Buffalo-Niagara Integrated Corridor Management

Final Report

Prepared for:

New York State Energy Research and Development Authority
Greater Buffalo-Niagara Regional Transportation Council
Niagara International Transportation Technology Coalition
Federal Highway Administration
Niagara Frontier Transportation Authority

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Notice

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Abstract

This report documents the Buffalo-Niagara Integrated Corridor Management (BNICM) deployment planning study for portions of the region's freeway network. Integrated Corridor Management (ICM) provides technology-enabled transportation management and operations strategies that seek to optimize the use of existing infrastructure. Following presentation of the overall concept of operations for the BNICM deployment, the report then presents detailed analysis of the impacts of two ICM alternatives, one freeway-focused only, and one also including arterial traffic signal optimization, with cost-benefit analysis determining that the latter is optimal. Travel-time savings was found to be the single largest category of benefits from the BNICM deployment, with benefits greater during day-to-day morning and afternoon rush hour periods than during less-usual scenarios (crashes, professional sports events, etc.). Of the ICM strategies considered, the highest-impact strategy was found to be Dynamic Traveler Information, Freeway Incident Detection and Service Patrol. This report concludes with a plan of next steps for implementing the BNICM's strategies and monitoring once operational.

Keywords

Integrated Corridor Management, Intelligent Transportation Systems

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Acronyms and Abbreviations

AMS	Analysis, Modeling and Simulation
ATSPM	Automated Traffic Signal Performance Measures
AVL	Automated Vehicle Location
BOD	Board of Directors
CBSA	Canada Border Services Agency
CO2	Carbon Dioxide
ConOps	Concept of Operations
CBP	Customs and Border Protection
DMS	Dynamic Message Signs
FHWA	Federal Highway Administration
GPS	Global Positioning System
GBNRTC	Greater Buffalo-Niagara Regional Transportation Council
HCM	Highway Capacity Manual
HELP	Highway Emergency Local Patrol
ICM	Integrated Corridor Management
IPDT	Integrated Product Development Team
ITS	Intelligent Transportation Systems
INCOSE	International Council on Systems Engineering
I	Interstate
MDSS	Maintenance Decision Support Systems
MPO	Metropolitan Planning Organization
MTO	Ministry of Transportation, Ontario
NPMRDS	National Performance Management Research Data Set
NYS	New York State
NYSDOT	New York State Department of Transportation
NYSERDA	New York State Energy Research and Development Authority
NYSP	New York State Police
NYSTA	New York State Thruway Authority
NFBC	Niagara Falls Bridge Commission
NFTA	Niagara Frontier Transportation Authority
NITTEC	Niagara International Transportation Technology Coalition
OCC	Ontario Chamber of Commerce
OPP	Ontario Provincial Police
O&M	Operations and Maintenance
PMBOK	Project Management Body of Knowledge
PMP	Project Management Plan

RWIS	Road Weather Information System
SEBoK	Systems Engineering Body of Knowledge
SEMP	System Engineering Management Plan
SEP	Systems Engineering Processes
TMC	Traffic Management Center
TSMO	Transportation Systems Management and Operations
TOPS-BC	Tools for Operations Benefit Cost Analysis
USCBP	United States Customs and Border Protection
USDOT	United States Department of Transportation
VHT	Vehicle Hours Traveled
VMT	Vehicle Miles Traveled
VSL	Variable Speed Limit

Executive Summary

This report documents the Buffalo-Niagara Integrated Corridor Management (BNICM) deployment planning study, which aimed at advancing the ICM concepts towards deployment both in the Buffalo-Niagara region. This project strives to take the current traffic management procedures to the next level by leveraging and building upon the available resources, tools and ICM goals and objectives. The overall BNICM planning study included a five-year process that developed a Project Management Plan (PMP), System Engineering Management Plan (SEMP), Concept of Operations (ConOps) and Requirements, Analysis Modelling and Simulation (AMS) and then an implementation plan for moving forward.

The study area of the Niagara Frontier is the border region that encompasses the Niagara River border crossings and is a strategic international gateway for the flow of trade and tourism between the United States and Canada. I-190 between the I-90 and I-290 interchanges is the primary focus area within the Buffalo-Niagara region for this study. The study area also includes the Peace Bridge border crossing.

The specific ICM strategies that were selected for consideration and inclusion in ICM response plans for the BNICM AMS include:

- Improved Dynamic Traveler Information
- Freeway Incident Detection and Service Patrol
- Ramp Metering
- Variable Speed Limits and Queue Warnings
- Variable Toll Pricing
- Signal Coordination (along Niagara Street)

The ICM strategies were evaluated for typical weekday commute AM and PM peak period conditions, vehicle crash conditions, holiday demands, snow conditions and game day conditions. Since the permutations of various ICM strategies and base conditions to be evaluated within the BNICM model presented an immense number of scenarios to simulate and analyze, two packages (A and B) of ICM strategy deployments were developed to streamline the simulation and evaluation of the effectiveness of the ICM strategies during the different base conditions. Package A focused on freeway ICM strategy deployment while Package B included freeway deployment as well as signal coordination along the arterial system.

The resulting benefit cost of the ICM strategies showed 2.77 for Package A and 3.37 for Package B. Based on the AMS performed for the BNICM on packages A and B, the key findings include:

- VHT showed the greatest benefit relative to deployment of the ICM strategies
- Typical weekday AM and PM peak period conditions improved or benefited the most of the ICM deployment whereas other conditions had improvement but to a lesser degree
- Traveler information and freeway incident clearance were the two strategies that provided the most improvements in the system related to the ICM strategies deployed
- Emissions positively benefited from deployment of ICM but only by a small amount when monetized
- Arterial signal management resulted in a large increase in the benefit-cost ratio

This study shows that based on the benefit cost of the ICM strategies efforts to design and deploy the systems on the region’s roadways are economically justifiable.

The next step towards an ICM deployment within the region would consist of a more detailed design and a more robust analysis of the costs to deploy, operate, and maintain the ICM system components within the region. Consideration should be given to staged or phased ICM deployment to spread the initial deployment costs. Specific to the cross-border corridor, next steps towards implementation should include a more detailed examination of the possibility of trucks changing their crossing locations on short notice to improve travel times from an incident on either side of the border.

While the study simulation and benefit-cost analysis demonstrates the feasibility and viability of an ICM deployment within the region, any potential deployment should also include a data driven process to continually monitor the performance of the ICM system and its response plans that are implemented in the field. The results of that performance monitoring should also carry forward into a continuous improvement framework to ensure that the ICM response plans implemented in the field are as beneficial as they can be for the given conditions as an ICM system operates over time. Performance monitoring would be conducted using both field data and the simulation model. The use of the BNICM simulation tool can also be leveraged for this performance reporting in a future ICM system. This performance reporting provides the data needed to enhance and improve the simulation model over time, which should in turn lead to more accurate predictions of the impacts of an ICM response plan under varying conditions and improved response plan performance in the real-world.

1.0 Introduction

This report documents the Buffalo-Niagara Integrated Corridor Management (BNICM) deployment planning study. The study was completed for New York State Energy Research and Development Authority (NYSERDA), Greater Buffalo-Niagara Regional Transportation Council (GBNRTC), Niagara Frontier Transportation Authority (NFTA), Niagara International Transportation Technology Coalition (NITTEC) and the USDOT's Federal Highway Administration (FHWA).

Integrated Corridor Management (ICM) provides transportation management and operations strategies, enabled by Intelligent Transportation Systems (ITS), that seek to optimize the use of existing infrastructure in a selected corridor network, while reducing the negative externalities associated to congestion and enhancing safety.

ICM provides advantages over the traditional approach of much less active management of a corridor's operations, through three mechanisms:

1. Motorists are provided better information to empower them to make better-informed decisions
2. Motorists may be charged tolls at variable rates, to incentivize them to choose less-congested 'shoulder' time periods before and after the most congested times, to better match network capacity with traffic demands
3. Network capacity is actively managed, by rapid removal of capacity-reducing incidents, better traffic signal optimization, etc.

1.1 Purpose

The purpose of the BNICM planning study is to develop a combined stakeholder vision of efficient transportation operations within the Interstate (I) 190 corridor. The ICM is intended to provide improved integration of operational procedures, facilitate improved emergency response, and improved dissemination of traveler information in the I-190 Corridor and in the larger Border Crossing corridor within the Niagara Frontier.

The outcome of the study is an implementation plan. The implementation plan is based on the Analysis, Modeling, and Simulation (AMS) of potential ICM deployments in the region. The AMS is used to determine the feasibility of an ICM deployment and assess benefits to operational and environmental conditions on the region's transportation network. The goals for the BNICM that guided the study are summarized in Table 1.

Table 1. ICM Goals

NITTEC Transportation Operations Integrated Corridor Management Requirement Document, February 2010

Goal Category	Goal Objective
Agency Coordination	Improve center-to-center communications
Traveler Information	Improve accuracy of congestion (travel time) information reliability
	Enable intermodal choices through improved traveler information
	Improve integration of weather information/data for traveler information, and for maintenance operations
	Improve integrated operations based on real-time data
Mobility (Arterial, Border, Freeway, Transit)	Maximize the free flow of traffic and reduce congestion
	Provide transit alternative and park-and-ride facilities
	Enhance border crossing clearance
	Facilitate ITS and operational improvements that will facilitate ICM mobility
	Enhance alternative route management capabilities
Incident Management	Establish incident classifications and severity guidelines
	Improve and coordinate incident management

The overall objectives of this BNICM study were to:

- Develop decision support tools needed to complete the required AMS assessments of the potential ICM deployment in the region
- Conduct AMS assessments of the potential ICM deployments
- Prove feasibility of an ICM deployment to improve operational and environmental conditions on the region's transportation network

The study ultimately aimed at advancing the ICM concepts towards deployment both in the Buffalo-Niagara region.

This BNICM project was built upon the previous foundations for exploring ICM concepts in the region conducted by NITTEC and documented in their NITTEC ICM Systems Operational Concepts report, Requirements report, and the Regional Concept for Transportation Operations Report. Those NITTEC documents established goals and potential framework of how ICM concepts could be leveraged in the region and were the starting point for this BNICM Planning Study.

1.2 Stakeholders

The Niagara region is a particularly complex area for transportation activities due to the interaction of different entities and activities. The ICM project was co-led by the Niagara International Transportation Technology Coalition (NITTEC) and the Greater Buffalo-Niagara Regional Transportation Council

(GBNRTC). NITTEC is coalition of transportation agencies in Western New York and Southern Ontario, allowing transportation agencies to collaborate and manage the multi-modal transportation systems, making it possible to reach mobility, reliability, and safety improvements in the region. NITTEC helps coordinate and facilitate communication between regional transportation agencies, in both Canada and the United States. Table 2 shows current NITTEC member agencies and related organizations. The project was also supported with efforts by the Greater Buffalo-Niagara Regional Transportation Council (GBNRTC). GBNRTC is the Metropolitan Planning Organization (MPO) for the Erie and Niagara Counties, which cover the U.S. portion of the region, and are one of NITTEC's partner agencies.

Table 2. NITTEC Agencies

NITTEC Transportation Operations Integrated Corridor Management Requirement Document, February 2010

Member Agencies	Other Related Organizations
Buffalo and Fort Erie Public Bridge Authority (PBA)	Canada Border Services Agency (CBSA)
City of Buffalo	Federal Highway Administration (FHWA)
City of Niagara Falls, New York	Greater Buffalo-Niagara Regional Transportation Council (GBNRTC)
City of Niagara Falls, Ontario	New York State Police (NYSP)
Erie County[a]	Ontario Provincial Police (OPP)
Ministry of Transportation, Ontario (MTO) [a]	United States Customs and Border Protection (USCBP)
New York State Department of Transportation (NYSDOT)[a]	State University of New York at Buffalo
New York State Thruway Authority (NYSTA) [a]	Other local and regional police and emergency services agencies
Niagara County	Recovery companies
Niagara Falls Bridge Commission (NFBC)	
Niagara Frontier Transportation Authority (NFTA)[a]	
Niagara Parks Commission	
Niagara Region	
Town of Fort Erie	

[a] Agencies included in the Policy Board

1.3 Study Area

The Niagara Frontier is the border region that encompasses the Niagara River border crossings and is a strategic international gateway for the flow of trade and tourism between the United States and Canada. The Niagara River, flowing from Lake Erie to Lake Ontario, forms the border between the United States and Canada. On the Canadian side, the Niagara Region covers approximately two-thirds of the Niagara Peninsula and consists of twelve local municipalities. On the United States side, the Buffalo-Niagara Frontier region forms the western border of New York State with the province of Ontario. The region consists of four counties: Erie, Niagara, Chautauqua, and Cattaraugus. The region contains 64 municipalities, and Native American lands. The City of Buffalo, the second largest city in New York State, is located at the easternmost end of Lake Erie, overlooking the Niagara River. The City of Niagara Falls, New York, is located 20 miles northwest of Buffalo in Niagara County opposite Niagara Falls, Ontario. Figure 1 shows a map of the region, the cities involved, and the primary corridor roadways considered in the ICM project.

The existing highway network in the Niagara Frontier Corridor includes a number of controlled access highways that serve the Niagara Frontier and border area. Figure 1 shows the existing highway network within New York State includes:

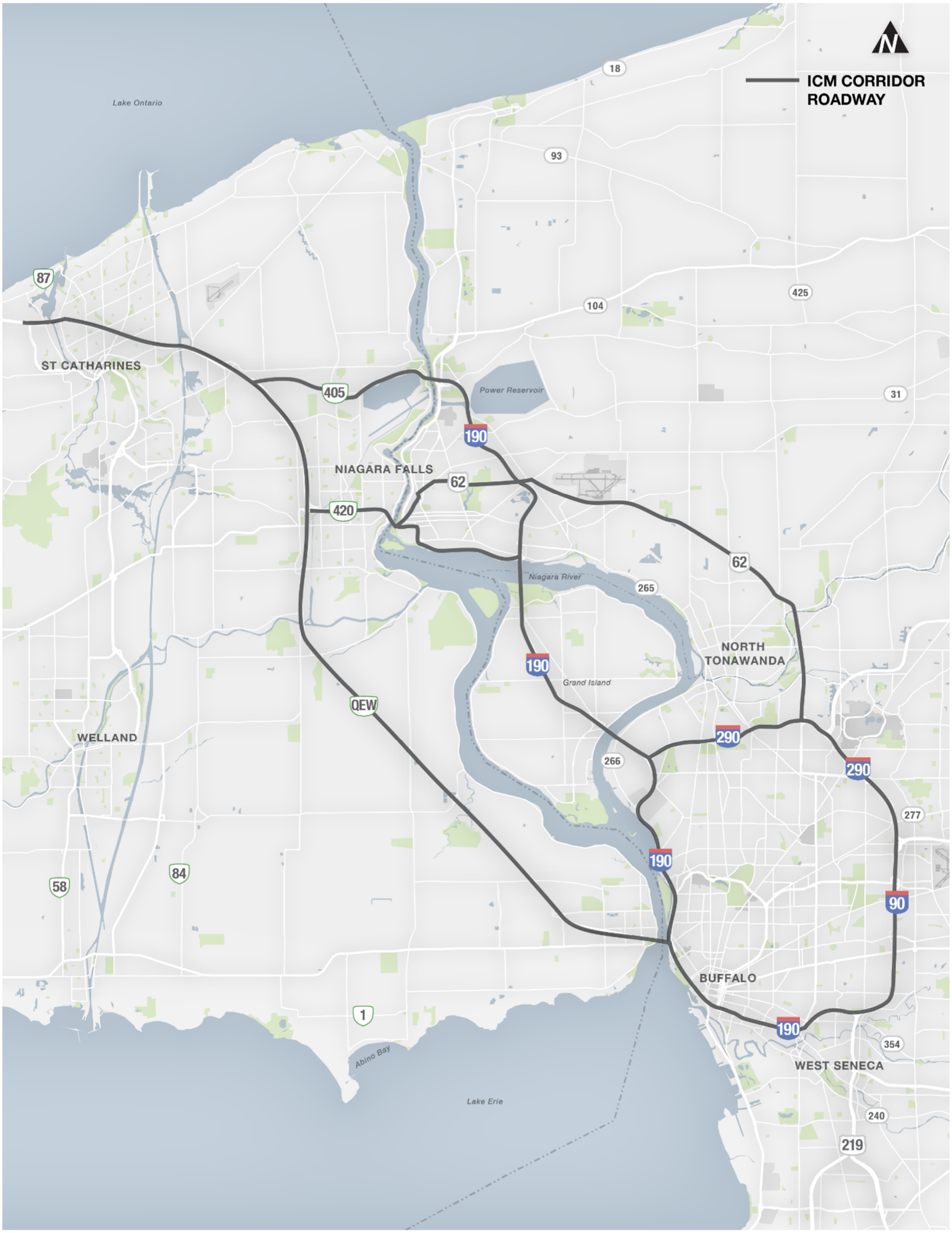
- I-190
- I-290
- I-90
- Route 33 (Kensington Expressway)
- Route 198 (Scajaquada Expressway)

I-190 between the I-90 and I-290 interchanges is the primary focus area within the Buffalo-Niagara region for this study. The study area also includes the Peace Bridge border crossing. The Peace Bridge along the I-190 corridor is one of the busiest commercial vehicle crossings between the US and Canada on the northern border. The bridge currently has a three-lane cross-section that uses a reversible lane in order to provide two lanes in either direction when warranted.

