to Lodge Freeway. The following two subsections discuss in greater detail outcomes of simulation for the Only Ramp Metering and Only CMS alternatives.

6.3.1 Only Ramp Metering

Table 11 lists the Only Ramp Metering metrics for all scenarios at the corridor level. The corridor throughput, speed, and average trip time for the Existing ITS non-event scenario are 48,080, 36.4 mph and 5.7 minutes respectively. The differences between these values and parallel values of the No ITS or Existing ITS alternatives are not statistically significant.

For event scenarios, corridor throughput ranges from 46,360 to 50,070, corridor speed ranges from 35.6 to 36.3 mph and trip time ranges from 5.9 to 8.7 minutes. Here, however, differences in corridor throughput are statistically significant for some scenarios between this alternative and both the No ITS and Existing ITS alternatives. Corridor throughput is as much as 130 trips and 160 trips per hour lower in this alternative as compared to the No ITS and Existing ITS alternatives, respectively. Because in this alternative ramp metering slows access to freeway without traveler information to reroute around the congested area, corridor throughput is slightly reduced. Corridor delay in the Only Ramp Metering alternative is either not statistically or practically different than corridor delay in the No ITS alternative for 14 of the 15 scenarios. In one scenario (average demand and major/minor Lodge incident) the Ramp Metering alternative actually has a 3.6% greater delay than the No ITS alternative at the corridor level.

Table 12 presents the Lodge northbound facility outcomes for the Only Ramp Metering alternative in terms of flow, speed, trip time, and delay for the 16 scenarios modeled. These metrics are based on all links in the corridor that are a component of Lodge northbound.

For the Only Ramp Metering non-event scenario average flow, speed, vehicle stops per mile, and trip time on Lodge north are 5140 vph, 59.5 mph, 680 stops per mile, and 7.7 minutes respectively. Metrics for this scenario are not statistically different from the No ITS or Existing ITS alternatives' metrics for the parallel non-event scenario.

ITS benefits in the Only Ramp Metering alternative are statistically and practically significant on Lodge north when variations in traffic occur. For event scenarios flow, speed, stops per mile, and delay respectively range from 4560 – 5440 vph, 37 – 56 mph, 680 – 2650 stops per mile, and 1.7 – 21.3 minutes. Scenario values of this alternative compared to the No ITS alternative constitute as much as a 250 vph flow and 4.0 mph speed increases for Lodge north. They also constitute as much as a 470 stops per mile and a 3.7-minute trip delay reduction for Lodge north compared to the No ITS alternative.

EXISTING ITS VERSUS NO ITS FOR 1 SCENARIO: AVERAGE DEMAND, MAJOR LODGE NB INCIDENT BEFORE DAVISON					
	Existing ITS			No ITS $\%\Delta_2$	Existing V. No ITS
	Non-Event	Event	$\%\Delta_4$		$\%\Delta_6$
Average Flow (vehicles/hour)					
M-10 N Mainlines	5141	4540	-12%	-14%	3.2%
I75 N Main	5143	5220	1%	0%	1.5%
M-10 N Ramps	660	566	-14%	-5%	-9.8%
Arterials to M-10 N	204	186	-9%	-5%	-3.8%
Macro-zone 2	341	338	-1%	0%	-0.8%
Macro-zone 3	230	227	-1%	0%	-1.5%
Macro-zone 4	235	222	-6%	0%	-5.7%
All Macro-zones	267	263	-2%	0%	-1.6%
Average Speed (miles/hour)					
M-10 N Mainlines	60	43	-27%	-36%	14.3%
I75 N Main	60	60	0%	0%	-0.5%
M-10 N Ramps	48	29	-39%	-30%	-25.8%
Arterials to M-10 N	20	21	4%	-3%	6.3%
Macro-zone 2	30	30	0%	0%	0.3%
Macro-zone 3	28	28	-1%	0%	-0.9%
Macro-zone 4	30	30	0%	0%	0.0%
All Macro-zones	27	27	0%	0%	0.0%
Average Stops (stops per mile)					
M-10 N Mainlines	679	2139	215%	297%	-20.6%
I75 N Main	654	669	2%	0%	2.2%
M-10 N Ramps	7	48	558%	342%	62.7%
Arterials to M-10 N	8	23	199%	102%	45.1%
Macro-zone 2	13	13	0%	0%	-0.1%
Macro-zone 3	20	25	28%	0%	29.8%
Macro-zone 4	11	11	-1%	0%	-1.2%
All Macro-zones	26	26	0%	0%	-0.4%