The Peace Bridge is one of four vehicular toll crossings over the Niagara River in the region. The other three crossings are the Lewiston-Queenston Bridge, the Whirlpool Rapids Bridge, and the Rainbow Bridge, which are owned and operated by the Niagara Falls Bridge Commission and are located roughly 20 highway miles north of the Peace Bridge. This study considered strategic diversion routes to the other border crossings in the region.

Figure 1. Buffalo-Niagara ICM Project Region.

ESRI ArcGIS StreetMap Data



1.4 Transportation Context

The Niagara Frontier region's transportation network is complex, servicing both passenger and freight by road and rail. The complexity of the transportation network in the region is not solely determined by the vast number of stakeholders involved, but by the interactions between transportation modes too, consisting primarily of five main transportation networks:

- **Border Crossings** consists of 4 international border-crossing bridges across the Niagara River international border. All four bridges are tolled one-way in the Canada-bound direction.
- **Highway Network** includes Queen Elizabeth Way, Highway 405, Highway 420 and other important highways in Canada as well as Interstate 190, Interstate 290, and Interstate 90, among other important State Routes in the United States.
- **Rail Network** with passenger and freight services provided by major rail carriers.
- **Bus Network** with inter-urban transit and municipal transit service.
- **Air Transportation** network with international and regional airports in the corridors.

The focus of this study is the street system including border crossings, highway network and bus network. High traffic volumes combined with operational and processing constraints at the Peace Bridge can result in significant border delays. Existing delays are generally related to congestion and operational matters at the border enforcement/processing plazas. Delays are often caused by large peaks in traffic volumes, such as midweek truck traffic peaks, holiday passenger vehicle peaks, or by additional security measures that may be undertaken from time to time. The major source of traffic at the Peace Bridge is a result of non-commuter related passenger cars as well as trucks. Due to tourist travel patterns, passenger car volumes are highest on Fridays and weekends, (heaviest in July and August). Truck traffic occurs predominantly during the weekdays, particularly on Wednesdays and Thursdays. Congestion is an increasing issue in the Niagara Frontier region. Border-crossing delay has become a critical problem with tremendous economic and social costs with continued increase in travel demand across the border coupled with the need for tighter security and inspection procedures after September 11, 2001. Two reports released by Ontario Chamber of Commerce (OCC) in 2004 and 2005 show that border delays cost the US economy approximately, $4.13 billion every year. The reports also warn that if the border delay issue is not adequately addressed, the US stands to lose close to 17,500 jobs by 2020 and close to 92,000 jobs by 2030. In a press release in 2008, Former US Transportation Secretary Mary E. Peters highlighted the border crossing delay problem. According to Secretary Peters, US-Bound Traffic from Canada encountered delays as high as three hours at several crossings with these delays costing businesses on both the Canadian and the US sides as many as $14 billion dollars in 2007 (USDOT, office of Public Affairs, 2008).

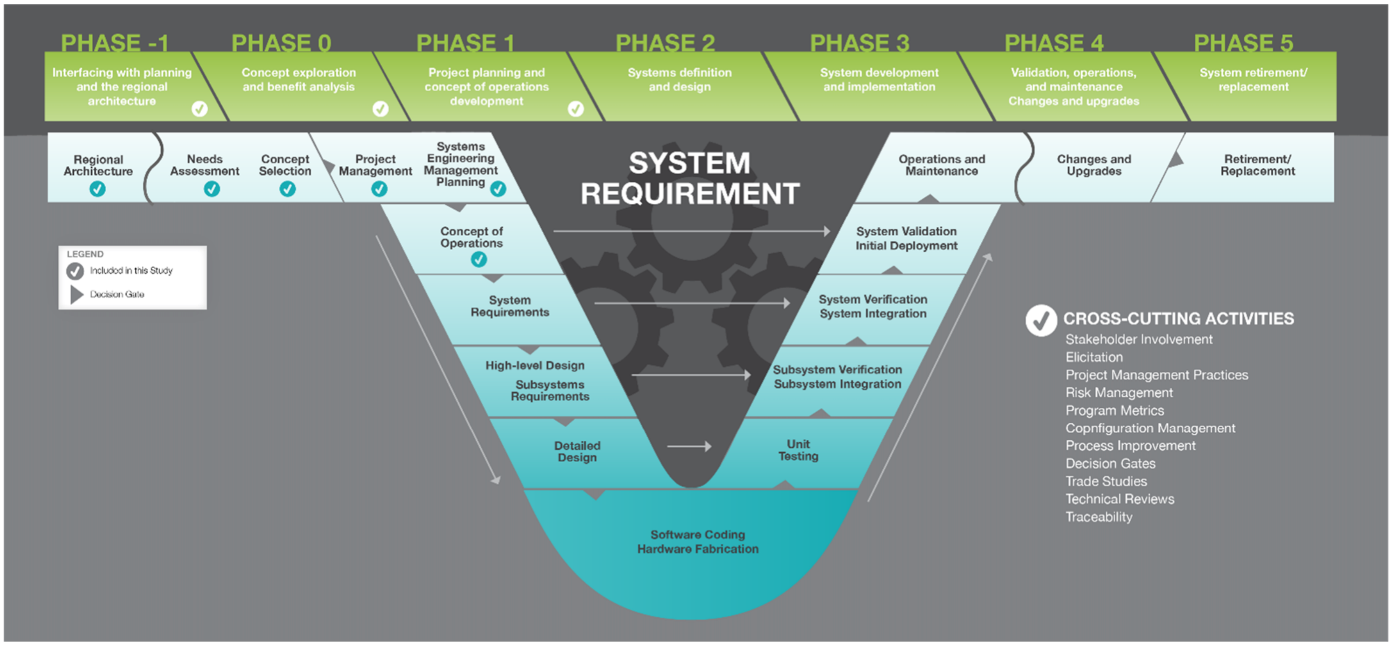
NITTEC and the members of this coalition updated their Canada-Bound Border Crossing Traffic Management Plan in January 2014. The Traffic Management Plan strategies include the use of traveler information systems and traffic management techniques to manage the border crossing traffic. The traveler information systems are used to inform motorists of traffic conditions at border crossings, both in advance of the event and in real time during the event. Traveler information is accomplished utilizing websites, an informational phone line and various Intelligent Transportation System (ITS) elements such as Dynamic Message Signs (DMS) and Highway Advisory Radio (HAR). Individual traffic management techniques have been developed for many scenarios, including normal conditions, congested conditions (in various increments), bridge closures, etc. Example traffic management techniques include diversion messaging, restriction of ramp/roadway access, and remote commercial vehicle staging. This project strives to take the current traffic management procedures to the next level by leveraging and building upon the available resources, tools and ICM goals and objectives.

1.5 Project Activities and Approach

This study fits into the larger systems engineering process, commonly illustrated using the 'Vee' diagram. As shown in Figure 2, the specific efforts in this study belong in the first half of the Vee and start to approach the system design stages of the project. The efforts undertaken here were meant to lay the groundwork for future design and deployment of ICM in the region by examining the strategies that could yield significant benefits and the costs for deploying strategies.

Figure 2. Project "Vee" Diagram.

Illustration of the systems engineering process and the steps included in this study for ICM.



The system engineering process increases the chances of a successful deployment by reducing the risk of unnecessary or unrealistic requirements, while validating that user needs (functional, political and budgetary) are met by the system. As described in Section 1.1 Purpose, the project is built on the artifacts developed previously by NITTEC to complete the activities in the systems engineering process. The key elements of this project include:

- **Project Management Plan (PMP)** describing how the project will be managed and performed considering the scope, budget and schedule. This document guides the execution of the work performed to complete this study.
- **System Engineering Management Plan (SEMP)** focuses on software and system integration component of the project and defines the system engineering process and methods. This plan ensures that the Concept of Operations and ultimate design of the ICM project are consistent with the goals and is fully integrated in a seamless and multimodal manner.
- **Concept of Operations (ConOps) and Requirements** based on the NITTEC initial framework of ICM regional ConOps and high-level requirements a more detailed concept of operations and requirements for the BNICM project was developed. Detail was provided in the *Final Report Buffalo-Niagara Integrated Corridor Management Proposed Changes to NITTEC's ICM System Operations Concept Report*, June 5, 2017.
- **Analysis, Modeling and Simulation (AMS)** to evaluate the benefits and recommendations for ICM strategies using an Aimsun Simulation model for hybrid mesoscopic and microscopic traffic simulation at the regional and ICM operations level.
- **Implementation Plan** for deployment of ICM within the I-190 and cross border corridors based on the ConOps and Requirements and AMS identified benefits. This implementation plan also includes a framework for performance monitoring of ICM deployment in the region.

The remainder of this report provides more detail on the key elements listed above and outlines the findings and recommended plan related to the BNICM.

2.0 Project Management Plan

The PMP is the master planning document for the ICM project. This document describes the activities in detail throughout the period of project development. The PMP defines the project management principles and procedures for the ConOps development. Guidelines from Project Management Body of Knowledge (PMBOK) were used to prepare the PMP. The PMP describes the program structure, project partners and participants, deliverables, related management plans and procedures, and the methods used to plan, monitor, control, and improve the project development efforts. Appendix A provides the PMP.

2.1 Scope

The PMP is a dynamic document and may be updated on a periodic basis to reflect all organizational changes, lessons learned, and advances in methodologies that occur throughout a project’s life cycle. Agreement and adherence to these procedures is one of the keys to successful project delivery.

2.2 Intended Audience

The PMP is intended to provide the project partners, participants, and FHWA officers with detailed information on how the ICM project is being developed.

2.3 Update Process

The PMP is monitored and updated as needed during the BNICM lifecycle. In case of major change to the scope, schedule or budget of the ICM implementation, an update of the PMP is generated as well to document the changes.

3.0 System Engineering Management Plan

The System Engineering Management Plan (SEMP) establishes the systems engineering activities used on the I-190 ICM Corridor Concept of Operations Study project and is included as Appendix B. The SEMP describes the framework for management and control of the systems engineering components during the ConOps development of the ICM corridor. The SEMP is a living document and continues to evolve as the project progresses beyond the ConOps into requirements, system design, and implementation.

3.1 Intended Audience

This SEMP provides the project partners, participants, and FHWA officers with detailed information on how the systems engineering process will be followed for the I-190 ICM project grant.

3.2 Relationship to PMP

The PMP is the master planning document for the project that describes the activities in detail throughout the period of project development. The PMP includes sections on scope, schedule, cost, communications, risk, procurement, staffing, and quality control. The SEMP is the master planning document for the systems engineering technical elements during the ConOps. The ConOps is described in Chapter 4. The SEMP provides a high-level overview of the technical activities and defines the systems engineering process and methods in detail. Both the SEMP and PMP have been developed in concert for this project and are consistent with each other. As the BNICM implementation project evolves, both planning documents will be updated periodically.

3.3 Update Process

The BNICM implementation's SEMP is updated on a quarterly basis during the project lifecycle and at the end of the project. The project stakeholders defined the timing for the first update.

4.0 Concept of Operations and Requirements

The “Final Report: Buffalo-Niagara Integrated Corridor Management, Proposed Changes to the NITTEC’s ICM System Operations Concept Report” prepared by Cambridge Systematics, Inc. dated June 5, 2017 provides updates to the original NITTEC ConOps and Requirements for the ICM project and is provided in Appendix C. The report provides a brief description of the current institutional, operational, and management framework in the Niagara region, and the ICM initiative as initially conceived. The initial description is used to identify sections, concepts, technologies, and measures that require changes to reflect the latest updates in the ICM concept and incorporate best-practices in cross-border activities.

4.1 Goals and Objectives

Existing goals and objectives identified by NITTEC for the ICM initiative are valid for this project; however, as part of this work goals were simplified for easier implementation and evaluation. Table 1 provided in Chapter 1 provides a summary of the objectives for this ICM project and detailed ICM goals and objectives are provided in Appendix C. As described previously, the overall objectives of this BNICM study were to:

- Develop decision support tools needed to complete the required AMS assessments of the potential ICM deployment in the region
- Conduct AMS assessments of potential ICM deployments
- Prove feasibility of an ICM deployment to improve operational and environmental conditions on the region's transportation network

4.2 System Components

Numerous different ICM strategies were considered for inclusion in the BNICM study. A detail discussion of the larger universe of strategies considered can be found in Appendix D ICM Strategies Primer. The specific ICM strategies that were selected for consideration and inclusion in ICM response plans for the BNICM are described in this section and include:

- Improved Dynamic Traveler Information
- Freeway Incident Detection and Service Patrol
- Ramp Metering
- Variable Speed Limits and Queue Warnings
- Variable Toll Pricing
- Signal Coordination
- Parking Intelligent Transportation Systems (ITS)
- Dynamic Lane Controls
- Road Weather Information System (RWIS) and Plow Management

Details on how the various strategies were implemented and incorporated into the AMS efforts to evaluate the effectiveness of the ICM strategies and to estimate the potential benefits to the operations in the Buffalo-Niagara region are also provided. The initial cost estimates for the strategies as simulated in the BNICM evaluations are presented, but detailed cost estimates for each component were not developed at this stage. The estimated costs to implement and operate the equipment were leveraged from FHWA's Version 4 of the "Tools for Operations Benefit Cost Analysis" (TOPS-BC). TOPS-BC is a spreadsheet-based toolbox that summarizes the typical benefits and costs of deploying various ITS and Transportation Systems Management and Operations (TSMO) strategies across the country. Costs are estimated as a mixture of the initial capital installation costs and the annual operating and maintenance costs associated with deploying various ITS and TSMO technologies. The overall annualized life-cycle cost can be estimated allowing a direct comparison to the annual monetized estimated benefits expected from the deployment of such technologies. The TOPS-BC tool includes a spreadsheet-based tool to estimate benefits, but only the cost components of the tool was used for this study because the benefit estimate was completed using a more robust simulation-based method described in more detail in Chapter 5.