$\%\Delta_4$ = (Event Scenario - NonEvent Scenario)/NonEvent Scenario for Existing ITS

$\%\Delta_2$ =(Event Scenario - NonEvent Scenario)/NonEvent Scenario for No ITS

$\%\Delta_6 = (\%\Delta_4 - \%\Delta_2)/\%\Delta_2$

Table 10. Exist ITS Event (Average Demand, Major Incident): Detailed Facility Metrics

Only Ramp Metering Alternative: Corridor Metrics							
		Throughput		Speed			
Incident Occurrence	Demand Occurrence	finished trips/hour	%Δ	miles/hour	%Δ	Trip Time (minutes)	Delay** (min.)
None	Average Demand	48078		36.41		5.7	
	10% increase CLS*	48265	0.4%	36.26	-0.4%	5.9	0.26
	25% 1/2 hour inc. CLS	48246	0.4%	36.28	-0.4%	5.9	0.24
	5% Global increase	50070	4.1%	36.15	-0.7%	6.1	0.42
Lodge N at Davison (major)	Average Demand	46470	-3.3%	35.74	-1.8%	8.2	2.56
	10% increase CLS	46363	-3.6%	35.69	-2.0%	8.7	2.97
	25% 1/2 hour inc. CLS	46379	-3.5%	35.72	-1.9%	8.6	2.95
	5% Global increase	48153	0.2%	35.57	-2.3%	8.7	3.04
Lodge N major and minor	Average Demand	46972	-2.3%	36.03	-1.0%	7.0	1.31
	10% increase CLS	46939	-2.4%	35.96	-1.2%	7.3	1.65
	25% 1/2 hour inc. CLS	46916	-2.4%	35.96	-1.2%	7.4	1.68
	5% Global increase	48752	1.4%	35.83	-1.6%	7.4	1.75
Lodge N Two Minor	Average Demand	48024	-0.1%	36.26	-0.4%	6.1	0.37
	10% increase CLS	48025	-0.1%	36.13	-0.8%	6.4	0.72
	25% 1/2 hour inc. CLS	48010	-0.1%	36.15	-0.7%	6.4	0.73
	5% Global increase	49833	3.7%	36.01	-1.1%	6.6	0.88

* CLS = CBD to Lodge Suburbs

** Delay = trip time$_{\text{event scenario}}$ - trip time$_{\text{Non-event scenario}}$

%Δ = (Event Scenario - Non-Event Scenario)/Non-Event Scenario

Table 11. Only Ramp Metering: Corridor Metrics

ONLY RAMP METERING ALTERNATIVE: LODGE NORTH METRICS									
		Flow		Speed		Stops / mile			
Incident Occurrence	Demand Occurrence	veh. / hour	%Δ	miles / hour	%Δ	number	%Δ	Trip Time (min.)	Delay ** (min.)
None	Average Demand	5142		60		679		8	
	10% increase CLS*	5438	6%	55	-8%	936	38%	10	1.9
	25% 1/2 hour inc. CLS	5352	4%	55	-7%	899	32%	10	1.9
	5% Global increase	5366	4%	55	-7%	899	32%	9	1.7
Lodge N at Davison (major)	Average Demand	4557	-11%	42	-30%	2257	232%	26	18.4
	10% increase CLS	4635	-10%	37	-37%	2654	291%	28	20.7
	25% 1/2 hour inc. CLS	4598	-11%	38	-37%	2618	285%	29	21.3
	5% Global increase	4613	-10%	39	-35%	2545	275%	28	20.2
Lodge N major and minor	Average Demand	4765	-7%	51	-14%	1453	114%	17	9.3
	10% increase CLS	4920	-4%	48	-20%	1754	158%	19	11.5
	25% 1/2 hour inc. CLS	4848	-6%	48	-20%	1763	159%	20	12.3
	5% Global increase	4875	-5%	49	-18%	1663	145%	19	11.0
Lodge N Two Minor	Average Demand	5132	0%	55	-8%	971	43%	11	2.9
	10% increase CLS	5343	4%	52	-13%	1218	79%	12	4.7
	25% 1/2 hour inc. CLS	5267	2%	52	-12%	1163	71%	12	4.5
	5% Global increase	5274	3%	52	-12%	1178	73%	12	4.5

* CLS = CBD to Lodge Suburbs

** Delay = trip time$_{\text{event scenario}}$ - trip time$_{\text{Non-event scenario}}$

%Δ = (Event Scenario - Non-Event Scenario)/Non-Event Scenario

Table 12. Only Ramp Metering: Lodge North Metrics

In comparison to the Existing ITS event scenarios, flows are as much as 40 vph higher and speeds are as much as 2 mph lower on Lodge north for the Only Ramp Metering alternative. In 10 of the 15 event scenarios flows are higher on average by 28vph. Speeds for the Only Ramp Metering alternative are statistically lower in about 8 of the 15 scenarios. Vehicle stops per mile are also greater in the Only Ramp Metering alternative compared to the Existing ITS alternative, by about 66 stops per mile across the 15 event scenarios. Delays across the 15 scenarios are on average 0.44 minutes greater for the Only Ramp Metering alternative compared to the Existing ITS alternative. This occurs because of the absence of traveler information that would have prompted route diversion off the Lodge North facility.

For example, when the major incident before Davison occurs and Lodge northbound demands are increased, speed improvements in the Only Ramp Metering alternative are only 60% of the Existing ITS improvements in speed from the No ITS alternative. This is because in the Existing ITS case, commuters use route diversions and thereby improve their own trip time and reduce Lodge north traffic. When minor or no incidents occur, route diversions are not as critical and Ramp Metering proves nearly as effective as Existing ITS at improving travel on Lodge north.

Due to the absence of traveler information promoting pre-trip route diversions in the Only Ramp Metering alternative, negative arterial facility impacts of ramp meters are much greater. Speeds on arterials leading to Lodge northbound freeway are reduced by 4% compared to the No ITS alternative in one option; whereas in the Existing ITS alternative, speeds remain unchanged. As such, corridor level average delay for some Ramp Metering event scenarios proved to be as much as 2% greater than without any ITS.

6.3.2 Only CMS Alternative

The CMS alternative did not significantly change either average flow, or speed of either freeway or arterial facilities over the entire PM peak period. Moreover, this alternative did not change the average stops per mile on the Lodge or I-75 freeways. On individual links just after a diversion point, however, flow on Lodge did decrease by 1% for some ITS scenarios. This was offset by greater merges directly after such links causing more stops per vehicle kilometer. In terms of corridor level metrics, again, the impacts of CMS were not statistically significant.

6.4 Future Alternatives

The No Ramp Metering alternative explores the policy option of turning off metered ramps in the Existing ITS alternative. We discuss outcomes in terms of the corridor, the Lodge north facility, and arterials leading to Lodge north. Scenarios are discussed in three groups: scenarios with no incidents, minor incidents, and major incidents. Findings are presented in Section 6.4.1.