While this level of cost analysis is appropriate for this level of planning for the a potential ICM deployment, it is recommended that more detailed costs estimates be developed as part of the design and implementation efforts that will be needed to actually deploy the technologies within the Buffalo-Niagara region.

4.2.1 Freeway Incident Detection and Service Patrol

Freeway incident detection allows for a faster detection of crashes or other incidents occurring on the roadways which in turn allows for faster response by the needed emergency responders, faster clearance of the crash or incident from the roadway, and faster restoration of the normal capacity of the roadway. All this equates to less overall user delays created by the crash or incident. While freeway incident detection has traditionally been completed by observations and confirmation via field cameras, freeway patrol vehicles, police or other responders, or even by public travelers, methods have improved in recent years with more wide-spread near real time probe-based speed information provided by 'big data' sources. Through the implementation of computer algorithms acting as 'virtual traffic management center (TMC) operators' who can monitor all roadway speeds in real-time, when any roadway section sees speeds drop from the normal or expected speeds for the given time of day and day of the week, alarms can be set to notify TMC operator of the speed drop long before building queues would be normally be noticed. The causation of the disruption can then be determined via field cameras, and the appropriate responders can be dispatched to attend to the crash or incident as appropriate.

While detecting the incident faster is one element that would improve corridor operations, Freeway Service Patrols would further improve on the incident clearance time and the corridor's time to return to normal operations. By having resources ready in the corridor to respond to the incident and help clear the incidents in less time. NYSDOT currently operates their Highway Emergency Local Patrol (HELP) program on many roadways across the state including along I-290 and SR-33 in the Buffalo-Niagara region; they currently do not operate patrol vehicles along the I-190 corridor. Adding resources to this program to add HELP vehicles to patrol the I-190 corridor during weekday peak periods would provide assistance and resources to the crashes and incidents along the I-190 corridor.

4.2.1.1. BNICM Implementation

The impacts of freeway incident detection system deployment and added freeway service patrols were simulated in for the BNICM based on estimates of the impacts of reduced incident response and lane clearance times. This study assumed that such a deployment would reduce the time to detect a crash by three minutes and that the time to clear a major crash would reduce by five minutes. Based on these assumptions, the overall duration of the lane blockage(s) from the crash to restoration of the full roadway capacity would be eight minutes faster under the ICM scenarios versus the similar non-ICM scenarios. The shorter incident clearance time was the only change to the inputs of the simulation models; other benefits in terms of reduced system user delays associated with the shortened clearance time are estimated by the simulation model.

4.2.1.2. Estimated Costs

Adding Freeway Incident Detection using real-time speed data feeds would require an incident detection software and integration of that system into NITTEC's existing TMC. NITTEC already has good camera coverage of most of the I-190 corridor, so no additional field cameras were assumed as part of the BNICM. NYSDOT also has a robust HELP program across the state and even within the Buffalo-Niagara region, so no additional system costs were assumed and only the incremental costs of addition patrol vehicles to the I-190 corridor were added. Costs to deploy an incident detection system and an expanded freeway service patrol along the I-190 corridor were taken from the TOPS-BC tool for selected components of traffic incident management systems and are summarized in Table 3.

Table 3. Cost Estimates for Freeway Incident Detection and Service Patrol

Description of Equipment	Useful Life (years)[a]	Capital / Replacement Costs ($)[a]	Annual O&M Costs ($)	Annualized Costs ($)
System Deployment Cost Components				
TMC System Integration	20	205,000	0	10,250
TMC Incident Response Software	2	15,300	770	8,420
Total System Costs		220,300	770	18,670
Incremental Deployment Cost Components				
Incident Response Vehicle	7	87,000	15,500	27,929
Incident Response Labor	1	0	96,000	96,000
Communication Line	5	770	260	414
Total Incremental Costs (per vehicle)		87,770	111,760	124,343
Total Incremental Costs (2 vehicles)				248,685
Total Deployment Levelized Costs (Incident Detection & 2 patrol vehicles)				**296,998**

[a] Useful life and unit costs from FHWA TOPS-BC v4.0.

A total life cycle costs for the detection system and expanded freeway patrol is estimated to cost $296,998 on average per year as shown in Table 3.

4.2.2 Ramp Metering

Ramp metering involves the placement of a traffic signal on the freeway on-ramps to meter the flow of traffic onto the freeway. It reduces the impact of closely spaced or platooned vehicles trying to enter the freeway in succession. The goal of the ramp meter is not to reduce the total number of vehicles using the ramp over a peak hour or peak period but is to smooth the flow of the on-ramp traffic across the time period. The ramp meter alternates between red and green signal states with a vehicle being allowed to proceed on the green lights; thus, spacing out or metering the flow of traffic that may arrive together at the on-ramp in a platooned state (say from a nearby arterial traffic signal). Spacing out the on-ramp vehicles minimizes the disruptions to the mainline (freeway) flows and improves freeway operations by providing more choice in gaps between mainline vehicles for on-ramp vehicles to make a more controlled merge into the freeway traffic stream. On-ramp vehicle delays may be increased by metering; however, freeway mainline lanes operate at higher speeds with ramp metering in place and overall mobility of the system improves. In addition to the mobility benefits, previous deployments of ramp metering have shown to have safety benefits by reducing the number of crashes occurring in the vicinity of the on-ramp.

Vehicle queue spillback from on-ramps with ramp metering could affect nearby arterial operations and increase traffic delays on the arterial system when there are surges in ramp demand and on-ramp vehicle queue storage fills. Queue detection is often added to the on-ramps near the acceptable end of the ramp meter queue to notify the meter controller when a queue has grown to a point where spillback to the connecting arterial streets is possible. When the queue detector is triggered, the ramp meter controller will reduce the timing between green lights, allowing an increased flow rate of vehicles past the ramp meter to shorten the queue to a point where arterial operations will not be impacted. This reduced timing could degrade the on-ramp junction freeway operations but it prevents queues from spilling back into and affecting the arterial system operations. Impacts to the arterial system could potentially negate the delay and safety benefits at the on-ramp junction with the freeway with implementation of the ramp meter and are therefore prevented with the queue detector.

In its most basic form, a simplistic time of day fixed-time metering algorithm can be used to meter traffic given pre-determined typical ramp volumes and freeway mainline conditions. This is akin to a fixed time of day traffic signal control plan at an intersection. While it is easy to implement and has limited sensors to build and maintain, this type of metering cannot easily adapt to varying conditions in the field, such as changing ramp or mainline demands or speeds as seen during high demand conditions or with nearby crash conditions on the roadways.

A more intermediate method of a locally responsive ramp metering system can also be implemented, which is similar to an actuated traffic signal controller. The traffic detection sensors are placed on the mainline freeway lanes to inform the ramp meter controller of the speed and flow of mainline operations. Given this information, the metering algorithm can decide how to vary the spacing of the green lights to allow the meter to respond to the mainline conditions present at that particular time. This system also allows the ramp meter to deactivate when mainline conditions are operating well enough that the metering of the on-ramp traffic is not needed since freeway operations allow for plenty of gaps for on-ramp traffic to merge effectively and safely without metering in place. The responsive ramp meter system prevents additional delay that could be seen at a ramp meter when the metering does not provide benefits to the freeway operations.

A third type ramp meter system treats the overall freeway system as a network of on-ramps and is similar to an adaptive traffic signal controller or a series of networked controllers where phase timings are influenced by the operations at multiple different signalized locations. This third type of ramp metering systems is the costliest to install and operate because of the integrated nature of the traffic detection and localized algorithms need to be developed to operate them effectively.

4.2.2.1. BNICM Implementation

For the BNICM implementation, the intermediate or locally responsive ramp metering systems were assumed to be deployed. The ramp meters would have traffic detection placed on the ramps to detect the presence of traffic (to call a green phase on the meter), queue detection sensors placed towards the start of the on-ramp to reduce impacts to the arterials and mainline sensors to measure the freeway mainline operational conditions to determine when ramp metering should activate.

Ramp meters were assumed to be placed on 28 on-ramps in the I-190 corridor between the I-90 and I-290 interchanges; no ramp meters were implemented on high speed and high volume freeway to freeway connector ramps from I-90 or I-290, or on the ramp from the Skyway (NY Route 5) to northbound I-190. Given the typical directional nature of congestion along I-190 by peak period, the ramp meters were assumed to be activated by corridor and peak period, with ramp metering active in the peak periods by direction as listed in Table 4. Ramp meters were set to operate during all three weekday AM peak period and all three weekday PM peak periods based on the mainline conditions.

Table 4. Proposed Ramp Meter Activations by Time Period

Direction	Weekday AM Peak Period	Weekday PM Peak Period
I-190 Northbound	Exit 1 Ogden St Exit 2 Clinton St Exit 3 Seneca St Exit 4 Smith St Exit 5 Hamburg/Louisiana St Exit 6 Elm/Oak St	Exit 7 Church St Exit 8 Niagara St Exit 9 Porter Ave Exit 9 Peace Bridge Exit 11 NY-198 Exit 14 Ontario St
I-190 Southbound	Exit 17 River Rd (NB loop) Exit 17 River Rd (SB slip) Exit 13 Hertel Ave / Austin St Exit 12 Hamilton / Amherst St Exit 11 NY-198 Exit 9 Peace Bridge Exit 9 Busti Ave Exit 8 Niagara St	Exit 8 Niagara St Exit 7 Church St Exit 7 NY-5 (Skyway) Exit 6 Elm/Oak St Exit 6 Washington St Exit 5 Hamburg St / Louisiana St Exit 4 Smith St Exit 2 Clinton St Exit 1 Odgen St

All ramp meters were coded into the BNICM simulation model using the Aimsun built-in flow metering logic. This is a simple logic that adjusts the timing of the metering to release vehicles at flow rate (vehicles per hour) input by the modeler. The input flow rates for the meters for each of the ICM scenarios were based on the simulated hourly flow rates from the corresponding non-ICM scenario. As is the case in real-world where the metering rates are not purely a function of the mainline conditions but must consider the overall demand for each individual ramp, using a flow meter-based approach was a simplified method to include local ramp metering rate calibrations for the individual ramps. The goal of the ramp meters is not to limit or cap the hourly throughput on the ramps, but instead to smooth the flow and headways between individual vehicles as they approach the freeway merge.

All ramp meters were coded to include both queue flush (i.e., to prevent arterial spillback) and mainline condition detectors. All detector measurements were reevaluated every minute of the BNICM simulation and the appropriate metering state (normal rates, queue flush rates, or deactivated) for each meter was set using Aimsun's Traffic Management operation tools to change the control parameters of each meter. Meters were coded to enter queue flush rates when the average density of the simulated queue detector exceeded 75 vehicles per mile per lane. The queue flush rates were set to double the normal metering rate, and the queue flush mode continued until the density on the queue detectors was reduced below the activation threshold. All freeway mainline detectors were placed roughly equally as far upstream on the mainline from the ramp merge point as the ramp meter was located on the ramp. All ramp meters were set to activate when the average mainline detector density increased above 35 vehicles per mile per lane (per "Highway Capacity Manual" (HCM) this represents the threshold between LOS D and LOS E operations for a basic freeway segment) and deactivate (a constant green provided) when the mainline densities were below that threshold value.

4.2.2.2. Estimated Costs

Different types of ramp metering systems and timing algorithms exist and have been used across the country. The different systems have varying benefits and costs. Costs to deploy a locally responsive ramp metering system were taken from the TOPS-BC tool for traffic actuated ramp meters and are summarized in Table 5.

Table 5. Cost Estimates for Ramp Metering Deployment

Description of Equipment	Useful Life (years)[a]	Capital / Replacement Costs ($)[a]	Annual O&M Costs ($)	Annualized Costs ($)
System Deployment Cost Components				
TMC Hardware	5	18,000	1,600	6,500
TMC Software / Integration	5	77,000	0	15,400
Labor		**0**	**56,000**	**56,000**
Total System Costs		**95,000**	**57,600**	**77,900**
Incremental Deployment Cost Components				
Ramp Meter (Signal, Controller)	10	30,000	1,900	4,900
Loop Detectors	10	20,000	480	2,480
Communication Line	5	770	260	414
Total Incremental Costs (per meter)		**50,770**	**2,640**	**7,794**
Total Incremental Costs (28 meters)				**218,232**
Total Deployment Levelized Costs (28 meters)				**356,791**

[a] Useful life and unit costs from FHWA TOPS-BC v4.0.

Table 5 shows a total levelized life cycle cost to deploy and operate the 28 ramp meters of $356,791 on average per year.

4.2.3 Variable Speed Limits and Queue Warning

A variable speed limit (VSL) system works by lowering the speed limits from the normal posted speed limits on selected portions of roadways given the operating conditions at hand, usually with the aim of preventing crashes or lowering the severity of crashes. The lower of speed could be in response to weather, work zone or road work, or due to slow or queued downstream congestion. While implementing a VSL system could provide benefits in the first two conditions, the latter condition of using a VSL system to warn drivers of downstream congestion conditions was the primary reasoning for deploying a VSL system within the Buffalo-Niagara region. In a modern VSL systems, speed limits are generally presented to the drivers either on gantries above the roadway, with one variable speed limit sign per lane, or on roadside signs. Overhead signs are preferred due to the increased visibility with drivers, although roadside units are much less expensive to deploy. Ideally, the variable speed limit changes are not simply advisory in nature but instead are regulatory and enforceable by police; this can increase the adherence of the driving populations to the reduced speed limits.

While some metering effects from a VLS system could in theory increase throughput at bottlenecks and improve travel times (similar to a ramp metering system) by limiting the size and severity of that bottleneck, here a VSL system is considered for deployment to improve safety by warning approaching traffic to slow speeds based on the downstream conditions and by minimizing the speed differentials of vehicles as they approach a bottleneck or queued conditions along a roadway. The resulting expectation from such a deployment is that the number of crashes associated with vehicles arriving at high speeds to the back of a queue on the freeway are reduced. This warning is especially important when the congested conditions are not expected by the drivers. Given the recurring nature of many bottlenecks during the typical commute periods, many drivers expect congestion at these locations and may alter their driving to be more cautious as they approach these locations. The VSL system can be helpful when drivers are unfamiliar with the normal roadway conditions (non-commuters) or when the bottlenecks and congestion existing in an unexpected way (e.g., a crash or unusually high demands). While the primary benefit is safety, there are associated mobility and reliability benefits from the prevented crashes. While this is not the primary intended effect of a VSL and queue warning system, there is the potential for substantial benefits from this aspect of the VSL implementation as well.