Based on the outcomes of the previously discussed alternatives, we found that route diversion predominantly occurs onto other major highways. Moreover, benefits from CMS were minimal for the scenarios evaluated. In addition, an analysis of queue lengths on the arterials to be considered for route diversion indicated that signals are already relatively well timed for northbound progression. As such, the expectation for potential benefit from accident-responsive signal coordination was low and the number of simulations conducted to evaluate potential benefits was limited to six random trials of one option. This single trial was based on average demand conditions, and the two minor incident supply variation. Major incident supply variations were not considered because diversions for those events were almost exclusively onto highway paths. ITS technologies include the Existing ITS and market penetration levels and real time coordination of signals along a primary detour route. Findings from simulation of this scenario are presented in Section 6.4.2.

6.4.1 No Ramp Metering Alternative

The No Ramp Metering and the Existing ITS alternatives are identical at the corridor level when compared using metrics of delay or speed, and for most scenarios in terms of throughput (Figure 13). When major incidents do occur, throughput is increased by 0.3% in the No Ramp metering alternative compared to the Existing ITS alternative. This difference though statistically significant is not very significant practically.

Focusing on Lodge north, the differences between the alternatives for the non-event scenario are not statistically or practically significant in terms of flow, speed, vehicle stops per mile or delay (Figure 13 △12). Focusing specifically on the metered ramps for the non-event scenario, all metrics are significantly better in the No Ramp Metering alternative compared to the Existing ITS alternative. Flow increase by about 1% on the metered ramps while speeds increase from 7 to 11 mph, and stops decrease by as much as 25% from the Existing ITS alternative. Also, arterials leading to Lodge north experience a 1% increase in flow, without practically significant decreases in speed or increases in vehicle stops per mile (Figure 13 △13).

For scenarios having minor incidents, differences in flow and speed on Lodge north are not statistically significant between the No Ramp Metering and the Existing ITS alternatives. The number of vehicle stops per mile and delay for trips using the entire stretch of Lodge north do increase somewhat when ramp meters are deactivated. Vehicle stops increase by as much as 7% or 80 stops per mile and delay increase by as much as 0.9 minutes per trip on Lodge north. Table 13 presents Lodge north metrics for this alternative.

For scenarios with a major incident on Lodge at Davison, the differences in outcomes clearly indicate significant Lodge mainline benefits of ramp metering. By deactivating ramp metering in these scenarios flow decreases by as much as 215 vph, speeds decrease by 4 mph, vehicle stops per mile increase by as much as 490, and delay increase by as much as 3.0 minutes for commuters traveling the entire stretch of Lodge north. Ramp metering benefits, however, are at a significant cost to arterials leading to the freeway. The vehicle stops per kilometer on arterials leading to Lodge northbound are almost 50% more in the Existing ITS alternative compared to the No Ramp Metering alternative. Speed and flow are also much lower on these arterials by as much as 3 mph and 5% flow.

No Ramp Metering Alternative: Lodge North Metrics

Incident Occurrence	Demand Occurrence	Flow		Speed		Stops / mile		Trip Time (min.)	Delay ** (min.)
		veh. / hour	%Δ	miles / hour	%Δ	number	%Δ		
None	Average Demand	5141		60		678		8	
	10% increase CLS*	5430	6%	55	-7%	926	37%	10	1.9
	25% 1/2 hour inc. CLS	5337	4%	56	-6%	879	30%	9	1.7
	5% Global increase	5358	4%	56	-7%	887	31%	9	1.7
Lodge N at Davison (major)	Average Demand	4414	-14%	39	-34%	2574	280%	28	20.3
	10% increase CLS	4424	-14%	36	-40%	2971	338%	30	22.4
	25% 1/2 hour inc. CLS	4400	-14%	36	-40%	2941	334%	31	23.0
	5% Global increase	4399	-14%	36	-39%	2899	328%	30	22.3
Lodge N major and minor	Average Demand	4694	-9%	49	-17%	1659	145%	18	10.8
	10% increase CLS	4794	-7%	46	-23%	2009	196%	21	13.1
	25% 1/2 hour inc. CLS	4735	-8%	46	-23%	2013	197%	22	13.9
	5% Global increase	4760	-7%	46	-22%	1940	186%	21	12.8
Lodge N Two Minor	Average Demand	5100	-1%	55	-7%	926	37%	10	2.6
	10% increase CLS	5300	3%	51	-14%	1237	82%	13	5.0
	25% 1/2 hour inc. CLS	5226	2%	52	-13%	1210	79%	13	5.2
	5% Global increase	5231	2%	52	-13%	1206	78%	13	4.8

* CLS = CBD to Lodge Suburbs

** Delay = trip $time_{event\ scenario}$ - trip $time_{Non\text{-}event\ scenario}$

%Δ = (Event Scenario - Non-Event Scenario)/Non-Event Scenario

Table 13. No Ramp Metering: Lodge North Metrics

6.4.2 Accident Signal Coordination Alternative

For this single trial, an incident occurs on Lodge northbound prior to the exit for Webb Avenue that reduces lane capacity by 33%. In the Existing ITS alternative, this capacity reduction causes traffic to slow to 10 – 28 mph from the incident back to as far as Grand Boulevard as compared to the non-event scenario. A second minor incident on Lodge northbound prior to the exit for Linwood Avenue reduces lane capacity by 25%. Due to the bottleneck prior to Webb Avenue, however, speeds are compromised no more than 10 mph through the incident.

Under the Existing ITS alternative for this event option, detours made by ITS users predominantly take the freeway exit for Chicago Avenue, travel shortly on Hamilton, make a left onto Chicago and a right onto the onramp for Lodge north. This detour eliminates having to travel on 0.5 miles of freeway that performs at speed ranging from 10-15 mph due to the incident prior to the exit for Webb Avenue. For the Existing ITS alternative, approximately 80 vehicles per hour utilize the aforementioned detour. Commuters detouring do not continue on Hamilton and enter Lodge north via the Webb Avenue onramp. This is because this possible detour requires 25% longer travel through three additional signalized intersections on urban arterials having travel speeds of 20-30 mph.

By implementing signal progression favoring northbound and left turning traffic on both the utilized detour route as well as the unutilized one, the number of detours increased to 120 vehicles per hour. At a corridor or Lodge freeway facility level, the impact of accident signal coordination on Lodge north speed, flow, or stops per kilometer is not statistically significant. However, focusing specifically on the short detoured segment of Lodge northbound, speed increase by 2mph for the hour of greatest incident based congestion. Flow also increases on the mainline segment detoured by 55 vph during the peak hour of accident-based congestion. Speed northbound on Hamilton, the detour route, increases by 3 mph as well. Speed south on Hamilton, however decreases and queues are 50% greater than in the Existing ITS alternative because green phasing time was taken to provide left and through movement for northbound Hamilton. Commuters (ITS users) making the detour reduced their delay by 20% on average whereas mainline users reduced their delay by approximately 2% on average for the PM peak period.

7.0 Summary of Findings

The intent of this study was to provide MDOT with ranges of quantified impacts from their existing ITS infrastructure, measures of freeway bias and its impact on corridor performance, and the modeled impacts of future changes in operations and/or policy on corridor performance. The results of this study were also generally relevant to national goals of cataloging the benefits of ITS from a variety of operational metropolitan ITS systems. Through a statistical analysis of various data and simulation of over 80 scenarios, we successfully addressed each of the five queries proposed in this undertaking. This section presents results for each of the queries listed in project objectives subsection.

With regard to measurable freeway bias in the corridor, we found through statistical analysis that speeds during the entire evening peak on freeways are significantly higher than on arterials. Data was not available to evaluate whether freeway bias is present during major incidents. As such, freeway bias was not present for average PM traffic conditions in the corridor and no freeway bias was incorporated in the simulation modeling effort.