While variable speed limits and queue warning systems have been used in a few locations in the U.S. for many years (e.g. New Jersey Turnpike), the use has more traditionally been based on static conditions, such as construction activities, congestion warnings, or adverse weather. These older systems would lower the regulatory speed limits, often by a fixed amount such as lowering speed limits on a bridge during high wind conditions, or purely warn drivers of congested or construction activities downstream of the drivers current locations. These changes would often result from an operator issuing the change command to field equipment, and the modified speed limits or warnings would generally not change until the condition was cleared. More modern variable speed limit and queue warning systems, such as those recently deployed in Europe and other locations around the world, are much more dynamic in nature and can be used to adjust the speed limits based on the downstream congestion and conditions throughout a peak period. This more modern system is what is proposed for deployment in the I-190 corridor, with upstream speed limits being set in response to the prevailing downstream operating speeds to warn of the downstream queued conditions.

4.2.3.1. BNICM Implementation

The VSL system was assumed to be in place and operate along the entirety of the I-190 corridor in both directions, from the approaches to the Lewiston-Queenston Bridge in the north to the interchange with I-90 in the south. To evaluate the impacts of the VSL system on travel time and speed operations within the BNICM model, protocols using traffic management tools within Aimsun were developed to simulate the dynamic speed sensing and speed limit changes as they would happen in the field. To simulate the VSL system, the entire I-190 corridor was divided into VSL zones approximately 1 mile in length in each direction. All Aimsun sections along I-190 within each of these zones were then identified. Traffic detectors were placed on the I-190 mainline lanes just downstream of the end of each VSL zone, with the average simulated speed of that detector reported every 60 seconds. Based on the average speed of that detector for the previous 60 seconds, the VSL signs for the VSL zone were set in 5 mile per hour increments such that the VSL sign presented a speed that was slightly higher than that downstream detected speed. For example, if the detector reported an average speed of 47.2 miles per hour, the VSL zone speed was set to 50 miles per hour, and all sections within that VSL zone were set to a speed limit to 50 miles per hour. The VSL speeds were adjusted up or down every 60 seconds in the simulation based on the detected downstream speed. If the downstream speeds increase, VSL speeds were increased; if speeds fell, then the VSL speeds were lowered. All VSL zones operated with the same maximum speed limit as currently exists in the field, and the minimum speed present on any VSL was 35 miles per hour. Figure 3 present an illustration of one of these VSL zones and its detection point long I-190 in the southbound direction on Grand Island.

Figure 3. Example of VSL Zone and Speed Detection Point.

4.2.3.2. Estimated Costs

The projected deployment of a VSL and queue warning system can have significant costs associated with the amount of infrastructure to be built to properly display the dynamic speed limit signs. While a more detailed engineering design would need to be undertaken to refine the projected costs, the estimated costs to deploy a VSL and queue warning system across the length of the I-190 corridor are presented in Table 6**.**

Table 6. Cost Estimates for Variable Speed Limits and Queue Warnings

Description of Equipment	Useful Life (years)[a]	Capital / Replacement Costs ($)[a]	Annual O&M Costs ($)	Annualized Costs ($)
System Deployment Cost Components				
Engineering Design	25	154,000	0	6,160
Software Module	20	300,000	3,000	18,000
ATM TOC Hardware	25	50,000	1,250	3,250
Total System Costs		504,000	4,250	27,410
Incremental Deployment Cost Components				
Gantries with large DMS and CCTV	25	920,000	18,400	55,200
Controller	10	25,000	1,250	3,750
Speed Limit / Lane Control Signs	10	10,000	500	1,500
Detectors	10	10,000	500	1,500
Mast Arm Assembly with Dynamic Speed Limit Signs	10	150,000	7,500	22,500
Roadside Dynamic Speed Limit Signs	25	20,000	1,000	1,800
Camera Assembly	10	65,000	3,250	9,750
Telecom / Power Duct Bank	25	250,000	6,250	16,250
Telecommunications	25	40,000	800	2,400
Power	25	40,000	400	2,000
On Site Backup Generator / UPS	10	10,000	250	1,250
Total Incremental Costs (per mile)		**1,540,000**	**40,100**	**117,900**
Total Incremental Costs (28 miles)				**3,301,200**
Total Deployment Levelized Costs (28 miles)				**4,137,343**

[a] Useful life and unit costs from FHWA TOPS-BC v4.0.

4.2.4 Variable Toll Pricing

Variable toll pricing involves modifying the facility toll rates paid by the traveling public based on the time that the facility is used, often by charging a higher toll rate during hours of peak usage and congestion versus the typical non-peak period conditions. By varying the toll rates by time, the pricing can be used as a demand management tool to provide economic incentives to the drivers to alter their normal behavior to use a congested toll facility during less congested times by paying a lower toll rate or by using an alternative route during the times of peak congestion. Variable tolling pricing is sometimes referred to as congestion pricing when the differential between off-peak and peak toll rates are set to encourage less peak period usage, which in turn improves peak period mobility and reliability.

A more robust method of variable toll pricing is dynamic toll pricing, which adjusts the toll rates in smaller increments (e.g. every 5 minutes). Dynamic tolling pricing are more commonly used in managed lane systems where the driver is presented with the toll rates and can decide whether or not to pay that rate to use the toll lane or opt for the non-tolled option that may have more congestion and longer travel times. Given that the alternative non-tolled options to the Grand Island Bridges are not immediately available to the drivers, dynamic tolling was not considered and instead a fixed time of day schedule based on recurring congestion to set higher peak period tolls based on normal recurring congestion was selected as the basis for a variable toll rate ICM strategy.

4.2.4.1. BNICM Implementation

Based on a review of the normal typical weekday congestion patterns on Grand Island, a two-hour morning peak period (7-9 a.m.) was selected for an increased southbound toll rate and a two-hour afternoon peak period (4-6 p.m.) was selected for an increased northbound toll rate. For both peak periods and directions, it was assumed a one-dollar increased toll rate would be charged during the peak periods as compared to the off-peak period. The change in toll rate could be implemented as a pure increase of the peak period toll rate, or as a combination of a slight reduction of the current toll rate for off-peak hours and a less than one dollar increase for the peak period by direction. Specifics on the rate change would need a more in-depth revenue assessment in consultation with the NYS Thruway Authority.

Drivers' responses to a toll change are best estimated through an examination of the traveling population's value of travel time and willingness to pay parameters. Since surveys or other estimates of such parameters from the Buffalo-Niagara region were not available, values were borrowed from a study of potential reintroduction of tolling in Connecticut prepared by Cambridge Systematics, Inc.

Drivers can react to the toll increases in one of three ways:

1. Incentivized to shift their travel schedule by departing slightly earlier or later than current done and pay off-peak toll rate
2. Seek an alternative route to avoid paying the toll rate
3. Continue to pay the increased toll rate because they do not see the increased toll rates as significant enough to adjust their travel schedule or routes

Each of these driver reactions were considered and incorporated into the BNICM modeling of the implementation of a variable toll ICM strategy. The results of the driver behavior are illustrated in Figure 4 for the southbound direction in the weekday AM peak period and Figure 5 for the northbound direction in the weekday PM peak period.

Figure 4. Variable Toll Impacts for Southbound Weekday AM Peak Period Traffic.

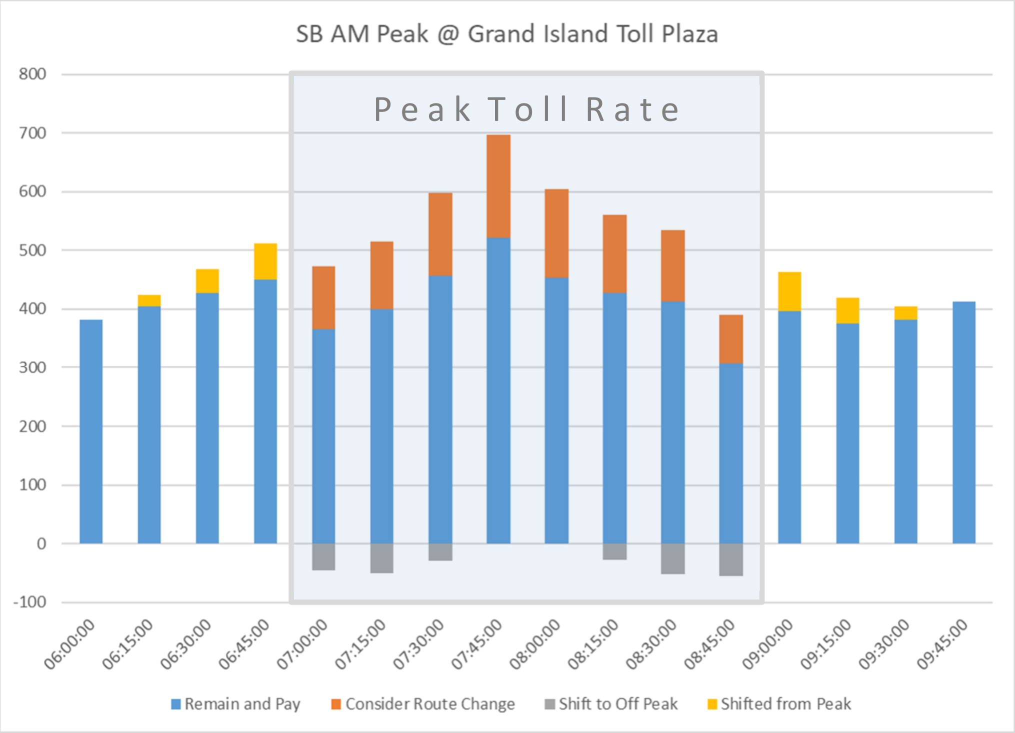
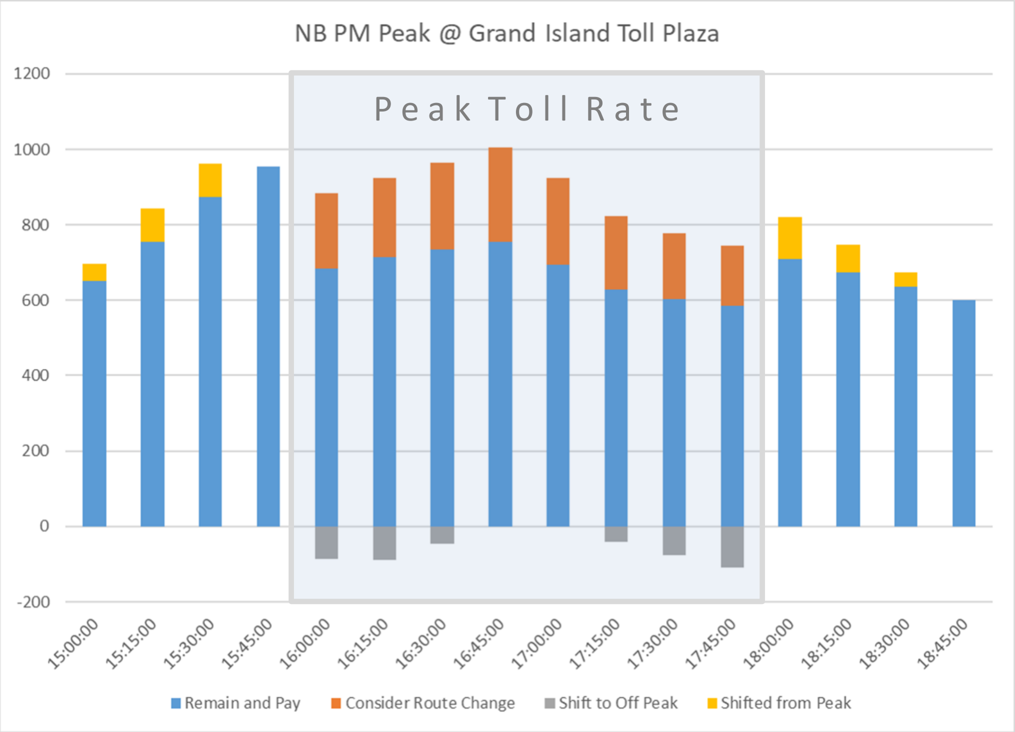


Figure 5. Variable Toll Impacts for Northbound Weekday PM Peak Period Traffic.



The drivers that would shift their travel times from the peak two-hour increased toll window into the off-peak was estimated by looking at the volumes and travel times for the simulation period and some presumed time shift sensitivities based on the above-mentioned Connecticut studies. The resulting shift in travel ranges from a high of 15% for the immediate start or end of the peak period windows to 0% for the core middle time intervals of the peak period. A select link analysis to extract the origin-destination pairs was undertaken for the non-ICM simulations and origin-destination demand matrices were manually adjusted to shift demands into the off-peak time intervals. These demands are illustrated in the figures in both grey (volumes shifted from the peak period) and in yellow (volumes shifted into the off-peak periods).

The portion of traffic that would change travel away from the Grand Island toll bridges all together was considered to be 25% of the drivers that remained in the peak period and did not shift trip departure times to the off-peak. This portion of the remaining peak period drivers were segmented out of the normal origin-destination demand pairs and a new vehicle class was created for these potential route shift drivers. For this new vehicle class in the simulation, the assumed habitual route choice models developed for the standard vehicle classes were removed and the new vehicle classes were allowed to select new routes to complete their trip based on the new increased toll rates and the resulting changes in the peak period congestion levels and travel times. Figures 5 and 6 represent the trips that change route in orange. It is important to note that these vehicles were only permitted to consider a new route during the simulation; they were not forced onto a new route. If travel time for the alternative travel routes without tolls were significantly larger than the equivalent value of time with the added one-dollar toll surcharge during the peak periods, then those trips would continue to use the Grand Island Bridges and pay the increased toll rate for the peak period.

For vehicles not considering a time shift or route shift, those vehicles remained and traveled at the same time along the same route. Those vehicles are represented it the figures in blue.

4.2.4.2. Estimated Costs

As both of the Grand Island Toll Plazas were recently demolished and replaced with cashless tolling methods using either electronic (E-ZPass) transponders or a camera-based pay by license plate method, the costs to implement adjust the peak period toll rates from the off peak rates should be minimal and negligible over the life of the deployment as it relates to the costs of toll collection.

It is recognized that the existing signage would need to be adjusted to reflect the new toll rates. Existing static signs could be modified if a purely weekday peak period time of day toll rates system were to be implemented. If adjustable pricing were to be put into effect, the existing signs could be modified to add a small dynamic sign to report the variable toll rates currently in effect. For either option, the costs associated with such a change should be minimal over the life of the ICM deployment.

Finally, while some additional revenue might be expected from a peak period toll increase, no added revenues were assumed to be received as part of this deployment. Instead, it was assumed that the variations between the off-peak and peak toll rates would be set such that the implementation of variable toll rates would be revenue neutral or any new revenues would be used to offset any forecasted costs associated with implementing a variable toll system.

4.2.5 Signal Coordination

As the previous ICM strategies have more predominantly targeted freeway facilities, it should also be noted that the arterial system has room to improve. Proper signal timing maintenance and coordination has always been an effort undertaken to optimize efficiencies on the arterial system by reducing the delays at the intersections. Signal timings can be updated and retimed throughout the years as normal travel patterns change, either from land use changes and growth or changes in nearby roadway capacities that alter the normal, regular flow of traffic.