With regard to the system and facility level performance of the existing ITS infrastructure, Mitretek identified ITS impacts through modeling and comparison of four alternatives: No ITS, Ramp Metering, CMS, and Existing ITS. The Existing ITS system proved very beneficial in improving flow and speed on Lodge Freeway, particularly when incidents occur. The Existing ITS technologies contributed to as high as a 250 vph and 5.4 mph increase on Lodge north over the case modeled of No ITS technologies. The Existing ITS technologies also constitute as much as a 610 stops per mile and 4.6-minute trip delay reduction for Lodge north compared to the No ITS alternative.

Overall, benefits from the Existing ITS system are significant at the corridor level for commuters and the system during the PM peak when significant changes in corridor demand and supply occur. The greatest benefit is in commuter delay reduction. The current ITS system mitigates delay across the corridor by as much as 22% among the scenarios modeled. Corridor speed and throughput are also at times marginally improved.

The ITS systems proved most beneficial under conditions of significant supply variations such as incidents. For demand variations ITS benefits are realized, but to a lesser extent. Ramp metering and pre-trip/HAR information proved equally valuable tools at reducing commuter delay and improving facility metrics in response to major incidents. In response to demand variations, pre-trip/HAR information proved most effective. Changeable (variable) message signs do benefit commuters in terms of awareness of traffic activities. CMS may have psychological/convenience benefits in terms of providing drivers with information about what is causing delays and congestion. In terms of delay reductions; however, commuters acting upon CMS messages of delay found little benefit, and at times also increased delay by diverting. Moreover, CMS proved no benefit to facility operation in terms of flow or speed. Ramp metering, although effective during major incident events, proved questionable in the absence of incidents or when minor incidents occurred.

ITS benefited all commuters in terms of delay reduction, but most of the benefits were realized by those using pre-trip or HAR information. Pre-trip and HAR ITS users realized delay reduction of over 80%, mainly through freeway-to-freeway route diversions. Although arterial signals are relatively well timed, arterial route diversions are relatively unattractive given the availability of freeways at much higher speeds.

Future operational enhancements considered in this study included retiming of arterials for signal progression, providing operational functionality for real time signal coordination to promote diversion around a freeway incident, and deactivating ramp metering.

Because a queue analysis of arterial signals indicated minimal queue formation at signals as well as relatively good signal progression, retiming for corridor progression was found not be necessary. We conducted a single scenario evaluation for accident signal coordination because predominantly, route diversion occurred freeway to freeway. This single evaluation proved significant benefits from coordination at the local level but not at the corridor level. The most significant operational change found to improve corridor performance is deactivating ramp metering for average conditions and when perturbations to the freeway facility are minor. During these conditions on Lodge north, freeway speeds are still equal or better than arterial speeds. By making this operational shift of turning off metered ramps in the absence of major events, delay on ramps and arterials leading to ramps proved in simulation to be significantly less without harming mainline operations.

The following bulleted list summarizes the characteristics of the corridor, the benefits from ITS in this corridor, and the future operational/policy shifts that should be considered by MDOT:

- The corridor evaluated has relatively minimal recurrent PM peak-period congestion and therefore parallel freeways serve as most favorable diversion routes. Arterials, although relatively well timed for signal progression in the corridor, are not attractive route alternatives.
- Freeway bias was not evident in the data available.
- In terms of ITS Benefits, pre-trip and HAR information proved most effective at reducing commuter delay while ramp metering proved very effective at improving facility performance when major incidents occur. Delay reductions of as much as 22% throughout the corridor were realized while flow and speed improvements of as much as 250 vph and 5mph on Lodge north were realized compared to a system without any ITS.
- The strategy of signal coordination should be considered when and if demand changes from those modeled in this study occur or if demand significantly increases in the corridor. Based on the system and demand evaluated, accident signal coordination provided benefit at the local level, but until arterial diversions become more attractive, benefits will not be significant at the corridor level. The MDOT ramp metering strategy should be re-evaluated, particularly for situations of no incidents or minor incidents.