However, as an ICM strategy, signal retiming and coordination go beyond the normal travel patterns and focus on adapting signal timings and coordination on key arterials that are pressed to play a role in relieving congestions from freeway based system disruptions or non-typical conditions (e.g. high demand days, crashes, weather impacts, and other conditions). The primary focus of signal coordination as an ICM strategy is to bring the signal timing and coordination on key arterials into alignment with the strategies being implemented to better manage the freeways, so that collectively the overall roadway network is improved, especially under atypical conditions. Drivers may seek alternative paths on the arterial roadway in attempts to avoid congestion on the freeways and this behavior is only reinforced through some of the other ICM strategies mentioned above, including better dissemination of travel information to the drivers. Signal coordination as an ICM strategy aims to implement modified signal timings and coordination parameters on arterials that can serve as key alternative routes for the freeways as a direct response to the ongoing event that is being managed. For example, if a crash on a freeway imposes a dramatic reduction in the capacity of the freeway, a signal coordination response plan could be selected in the TMC and be pushed to signal controllers in the field to improve green times and coordination in the direction of flow on the arterial that are expected to see increased traffic flows and congestion as drivers divert away from the freeway during the crash blockage. Such response plans, often referred to as signal flush plans, aim to move or flush that increased or unexpected traffic through the arterials as much as possible without adversely affecting the overall operations of the arterial system. After the crash is removed and any potential increased traffic flows on the arterial are returned to normal, the signal response plans can be removed, and signal timings can return to their normal time-of-day operations.

It is important to remember when developing ICM signal coordination of flush plans that the overall safe operations of the arterial system must remain intact. Safe operations include maintaining acceptable minimum green times on all needed phases to provide safe pedestrian crossing times, and not minimizing green times provided to phases not serving the increased detour traffic flows to the point where delays become unreasonable. The increases in delays on the side streets may offset any potential travel time savings to the diverted drives or even worse delayed drivers may become increasingly impatient and start to drive in more unsafe manners, such as aggressively using clearance times at signals or accepting smaller and less safe gaps in vehicle flows. The important element is that the signal response plans are tailored to the problem at hand and look at the overall network, not just the diversion flows that are added to the arterial system. Tailored plans are especially true on already heavily traveled and congested arterials.

Response plans should be developed and evaluated well ahead of any actual event occurring in the field and the implementation of the response plans in the field. While the exact timing and nature of the crash or disruption in the field cannot be known, a variety of response plans can be developed in advance knowing when and where disruptions usually occur through reviewing historical crash records. When a crash or other event occurs in the field, a response plan that was developed for a similar type of crash could be implemented to adjust the signal timings in the field to help the overall roadway network respond to the event. Testing of the developed response plans through planning exercises such as simulating the response plans and assessing the impacts of the signal timing changes and refining the response plans is highly suggested prior to implementation of a response plan in the field.

It is also important to know the state of the arterial system and roadways on which signal timing changes will be made, so adding detection of traffic speeds and flows on the arterial to be adjusted should also be implemented in addition to upgrading the signal controller and communications needed to push signal timing response plans to the field in near-real-time. This detection of arterial conditions can be used to determine if the arterial is actually functioning in a normal condition manner similar to what was assumed in the development of the response plans. If the arterial is also experiencing unusual conditions, either from a separate crash, construction, demand-attracting event, or signal hardware malfunction, the developed response plans may not function as intended, and subsequent changes could make overall delays and travel times on the arterial worse.

4.2.5.1. BNICM Implementation

To determine the possible corridors to consider developing response plan retiming strategies for, major arterial corridors in the region were first reviewed by GBNTRC and NITTEC staff to select potential corridors for response plan signal retiming. These corridors included the major arterial corridors of Niagara Street, Delaware Avenue, South Park Avenue, Seneca Street, Clinton Street, Military Road, and Grand Island Boulevard. Figure 6 presents these corridors and their limits within the overall BNICM network.

Figure 6. Corridors Considered for Signal Coordination.

Following the identification of the potential corridors to be updated, the base condition models that were developed to evaluate the ICM strategies were reviewed with the potential of the corridors to assist in the management of traffic in response to conditions going beyond the normal typical commute periods. For both the weekday AM Crash and the weekday PM Crash BNICM models, it was determined that the Niagara Street corridor could have signal timings adjusted to assist in the management of the simulated crash conditions. As both simulated crash conditions occurred on I-190 near the SR-198 interchange, the proximity and the ramp connections to Niagara Street made it a clear choice to serve detour traffic during the crash events. For each of the weekday AM and PM Crash conditions, a separate response plan was developed that retimed all twenty-six signals between and including Elmwood Avenue in the south to Ontario Street in the north. These sections of Niagara Street were selected to be adjusted considering the severity of the crash, the duration of the lane blockages.

For each of the Crash conditions periods, the response plans were initially based on the existing typical weekday AM or PM peak period signal timings but adjusted in two different ways.

1. Signal controllers were revised to run a common cycle length of 120 seconds for most of the signals or 60 seconds for some minor intersections.
2. Signals were retimed to add additional green time (up to 10 percent) to the direction of travel that we would expect to see increased flows in as part of the driver responses to the crash conditions including the southbound in the weekday AM Crash base condition and northbound the weekday PM Crash base condition.

Green time changes were not made uniformly to all signals, but instead changes were made signal by signal considering how much green time per cycle the peak direction already received before the timing adjustments, as well as the level of the volumes that the side streets process under normal operating conditions at intersections with other major arterials.

The overall goal in the response plans was to allow a larger green wave of progression through the Niagara Street corridor in the peak direction to allow improved throughput during the Crash event without unreasonably disrupting the operations of the corridor. The response plan signal timings were tested several times, and the final selected response plans for the weekday AM Crash and PM Crash conditions were developed by reviewing the initial simulations and revising and improving upon the previous response plans, but the retiming fell short of an optimization of the signals timings to the simulated flows. This optimization was purposefully not done to maintain a more realistic retiming considering that the true field conditions signal by signal would not truly be available and the response plans are still preset timing plans planned for a Crash similar to the simulated condition, and optimization is not able to be determined unless a more robust (and expensive) adaptive signal system is implemented.

Some latency was also assumed in the timing of the implemented response plans being implemented in the field. With operations in the field, it will take a several minutes to detect the crash, decide on a response plan to implement, push that response plan to the field, and allows for the signal controller to transition from the existing timings to the new response plan timings. Accordingly, the timing of the implementation of the response plans taking effect in the simulation model lag the actual time of the simulated crash by an assumed ten minutes latency. Similarly, the response plans continued in the simulation model after the crash itself has been cleared, as the response plans in the field would ideally continue until the congestion impacts from the crash are resolved and the volumes on the arterials return to normal conditions.

4.2.5.2. Estimated Costs

In order to implement a signal coordination system that is capable of changing timing plans at key signal controllers in near real-time as part of an ICM incident response plans, several components would need to be updated in the field. First, the signal controllers would need to be updated to modern signal controllers capable of remote communication with the capacity to store and implement numerous different preset timing plans associated with different types of ICM events. Next, a real-time communication link to the signal would need to be established and maintained. Finally, adding sufficient detection at the signalized intersection would be advisable to provide greater real-time feedback on operations of the arterial and the signalized intersections, both before and during a response plan implementation.

The estimated costs to implement all needed changes are presented in Table 7, and were estimated by reviewing recent cost data provided by NITTEC associated with upgrading signal controllers in the region. The costs listed are only for the Niagara Street Corridor as evaluated in this project. While other arterial corridors would also expect to be upgraded and response plans developed to allow a deployed ICM system to use those other arterial corridors in a similar manner to the proposed ICM strategy discussed here, only costs associated with upgrading the Niagara Street corridor are included since that is the only corridor where signal coordination in response to an ICM event was tested (and therefore only those benefits are estimated to date).

Table 7. Cost Estimates for Signal Coordination

NITTEC recent signal controller upgrade costs in the region

Description of Equipment	Useful Life (years)	Capital / Replacement Costs ($)	Annual O&M Costs ($)	Annualized Costs ($)
System Deployment Cost Components				
TMC Software for Signal Control	5	32,000	3,200	9,600
Total System Costs		32,000	3,200	9,600
Incremental Deployment Cost Components				
Signal Controller Upgrades	10	7,500	340	1,090
Communications	1	0	1,200	1,200
On Site Backup Generator / UPS	5	12,000	1,000	3,400
Total Incremental Costs (per signal)		19,500	2,540	5,690
Total Incremental Costs (26 Signals along Niagara St)				**147,940**
Total Deployment Levelized Costs (26 Signals)				**173,306**

4.2.6 Other Strategies Considered

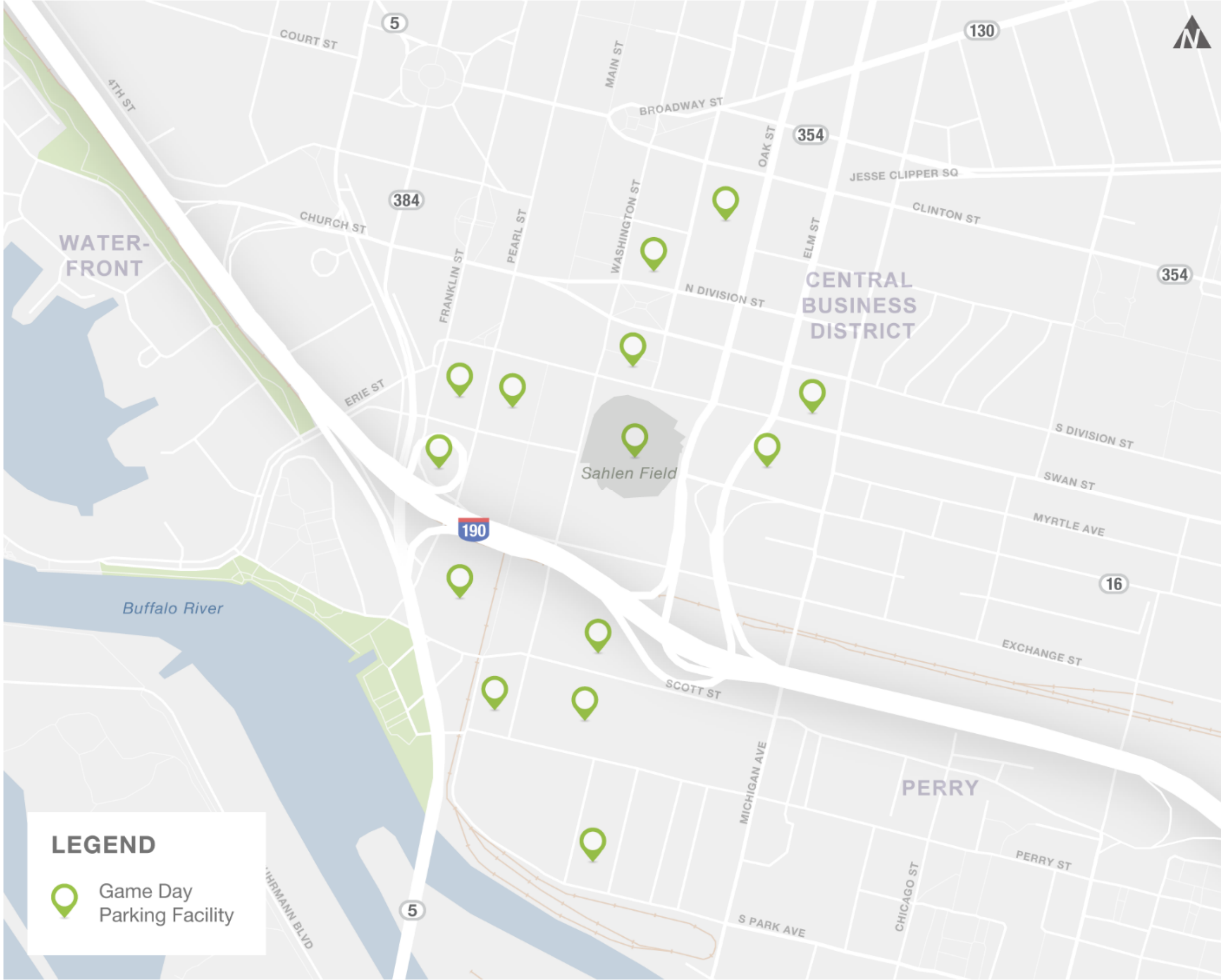
In addition to the above selected ICM strategies, a handful of other potential ICM strategies were selected for consideration under certain base conditions. These strategies were not directly tested or evaluated for effectiveness or benefit to cost efficiencies as part of this study. The following sections describe the strategies generally and how they could potentially improve on conditions within the Buffalo-Niagara Region. It is suggested that these strategies be revisited and analyzed in the future before any future ICM design or deployment activities occur under future efforts.

4.2.6.1. Parking ITS

In order to help improve congestion seen downtown during events like those modeled in the Game Day Base Condition, a Parking ITS system could be deployed to help guide and better distribute event attendees arriving in private vehicles towards appropriate and available parking lots. The goal of such a system would be to minimize travel delays and congestion on the arterials in the vicinity of the Keybank Center. While a parking ITS system would expected to be most beneficial during Game Day conditions or similar special events which attract a large numbers of attendees, there could potentially be additional benefits seen during normal peak hours to help general, non-event generated traffic find available parking more quickly and with less delays and less circulating on the roadways looking for available parking.

Most Parking ITS deployments utilize small roadside dynamic message signs on arterials which could act as both a dynamic trailblazer sign to help direct drivers unfamiliar with the roadways and facilities given current operations conditions and levels of congestion in the area and act as a real-time parking information system to display the number of currently available parking spots at various parking lots in the area. Figure 7 presents the blocks with significant parking facilities in the vicinity of the Keybank Center. By leveraging the information provided at selected locations, drivers can be directed along more optimum routes to avoid congestion hot spots and direct them to nearby logical parking facilities with spaces rather than having the driver circulate the area looking for parking spots.

Figure 7. Game Day Parking Facilities.



In addition to the roadside signs, a Parking ITS system would also require the installation of sensing equipment at parking facilities (surface lots or parking ramps) to determine and provide back to a central control center the current number of available parking spaces in that particular facility. Knowing the capacity of the facilities, gate controls and counters can be used measure number of entering and exiting vehicles over time to determine the number of available spaces at the given time. While not nearly as commonplace, curbside parking sensors are also now becoming more widely used to help measure and report curbside parking space occupancy and availability as well.

4.2.6.2. Dynamic Lane Controls

Dynamic Lane Controls could be implemented to help improve safety and operations in a variety of conditions. Usually used on freeways, a deployed system places small dynamic signs above each lane to dynamically open and close lanes, usually in advance of unusual downstream conditions, such as a crash, construction, or other lane blockages. Drivers can be told which lanes to use to help better move vehicles around closed lanes, and to help make for safer conditions for emergency responders or construction workers working on the roadways. Within the Buffalo-Niagara Region, such a system could be leveraged during crash events, or potentially during snow events when plows are actively working on the roadways, when snow is only partially removed from the roadway, or potentially when ramps may be closed due to snow conditions.

The primary benefits of dynamic lane control systems are expected to be improved safety and prevention of either primary or more often secondary crashes, in unexpected conditions. However, it is noted that mobility and reliability benefits could also be seen as a secondary benefit of those prevented crashes. The system could potentially be integrated with the proposed variable speed limit system to minimize hardware installation costs, but further investigations into the potential system integrations would be needed.

4.2.6.3. Road Weather Information Systems & Plow Management

Directly applicable to snow impacted conditions, an improved Road Weather Information System (RWIS) and a Plow Management system could be leveraged to help provide information to the traveling public during adverse weather conditions. RWIS sensors can be placed in the field to assess the environmental conditions, potentially including sensors to measure roadway surface temperatures to advise of conditions in which roadway surface freezing is likely or localized limitations in visibility. While general environmental weather monitoring can help provide these estimates, more detailed and localized information from RWIS sensors can help with more accurate forecasts and reporting of roadway surface conditions and limited visibility during inclement weather. Advisories of potential freeze conditions could be shared with drivers on DMS directly in advance of the area of concern, or more broadly distributed to the traveling public in an attempt to change trip making and route choice decisions either en-route or even before a traveler leaves their current location.

A plow management system usually operates by placing automated vehicle location (AVL) devices on the plows and further knows the current state of the snowplow and/or salt/sand spreading devices. Such systems are often used by agencies as part of Maintenance Decision Support Systems (MDSS) to help manage plow assets during a snow removal event and to help make snow removal operations more efficient. However, by transmitting the GPS and snow removal status of plows back to the TMC, roadway managers can monitor which roadways have been recently plowed or treated and advise the traveling public of such information, either on DMS signs around the region, via 511, or via website or mobile phone applications so that drivers can make more informed decisions about which roadways they choose to complete their trips, or even to modify the departure of a trip given the status of the roadway conditions and how recently their preferred travel route has been cleared of snow or treated.

Both systems aim to better inform the public of road conditions during a snow event to allow them to make more informed and better decisions about their travel during snow events, and to ultimately reduce weather-related crashes from occurring during snow events.

4.3 System Evaluation

In order to evaluate the ICM strategies described above, performance measures were outlined, and short-term and long-term targets were determined for the ICM project. A set of 15 performance measures were identified and the SEMP noted the ICM initiative may benefit from reducing the number of performance measures and ensuring all modes of transportation are evaluated. The following suggestions for reducing and combining performance measures are described in the SEMP:

- **Traveler Information Usage.** Although it is desirable to measure the effectiveness of traveler information systems, the set goals of 150% increase in the short-term horizon, and a 200% increase in the long-term horizon, may be too high considering the changing technology paradigm of wide-spread smartphones and with it increased access to traveler information. In the long-term traveler information is becoming increasingly available through private sources, and this is likely to continue as these capabilities are increasingly available in vehicle telematics systems. This performance measure also requires baseline usage, which might be complicated to obtain from privately owned information distribution means. Through the current ICM AMS efforts, these goals may be recommended to be reconsidered.
- **Back to Normal Conditions Time.** This performance measure seeks to describe the overall average time from detection to back-to-normal conditions. Back-to-normal conditions may need to be defined more clearly, as conditions on different times of day may show different "normal" conditions. Instead, the metric may be renamed 'Time to Return to Acceptable Operations' or 'Time to Return to Expected Operations' or even another term may be considered. While other influences will certainly influence this time, it is noted that this metric is directly influenced by the 'Arrival Time' and 'Clearance Time' metrics that are already evaluating the effectiveness of incident management improvements.
- **Arterial Coordination.** This performance measure targets the number of jurisdictions coordinated, and acts as a metric of interagency collaboration. An additional metric more purely related to the performance of the arterial and/or signal system may be warranted or desirable.

The ICM project also identifies specific performance measures and evaluation methods for the AMS tied to the goals and objectives of ICM deployment. Appendix E provides the memorandum to Buffalo-Niagara ICM Project Team "BNICM AMS Performance Measures and Evaluation Methods," June 5, 2017. The performance measures are used to evaluate the impact of various packages of ICM strategies on events or other conditions. The overall impacts of ICM strategies are assessed by looking at changes in performance metrics between the without and with ICM scenario.

The benefits of the system operations may not be shared equally on the components of the transportation system and strategies may have negative impacts. For example, a ramp metering system improves freeway mainline operations but may degrade ramp and parallel arterial conditions. Performance metrics are further stratified by roadway class, vehicle type, origin-destination of trips, or subset of roadways to assess who or where may benefit from the ICM strategies.

The AMS uses the overall benefit-cost ratio for the IMC strategies to understand the viability of the ICM system. The metrics monetized for this work include:

- **Mobility:** Apply the mean user's value of time ($/hr) to the overall vehicle hours of time saved. Higher values of time may be appropriate for truck versus the general traveling public.
- **Reliability:** Apply the mean user's value of time ($/hr) to the change in the standard deviation of the travel times for the traveling public. Higher values of time may be appropriate for truck versus the general traveling public.
- **Environmental:** Apply the average retail fuel costs ($/gal) can be applied to the estimated change in gallons of fuel consumption; estimated average cost of treatment ($/ton of pollutant) can be used to monetize changes in tailpipe emissions.

The overall evaluation is based on an assemblance of two strategy packages (A and B), which are described in more detail below.

4.3.1 Strategy Packages for Base Conditions

The previous sections outline the ICM strategies that were considered to be included in a response plan to better manage the roadway network during an ICM event seen it the field. However, certain strategies by their nature are more applicable during certain operational conditions. Table 8 presents the matrix of the ICM strategies against the evaluation scenario (or base condition) where BNICM Models were developed. Within this matrix, cells are marked with dots where specific ICM strategies are expected to provide benefits under each of the operational base conditions. Dots indicate that those strategies were evaluated within the BNICM simulation models, with those results discussed in the next chapter. Xs are combinations of strategies and base conditions that expect to see benefits but estimates of those benefits have not been completed with the BNICM model simulations or included in the overall benefit cost analyses.

Since the permutations of various ICM strategies and base conditions to be evaluated within the BNICM model presented an immense number of scenarios to simulate and analyze, packages of ICM strategy deployments were developed to streamline the simulation and evaluation of the effectiveness of the ICM strategies during the different base conditions. The first package is targeted at deploying freeway focused ICM strategies and includes all of the first five strategies listed in the table. The second package retained those freeway-focused ICM strategies but also added the signal coordination strategy to the response plans to present more of a network-wide response plan.

Table 8. ICM Strategies by Base Condition

ICM Strategies	Base Condition[a]					
	AM / PM Typical Commute	Vehicle Crash Conditions	Holiday Demands	Snow Conditions	Game Day Conditions	Inclusion in Evaluation Packages
Dynamic Traveler Information	●	●	●	●	●	Included in both A and B
Freeway Incident Detection and Service Patrol	●	●				Included in both A and B
Ramp Metering	●	●				Included in both A and B
Variable Speed Limits and Queue Warning	●	●		●		Included in both A and B
Variable Toll Pricing	●		●			Included in both A and B
Signal Coordination	●	●	●		●	Included only in B
Parking ITS					X	
Dynamic Lane Controls		X		X		
Road Weather Information Systems and Plow Management System				X		

[a] ● (filled dot) indicates strategy evaluated in the ICM project simulation model and X indicates the ICM strategy is expected to have benefit but no analysis was performed using the model.

Further details regarding the simulation-based evaluations of the ICM strategies are presented in the next chapter.

5.0 Analysis, Modeling and Simulation

Previous ICM planning efforts completed for the region were built on to complete the Analysis, Modeling, and Simulation (AMS) of potential ICM deployments in the region. This chapter describes the AMS process including development of the model, measures used to evaluate ICM strategies and the results of the ICM analysis. A more detailed discussion of the AMS is provided in Appendix F.

5.1 Model Development

A robust analysis tool was developed to simulate the conditions where ICM response plans and strategies could be deployed. The BNICM project used an Aimsun hybrid microscopic – mesoscopic simulation model. The microscopic model simulates individual vehicle characteristics and interactions to assess operations of specific roadways or corridors while the mesoscopic model simulates individual vehicles and provides operational information at an aggregate or regional level. The hybrid model allows for simulation at both the regional and local levels to evaluate technologies along key freeway corridors and certain ITS strategies. The framework for the BNICM analysis tool was also selected to potentially be expanded into use as a near real-time predictive element of a future ICM decision support system (DSS) tool for real-world ICM deployments, as has been done in previous ICM deployments in the U.S. and in other countries.

The model was development through calibration to existing transportation conditions. The BNICM model covers the entirety of the I-190 corridor from I-90, through downtown Buffalo, across Grand Island, through the Niagara region, and terminating at the Lewiston-Queenston Bridge crossing between United States and Canada. The model includes all parallel freeway and arterials, and the larger bi-national corridor comprised of the three major bridge crossings between Canada and the United States in the Buffalo-Niagara region and all connecting roadways between those crossings on both sides of the border.

5.2 Evaluation Scenarios

As described in Chapter 4, potential benefits of ICM deployment were evaluated for five conditions:

- Typical weekday AM and PM peak periods (Typical Base Condition)
- Major crashes in the weekday AM and PM peak periods (Non-Typical Base Condition)
- Weekday AM peak period snow conditions (Non-Typical Base Condition)
- High Cross-Border Traffic Demand (Canada Day & Independence Day Holidays) in the weekday PM peak period (Non-Typical Base Condition)
- Sabres hockey game high traffic demand in Downtown Buffalo during the weekday PM peak period (Non-Typical Base Condition)

A typical base condition model was developed and calibrated to existing weekday AM and PM peak periods. A representative day from recent years was selected for the non-typical scenarios and models were developed by altering the base condition model (typical weekday AM and PM peak periods). The non-typical base conditions models were calibrated to represent the existing available speed and count data for the representative condition.

Table 8 presented in Chapter 4 indicates the two packages (Package A and Package B) of ICM strategy developed to streamline the simulation and evaluation of ICM strategies effects. Package A is targeted at deploying freeway focused ICM strategies and includes dynamic traveler information, freeway incident detection and service patrol, ramp metering, variable speed limits and queue warnings and variable toll pricing. Package B retained the freeway-focused ICM strategies but also added the signal coordination strategy to provide a network-wide response plan.

5.3 Performance Metrics

ICM Package A and B were evaluated for the scenarios described above using the ICM model. The impacts of the ICM strategies were determined by comparing the with and without conditions for performance metrics. The performance metrics used to evaluate the ICM operational impacts include travel time in total vehicle hours traveled (VHT), vehicle miles travelled, and metric tons of Carbon Dioxide (CO2) emissions from vehicle operations. This provided a broad overview of evaluate the impacts on all relevant regional roadways, including both freeways and arterials. Further analysis to calculate additional metrics would be relatively resource-intensive and disproportionate with the scale of this project, and unlikely to fundamentally alter the conclusions.

The benefits of some ICM strategy deployments could not be estimated using the model so impacts and benefits were estimated based on savings from improved safety conditions and resulting prevented crashes. Previous studies presenting the observed impacts of the similar ICM strategy deployments on reducing crash rates were leveraged along with existing crash statistics for the study corridors to estimate the number of prevented crashes that could be expected.

The performance metrics were converted to monetary values to determine the benefit cost of the ICM strategy. VHT was converted to cost using assumed drivers' value of time estimates. Safety benefits were converted into dollar values using crash cost estimation methods.

The inclusion of further metrics that were not analyzed in this study, such as emissions of local-scale air pollutants (e.g. SOx, NOx, particulates, etc.), would tend to increase the scale of the calculated benefits. Thus, the benefit calculations and hence the benefit-cost ratios should be interpreted as conservatively low.

5.4 Results

Appendix F contains the full set of AMS documentation and results. This section presents a summary of the results including:

- Sections 5.5.1, 5.5.2, and 5.5.3 showing VHT, VMT, and CO2 Emissions, respectively
- Section 5.5.4 showing project-level benefit-cost ratio calculations for Packages A and B

5.4.1 Vehicle Hours Traveled

As discussed in previous sections, the mobility performance metrics attributed to the simulated strategies were taken as the difference between the average results of the with ICM simulation models and the No Build (without ICM) simulation models. The benefits presented here represent the cumulative deployment of the entire package of ICM strategies (A and B). The results presented do include the interpreted relative performance of the ICM strategies as they contribute to the overall total benefits of the combined package of ICM strategy deployment. Table 9 presents the change in vehicle hours travelled as estimated by the simulation of ICM strategies versus simulations without ICM strategies under the different established base conditions for weekday peak period, as well as the percent reduction in VHT seen as a result of the ICM deployment for the entire Package A deployment. The negative values represent an increase in the VHT as a result of the ICM deployment, while positive values indicate benefits (decrease in VHT) from the ICM deployment. While the mobility benefits vary by base condition and do in some cases increase the VHT on the roadways, an overall general trend of the impacts of the different ICM strategies on mobility can still be seen while looking at the results by ICM strategy.

Table 9. Daily VHT Benefits from ICM Deployment Package A

Base Condition	Peak Period	Dynamic Traveler Information, Incident Detection & Freeway Service Patrol	Ramp Metering[a]	Variable Speed Limits and Queue Warning[a]	Variable Toll Pricing[a]	Total	Total Percent Reduction
Typical Commute	AM	1,457	-658	235	418	1,452	4.3%
Crash	AM	-240	106	-64	n/a	-197	-0.6%
Snow Condition	AM	800	172	53	n/a	1,024	2.3%
Typical Commute	PM	1,768	-97	-92	331	1,909	4.4%
Crash	PM	309	-215	-997	n/a	-903	-2.0%
Holiday Demand	PM	209	-171	143	n/a	-237	-0.6%
Game Day	PM	312	-464	381	n/a	-396	-0.9%

[a] Represents marginal impact beyond what is shown in the column to the left.

As shown in Table 9, the deployment of improved dynamic traveler information systems, a freeway incident detection system, and an expanded freeway patrol program in the region generally yields reductions in vehicle hours traveled in all cases except for the AM crash base condition. That general trend of a reduction of VHT is expected, as with better information about the dynamic nature of conditions, travelers will be empowered to use more efficient routes thus reducing overall travel time. The negative benefits found in the AM Crash condition can be attributed to increases in travel times in areas of the region where drivers divert in unsuccessful attempts to avoid congestion on the freeway from the crash condition, onto the arterial network that cannot handle the traffic demand.

Ramp metering impacts can be seen to generally provide disbenefits in terms of vehicle hours travelled, by slightly increasing the vehicle hours traveled (due to delaying drivers on-ramp before they are allowed to enter the freeway). While some of the base conditions do improve, most of the simulated base conditions see increases in total vehicle hours of travel. This too can be expected, as the introduction of meters on the ramps inherently add some additional delay and travel time to vehicles entering the freeway system. The freeway mainline conditions would be expected to operate with improved conditions with the metering of the ramps, however, some of those improvements to the freeway main line should be expected to see moved to the ramps and potentially the arterial system through the introduction of the meters. It is important to remember that aside from mobility impacts of the ramp meters, benefits should also be expected to provide safety benefits through lowered crash rates as well as improvements in reliability over the course of a year with fewer crashes occurring per year, which would offset the increases in travel times on a per peak basis.

The travel time impacts of the deployment of a variable speed limit and queue warning system see varied amounts of travel time benefits and disbenefits, as seen with the ramp meters. The goal of this deployment specifically aims to reduce the speeds and slow traffic as it approaches congested conditions to improve safety conditions and is not generally reported to improve mobility when deployed. It is noted that for the majority of the conditions where disbenefits in terms of travel times are seen from this strategy, the overall scale of the disbenefits is not large. Again, it is noted that these metrics are isolated to the mobility benefits and any of the safety benefits from the ICM deployment should offset any disbenefits seen in travel times.

The introduction of variable tolls can be seen to have positive impacts on simulated vehicle hours of travel in both the AM and PM typical commute conditions. These benefits are expected as the higher toll rates during the core peak hours would encourage travel in the less congested peak shoulder hours or potentially on alternative routes.

For all of the base conditions analyzed, it is noted that the traffic signal controls on the arterial network are unchanged during the ICM deployment of strategy Package A. As a result, no signal timing plans were adjusted as part of a response plan deployed during the ICM event in an attempt to allow the arterial network to process any additional traffic that may detour from the freeway. Doing so could improve operations on the arterial system during an ICM and includes a more holistic approach of using ICM strategies with regards to the entire roadway network management. Please see the next section presenting the results of the ICM deployment strategy Package B for revised results estimates considering the deployment of additional strategies on the arterial system to help manage the potential impacts of increased traffic flows on those arterial streets resulting from the ICM Package A deployment.

While it is recommend that the arterial systems be upgraded to allow for real-time signal timing plan adjustments to allow more flexibility in using the arterials to help manage an ICM event, the results of Package A are still presented to understand the impact of various ICM strategies that could be deployed without the integration of real-time signal control systems on the arterial network. Freeway control systems are generally controlled by fewer agencies and entities and deployment would be expected to involve less interagency coordination and could be deployed more quickly. While not tested or evaluated under this effort, certain ICM strategies that encourage the use of arterial systems may be more selectively activated or deactivated under certain base conditions until the ability to expand arterial operations to allow real time adjustments and coordination with local agencies operating signals can be incorporated into a real-time ICM deployment strategy.

Following the simulation of the Package B ICM deployment for the crash scenarios, performance metrics were extracted from the scenarios and compared those from the No Build (without ICM) scenario simulations to assess the overall Package B deployment impacts under each of the base conditions simulated. Table 10 presents the overall Impact of the Package B ICM deployment on the VHT on the daily basis. It is noted that only performance metrics for the crash conditions were simulated and adjusted. The response plans and signal coordination is expected to provide the most benefits under a crash condition, when significant additional demands can be expected on select arterial roadways. While there is the potential for further improvement under the non-crash conditions, the potential for these benefits has not yet been evaluated. However, all base conditions are still presented here to provide a complete picture of the benefits estimated for the Package B deployment.

Table 10. Daily VHT Benefits from ICM Deployment Package B

Base Condition	Peak Period	Dynamic Traveler Information, Incident Detection & Freeway Service Patrol	Ramp Metering[a]	Variable Speed Limits and Queue Warning[a]	Variable Toll Pricing[a]	Signal Coord. During ICM Events[a]	Total	Total Percent Reduction
Typical Commute	AM	1,457	-658	235	418	n/a	1,452	4.3%
Crash	AM	-240	106	-64	n/a	215	18	0.1%
Snow Condition	AM	800	172	53	n/a	n/a	1,024	2.3%
Typical Commute	PM	1,768	-97	-92	331	n/a	1,909	4.4%
Crash	PM	309	-215	-997	n/a	1589	686	1.6%
Holiday Demand	PM	209	-171	143	n/a	n/a	-237	-0.6%
Game Day	PM	312	-464	381	n/a	n/a	-396	-0.9%

[a] Represents marginal impact beyond what is shown in the column to the left.

As compared to the Package A results, mobility impacts seen under a Package B ICM deployment in the crash conditions improve significantly. In the AM Crash scenario, previously seen disbenefits are removed and the net overall impact on VHT of the Package B ICM deployment shows benefits, albeit minor. In the PM Crash scenario, the improvements over Package A performance are more significant and positive benefits are seen across the network.

The implemented signal coordination response plans during the crash events improve on the operational performance of Niagara Street; both increases in the demands able to be served and reductions in delays per vehicle were seen. Additional delays seen on the side street approaches to Niagara Street can be expected with the shift of some green time to the Niagara Street phases, but the net overall impact on mobility during the crash scenarios was still positive and was far improved over the Package A simulation results when signal coordination response plans were not included as part of the ICM response package.

5.4.2 Vehicle Miles Traveled

Table 11 and Table 12 contain the impacts on vehicle-miles of travel from ICM Packages A (freeway-only) and B (freeway plus arterial signal coordination), respectively. VMT refers to the aggregate miles driven by all drivers, in a given scenario. Positive numbers show in the results indicate reduced VMT, and negative numbers reflect increased VMT.

Table 11. Daily VMT Benefits from ICM Deployment Package A

Base Condition	Peak Period	Dynamic Traveler Information, Incident Detection & Freeway Service Patrol	Ramp Metering[a]	Variable Speed Limits and Queue Warning[a]	Variable Toll Pricing[a]	Total	Total Percent Reduction
Typical Commute	AM	-11,554	-90	6,300	35,360	30,016	1.3%
Crash	AM	-8,219	-2,570	1,792	n/a	-8,997	-0.4%
Snow Condition	AM	-128,383	-17,707	18,443	n/a	-127,647	-6.1%
Typical Commute	PM	-307	1,938	-422	29,064	30,273	1.1%
Crash	PM	-11,506	-19	-25,513	n/a	-37,038	-1.4%
Holiday Demand	PM	-12,747	1,347	-3,941	n/a	-15,341	-0.5%
Game Day	PM	-2,778	8,668	-2,211	n/a	3,679	0.1%

[a] Represents marginal impact beyond what is shown in the column to the left.

As shown in Table 11, the combined strategies of freeway ICM lead to decreased VMT during the AM and PM typical commute periods. This decrease is mainly from the addition of Variable Tolling strategies, which encourages some traffic to shift away from the core peak period or other corridors. The combined strategies yield the largest increase in VMT during the Snow condition, which is due to drivers taking alternate routes which are faster (but longer) to their destinations to avoid their normal routes that see increase congestion under the reduced capacity conditions of the Snow event. During the AM Crash condition, the dominant benefit is from Traveler Information, Incident Detection, and Freeway Service Patrol (though the impact on VMT is smaller than seen for other ICM strategies during other conditions).

Table 12. Daily VMT Benefits from ICM Deployment Package B

Base Condition	Peak Period	Dynamic Traveler Information, Incident Detection & Freeway Service Patrol	Ramp Metering[a]	Variable Speed Limits and Queue Warning[a]	Variable Toll Pricing[a]	Signal Coord. During ICM Events[a]	Total	Total Percent Reduction
Typical Commute	AM	-11,554	-90	6,300	35,360	n/a	30,016	1.3%
Crash	AM	-8,219	-2,570	1,792	n/a	-5,224	-14,221	-0.6%
Snow Condition	AM	-128,383	-17,707	18,443	n/a	n/a	-127,647	-6.1%
Typical Commute	PM	-307	1,938	-422	29,064	n/a	30,273	1.1%
Crash	PM	-11,506	-19	-25,513	n/a	70,226	33,188	1.2%
Holiday Demand	PM	-12,747	1,347	-3,941	n/a	n/a	-15,341	-0.5%
Game Day	PM	-2,778	8,668	-2,211	n/a	n/a	3,679	0.1%

[a] Represents marginal impact beyond what is shown in the column to the left.

As shown in Table 12, for Package B during the AM crash condition VMT are increased, but during the PM crash period VMT are increased much more (~ -5,000 vs. ~ +70,000 VMT). The former result is due to the increased traffic-moving capacity of the arterial system enabling more drivers to find suitable longer-distance alternative routings to their preferred routing in the typical condition when there are no crash incidents.

5.4.3 Emissions

Emissions are tracked in units of metric tons, and relate in complex ways to VHT, VMT, and operating speed profile (choice of cruising speed and rates of acceleration). In general, smooth flowing traffic at moderate speeds provides the lowest rate of emissions per mile traveled. A metric ton is 1,000 kg, and to establish scale, we note that the quoted average emissions rate for a mid-size sedan (Toyota Camry, 2018 Model Year) is 264 grams per mile driven based on data from the US on fuel economy. For this study, Carbon Dioxide (CO2) was the emissions species tracked. The production of CO2 is proportional to fuel consumed, thus is effectively also a proxy for the total level of fuel consumption by all drivers combined.

Table 13 and Table 14 show the emissions impacts of Packages A and B, respectively.

Table 13. Daily Emissions Benefits (metric tons CO2) from ICM Deployment Package A

Base Condition	Peak Period	Dynamic Traveler Information, Incident Detection & Freeway Service Patrol	Ramp Metering[a]	Variable Speed Limits and Queue Warning[a]	Variable Toll Pricing[a]	Total	Total Percent Reduction
Typical Commute	AM	-2.37	-1.52	3.06	11.36	10.53	1.0%
Crash	AM	-2.82	-1.61	1.67	n/a	-2.75	-0.3%
Snow Condition	AM	-46.10	-5.93	4.59	n/a	-47.44	-4.6%
Typical Commute	PM	-0.11	-0.37	1.82	9.30	10.64	0.8%
Crash	PM	-5.48	-0.45	-9.84	n/a	-15.77	-1.3%
Holiday Demand	PM	-5.51	-0.72	0.97	n/a	-5.27	-0.4%
Game Day	PM	-1.44	1.11	2.08	n/a	1.76	0.1%

[a] Represents marginal impact beyond what is shown in the column to the left.

Table 14. Daily Emissions Benefits (metric tons CO2) from ICM Deployment Package B

Base Condition	Peak Period	Dynamic Traveler Information, Incident Detection & Freeway Service Patrol	Ramp Metering[a]	Variable Speed Limits and Queue Warning[a]	Variable Toll Pricing[a]	Signal Coord. During ICM Events[a]	Total	Total Percent Reduction
Typical Commute	AM	-2.37	-1.52	3.06	11.36	n/a	10.53	1.0%
Crash	AM	-2.82	-1.61	1.67	0.00	-1.36	-4.12	-0.4%
Snow Condition	AM	-46.10	-5.93	4.59	0.00	n/a	-47.44	-4.6%
Typical Commute	PM	-0.11	-0.37	1.82	9.30	n/a	10.64	0.8%
Crash	PM	-5.48	-0.45	-9.84	n/a	28.71	12.94	1.1%
Holiday Demand	PM	-5.51	-0.72	0.97	n/a	n/a	-5.27	-0.4%
Game Day	PM	-1.44	1.11	2.08	n/a	n/a	1.76	0.1%

[a] Represents marginal impact beyond what is shown in the column to the left.

As with VMT, there is a decrease in CO2 emissions during the typical commute period and an increase during the Crash and Snow AM conditions. The single most impactful ICM strategy during the AM and PM Typical Commute periods at reducing CO2 emissions is Variable Tolling Pricing.

5.4.4 Benefit-Cost

This section first describes the approach for calculating benefit-to-cost ratios for Packages A and B, and then presents the results of the calculations.

The basic logic of a benefit-cost ratio is to monetize all benefits and costs into units of dollars, allowing them to be directly compared relative to each other. The benefit-cost ratio is the ratio of monetized benefits divided by monetized costs. An economically viable project will have a benefit-cost ratio value greater than 1.0, meaning that its benefits exceed costs. Above the 1.0 threshold for project viability, larger benefit-cost ratios are more desirable than smaller ratios.

It is important to note that the benefit-cost ratio metric does not indicate which parties are bearing which benefits and costs. In the case of the BNICM, in general the majority of the costs would be borne by the public-sector entities that manage and operate the road network, with the benefits accruing to individual travelers. It is also worth noting that a limitation of benefit-cost analysis is that it is not always possible to credibly monetize (i.e. convert into dollar values) all impacts. This is a larger issue when considering major infrastructure projects (e.g. new or wider roadway facilities), and less of an issue when the proposed infrastructure has a small physical footprint, such as the technology systems needed for ICM implementation. Finally, it should be noted that the calculation of benefits is only during the specific time periods studied. To the extent that additional benefits would occur outside of the time periods we analyzed, the benefit calculations would be expected to increase. The implication is that this analysis has produced conservatively low benefit calculations and hence benefit/cost ratio calculations, by not tallying benefits during other time periods. Under the Package A (freeway ICM deployment), an annual savings of over half a million VHT could be expected, or when converted into dollars (at a standard Value-of-Time of $14.92 per vehicle-hour) a savings of over $7.5 million. The annual impact is calculated by taking the condition-specific impacts and multiplying by the number of times the condition is expected during a year (e.g. 190 occurrences per year for the AM typical commute period, 25 times for the Sabres Game Day condition, etc.).

5.4.4.1. Package A

Table 15 presents the calculation of VHT benefits, Table 16 VMT benefits, and Table 17 Emissions benefits.

Table 15. Annual VHT Benefits from ICM Deployment Package A

Base Condition	Peak Period	Number of Days per Year	VHT Benefits per Occurrence (veh-hr)	Annual VHT Benefits (veh-hr)	Monetized Annual VHT Benefits ($)
Typical Commute	AM	190	1,452	275,827	$4,115,341
Crash	AM	45	-197	-8,881	- $132,509
Snow Condition	AM	15	1,024	15,359	$229,150
Annual Weekday AM Peaks		250	n/a	282,304	$4,221,982
Typical Commute	PM	154	1,909	293,926	$4,385,376
Crash	PM	63	-903	-56,864	- $844,852
Holiday Demand	PM	8	-237	-1,896	- $28,285
Game Day	PM	25	-396	-9,892	- $147,594
Annual Weekday PM Peaks		250	n/a	225,244	$3,360,646
Annual Recurring Mobility Benefits (Weekday Peak Periods)				**507,549**	**$ 7,572,628**

As shown in Table 15, the aggregated VHT benefit for Package A is an annual cost of approximately $7.5 million.

Table 16. Annual VMT Benefits from ICM Deployment Package A

Base Condition	Peak Period	Number of Days per Year	VMT Benefits per Occurrence (veh-mi)	Annual VMT Benefits (veh-mi)	Monetized Annual VMT Benefits ($)
Typical Commute	AM	190	30,016	5,702,975	$2,604,117
Crash	AM	45	-8,997	-404,865	-$184,871
Snow Condition	AM	15	-127,647	-1,914,705	-$874,301
Annual Weekday AM Peaks		250	n/a	3,383,405	$1,544,945
Typical Commute	PM	154	30,273	4,662,042	$2,011,927
Crash	PM	63	-37,038	-2,333,394	-$1,006,988
Holiday Demand	PM	8	-15,341	-122,728	-$52,964
Game Day	PM	25	3,679	91,975	$39,692
Annual Weekday PM Peaks		250	n/a	2,297,895	$991,668
Annual Recurring Mobility Benefits (Weekday Peak Periods)				**5,681,300**	**$2,536,613**

VMT reductions from Package A are calculated by summing fuel costs ($3.18 and $3.00 for a gallon of gasoline and diesel fuel, respectively) at representative fuel efficiency levels and non-fuel costs ($0.313 and $0.429 for cars and trucks, respectively). As shown in Table 16, for Package A, the aggregate benefits from reducing VMT are approximately $2.5 million.

Table 17. Annual Emissions Benefits (metric tons CO2) from ICM Deployment Package A

Base Condition	Peak Period	Number of Days per Year	Emissions Benefits per Occurrence (tons CO2)	Annual Emissions Benefits (tons CO2)	Monetized Annual Emissions Benefits ($)
Typical Commute	AM	190	10.53	2,000.7	$72,025
Crash	AM	45	-2.75	-123.8	-$4,455
Snow Condition	AM	15	-47.44	-711.6	-$25,618
Annual Weekday AM Peaks		250	n/a	1,165.4	$41,953
Typical Commute	PM	154	10.64	1,638.6	$58,988
Crash	PM	63	-15.77	-993.5	-$35,766
Holiday Demand	PM	8	-5.27	-42.2	-$1,518
Game Day	PM	25	1.76	44.0	$1,584
Annual Weekday PM Peaks		250	n/a	646.9	$23,288
Annual Recurring Emissions Benefits (Weekday Peak Periods)				**1,812.2**	**$65,241**

The emissions impacts are monetized at the standard rate of $36/CO2-metric-ton. As shown in Table 17, in dollar terms, this category of benefit is much smaller than VHT and VMT, at approximately $65,000.

Along with the benefit and cost values described above, the deployment of Package A could be expected to prevent approximately 5 medium to major peak period crashes per year and 22 minor peak period crashes per year. The estimated mobility benefits of the additional VHT savings from those prevented crashes added another three quarters of a million dollars in benefits, and the societal savings of those prevented crash costs was estimated at over $2.7 million per year. Table 18 presents the overall calculation of the benefit-cost ratio for Package A.

Table 18. Benefit Cost Ratio for ICM Deployment Package A

Item	Annual Value ($)
Recurring VHT Benefits (Weekday Peak Periods)	$ 7,572,628
Recurring VMT Benefits (Weekday Peak Periods)	$2,536,613
Recurring Emissions Benefits (Weekday Peak Periods)	$65,241
Mobility Benefits from Prevented Crashes	$ 765,021
Prevented Crash Costs	$ 2,757,205
Total Benefits	**$13,696,708**
Additional DMS	$ 144,978
Ramp Metering	$ 356,791
Variable Speed Limits / Queue Warnings	$ 4,137,343
Freeway Incident Detection & Patrol	$ 296,998
Total Costs	**$ 4,936,110**
Benefit/Cost Ratio for ICM Deployment Package A	**2.77**

As shown in the table, collectively Package A ICM deployment was estimated to produce benefits of approximately $13.7 million per year. Compared to the estimated annualized costs of the Package A deployment of $4.9 million per year, the benefit to cost ratio is estimated to be 2.77.

5.4.4.2. Package B

Package B includes the addition of the arterial signal optimization strategy, which increases both costs and benefits. Table 19 presents updated annualized VHT benefits for each of the analyzed base conditions under a Package B ICM deployment. Table 20 and Table 21 present the VMT and emissions savings, respectively.

Table 19. Annual VHT Benefits from ICM Deployment Package B

Base Condition	Peak Period	Number of Days per Year	Monetized VHT Benefits per Occurrence (veh-hr)	Annual VHT Benefits (veh-hr)	Monetized Annual VHT Benefits ($)
Typical Commute	AM	190	1,452	275,827	$ 4,115,341
Crash	AM	45	18	793	$ 11,838
Snow Condition	AM	15	1,024	15,359	$ 229,150
Annual Weekday AM Peaks		250	n/a	291,979	$ 4,356,328
Typical Commute	PM	154	1,909	293,926	$ 4,385,376
Crash	PM	63	686	43,210	$ 644,690
Holiday Demand	PM	8	-237	-1,896	- $ 28,285
Game Day	PM	25	-396	-9,892	- $ 147,594
Annual Weekday PM Peaks		250	n/a	325,348	$ 4,854,188
Annual Recurring Mobility Benefits (Weekday Peak Periods)				**617,327**	**$ 9,210,516**

As a result of the addition of the signal coordination response plans under Crash AM and PM base conditions, the total annual VHT benefits increase by more than 20% from the Package A benefits, with a total of over 617,000 vehicle hours traveled, or an equivalent $9.2 million in mobility benefits.

Table 20. Annual VMT Benefits from ICM Deployment Package B

Base Condition	Peak Period	Number of Days per Year	VMT Benefits per Occurrence (veh-mi)	Annual VMT Benefits (veh-mi)	Monetized Annual VMT Benefits ($)
Typical Commute	AM	190	30,016	5,702,975	$2,604,117
Crash	AM	45	-14,221	-639945	-$292,214
Snow Condition	AM	15	-127,647	-1914705	-$874,301
Annual Weekday AM Peaks		250	n/a	3,148,325	$1,437,602
Typical Commute	PM	154	30,273	4,662,042	$2,011,927
Crash	PM	63	33,188	2,090,844	$902,314
Holiday Demand	PM	8	-15,341	-122,728	-$52,964
Game Day	PM	25	3,679	91,975	$39,692
Annual Weekday PM Peaks		250	n/a	6,722,133	$2,900,970
Annual Recurring Mobility Benefits (Weekday Peak Periods)				9,870,458	$4,338,572

As shown in the table above, VMT benefits are calculated to be approximately $4.3 million.

Table 21. Annual Emissions Benefits (metric tons CO2) from ICM Deployment Package B

Base Condition	Peak Period	Number of Days per Year	Emissions Benefits per Occurrence (tons CO2)	Annual Emissions Benefits (tons CO2)	Monetized Annual Emissions Benefits ($)
Typical Commute	AM	190	10.53	2,000.7	$72,025
Crash	AM	45	-4.12	-185.4	-$6,674
Snow Condition	AM	15	-47.44	-711.6	-$25,618
Annual Weekday AM Peaks		250	n/a	1,103.7	$39,733
Typical Commute	PM	154	10.64	1,638.6	$58,988
Crash	PM	63	12.94	815.2	$29,348
Holiday Demand	PM	8	-5.27	-42.2	-$1,518
Game Day	PM	25	1.76	44.0	$1,584
Annual Weekday PM Peaks		250	n/a	2,455.6	$88,402
Annual Recurring Emissions Benefits (Weekday Peak Periods)				3,559.3	$128,136

As shown in Table 21, emissions savings are calculated to be approximately $128,000.

Table 22 shows the overall benefit cost for Package B. As the Package B deployment was not predicted to further improve safety benefits over the Package A ICM deployment, the Package B safety benefits remained unchanged from Package A.

Table 22. Benefit Cost Ratio for ICM Deployment Package B

Item	Annual Value ($)
Recurring VHT Benefits (Weekday Peak Periods)	$ 9,210,516
Recurring VMT Benefits (Weekday Peak Periods)	$4,338,572
Recurring Emissions Benefits (Weekday Peak Periods)	$128,136
Mobility Benefits from Prevented Crashes	$ 765,021
Prevented Crash Costs	$ 2,757,205
Total Benefits	$17,199,449
Additional DMS	$ 144,978
Ramp Metering	$ 356,791
Variable Speed Limits / Queue Warnings	$ 4,137,343
Freeway Incident Detection & Patrol	$ 296,998
Signal Controller Upgrades	$ 173,306
Total Costs	$ 5,109,416
Benefit/Cost Ratio for ICM Deployment Package B	**3.37**

As shown in Table 22, the total benefits of the Package B ICM deployment is estimated to be $17.2 million per year.

While Package B's addition of the signal coordination response plans during an ICM crash event improved the mobility benefits of the deployment, it was assumed that no additional safety benefits would be produced. As such the change in the total benefits seen under a package be deployment are only from the improved benefits of VHT, VMT and Emissions, with a net annual benefit (benefit minus cost) of approximately $12.1 million to be expected under a Package B ICM deployment. Annual costs also increase, as the inclusion of signal coordination elements as part of the ICM system require an upgrade of signal controllers and the addition of additional sensing equipment at the intersections to monitor the arterial performance in real time. In considering the costs to upgrade the Niagara Street corridor, the total costs for a Package B deployment increase to approximately $5.1 million. Overall, the Package B deployment has a benefit to cost ratio of 3.37, which is an improvement on the 2.77 ratio for Package A.

5.5 Lessons Learned

Based on the AMS performed for the BNICM on packages A and B, the key findings include:

- VHT showed the greatest benefit relative to deployment of the ICM strategies
- Typical weekday AM and PM peak period conditions improved or benefited the most of the ICM deployment whereas other conditions had improvement but to a lesser degree
- Traveler information and freeway incident clearance were the two strategies that provided the most improvements in the system related to the ICM strategies deployed
- Emissions positively benefited from deployment of ICM but only by a small amount when monetized
- Arterial signal managed resulted in a large increase in the benefit-cost ratio

6.0 Implementation Plan

This study's analysis of the proposed ICM strategies indicates that the benefits of deploying them in the Buffalo-Niagara corridor are well in excess of the costs, with benefit-to-cost ratios in the range of ~3.0. It can therefore be concluded that efforts to design and deploy the systems on the region's roadways are economically justifiable.

However, ICM benefits are typically measured in inches and not yards; further testing of refined ICM deployments and response plans may be able to further extract benefits from the deployment of ICM strategies. Additionally, the examination of staged deployments of the ICM systems and equipment may also be prudent to distribute initial deployment costs while still seeing benefits from the initial staged deployments.

An additional needed step towards deployment would be more detailed design and a more robust analysis of the costs to deploy and operate field equipment needed to implement ICM response plans. While annual costs for deployment and operation were estimated as part of this study using the best information at hand, more detailed design and implementation plans should include detailed costs to ensure the estimates are reasonable and do not greatly affect the resulting benefit to cost ratios of the ICM deployment.

6.1 Deployment and Implementation Next Steps

As the next steps in moving towards the deployment of ICM in the region, it is recommended to revisit the details of the ICM deployment plans that were evaluated in this study and expand the analysis as part of the design efforts. The expanded analysis would address additional scenarios where ICM response plans might be executed. Examples of new scenarios for response plan evaluation are additional event conditions or crash conditions with varying severities and in different locations on the region's roadways.

The further refinement of ICM strategy deployments under certain studied base conditions should also be considered. For example, while safety benefits would be seen from the deployment of the ICM strategies, under certain base conditions mobility disbenefits were also created from the deployments. Additional refinement of the ICM response plans to the ICM strategies in those conditions could result in even further improved benefits. Additionally, should further refinement of strategies not be discovered, during those selected conditions it may be best to not deploy select ICM strategies to prevent creating disbenefits.

Additionally, there could still exist the potential for additional benefits from the operation of an ICM system outside of the weekday peak periods, especially under crash conditions where slower operating speeds and unanticipated congestion are experienced on the roadways. The installation costs for deploying equipment in the field to operate during the weekday peak periods would already be incurred and minimal additional costs would be needed to operate ICM strategies during the off-peak periods. Therefore, the addition of potential benefits from off-peak period ICM operations would increase the benefit cost ratio beyond the current levels, but the degree to which it would increase is not currently known. Additional analysis of the potential off-peak benefits could be examined as part of more detailed planning and design efforts leading to the deployment of the ICM systems. It is noted that to analyze the potential benefits of off-peak ICM operations, the development of off-peak BNICM models would be required.

While the analyzed ICM deployment yields positive benefits, it is recognized that the costs of deploying the systems as a whole may be prohibitively expensive, and a more staged deployment of the ICM strategies and field equipment could be considered to the specific costs as well as the projected benefits of different subsystems. An example of such a staged deployment could be the deployment of the variable speed limit and queue warning system. As tested, the variable speed limit and queue warning system included the entire I-190 corridor in order to provide benefits not only in the I-190 corridor larger cross border corridor as well. However, given accident records, safety benefits are not expected to be uniform across each mile of roadway as the majority of crashes on the I-190 corridor currently are seen to occur between I-290 and I-90. A staged deployment of the variable speed limit and queue warning system between I-290 and I-90 may be considered to lower the initial overall deployment costs of building out roadway gantries and dynamic signage for the entire I-190 corridor and to target the areas where safety benefits are more likely to be seen. A second stage of deployment to extent the system to other portions of I-190 or even onto other freeways in the regions could follow. It is recommended that additional simulation analysis of any proposed staged deployments be conducted first to reinforce the impacts on the potential benefits and costs from a staged deployment prior to detailed design and field implementation.

Any future ICM deployment considerations should ensure a constant monitoring and evaluation process is included. While good real-time speed data is already available, similar real-time volume data should also be considered in selecting in real time ICM deployment plans is lacking. While some of the proposed

ICM deployments include the ability for such monitoring (e.g. signal system upgrades), the deployment of additional volume monitoring systems should be considered for deployment prior to the full deployment of the ICM field response equipment and systems, especially on the freeway facilities. The initial deployment of the additional sensing equipment prior to the full ICM deployment could also help with further refinement of the ICM response strategy for further evaluation prior to ICM deployment.

Finally, a performance evaluation program that evaluates the effectiveness of ICM response plans as they are implemented in the field is needed. This will require additional efforts to better tune the BNICM simulation model to better predict real-world responses to the implemented ICM strategies. This is useful to better design ICM responses to given events, to better prepare for additional future ICM events. This is true regardless of whether a future ICM effort includes the BNICM model in a real-time support role or only in an offline planning role.

6.2 I-190 Corridor Implementation Plan

To further the deployment of an ICM system on the I-190 corridor, the previously discussed recommended prioritizations and refined response plan strategies should first be conducted. Benefits were seen for all analyzed ICM strategies. The further development of analyzed strategies with prioritization and follow up refinement efforts should be considered. The following key steps specific to the I-190 corridor should be undertaken to move towards system design and deployment:

- Refine ICM deployment costs with initial designs
- Refine ramp meter algorithms based on efforts recently undertaken to deploy ramp metering in other areas in New York and use details of those deployments to potentially reduce design costs
- Evaluate projected benefits for partial or staged I-190 deployments such as reducing costs associated with deploying overhead gantries and dynamic signage through partial deployment targeting only the areas with routine congestion and/or increased crash histories
- Test signal coordination and ICM response plans for arterial corridors other than the Niagara Street for use in the ICM response plans for crashes or other incidents along other portions of I-190 such as Delaware Avenue, South Park Avenue, Seneca Street, Clinton Street, Military Road, and Grand Island Boulevard

6.3 Border Crossing Implementation Plan

ICM at the border crossing can also be advanced through the deployment and implementation next steps and the I-190 corridor implementation plan described above. Improvements to cross border operations have already been undertaken since the ICM project started. The improvements mostly are related to increased traveler information sharing with expansion of the border crossing delay monitoring system and refined and more detailed reporting of the border crossing delays via NITTEC's internet systems (website and mobile phone applications) and via DMS across the transportation system.

Further investigations into the potential for trans-border truck operations should be conducted. While private autos can use the crossing of their choice, trucks are often limited in their choice at the time of an event given the paperwork and credentials needed to cross the border with commercial goods. While the control of such changes are well beyond the extents of what NITTEC or even MTO can implement by themselves, the allowance of truckers to select which crossing is best to use in response to a real-time event will help ensure that truckers and autos can be served by an ICM deployment.

Specific to the border crossing operations, continued efforts to coordinate with the MTO on an international ICM response plan approach should be undertaken. This will prevent each agency from implementing conflicting strategies at the same time. As much as possible, this coordination should also include the U.S. Customs and Border Protection (CBP) and the Canada Border Services Agency (CBSA) so that the operations of the border crossing stations are included in the determination of an appropriate response plan. While all of these agencies are already involved with NITTEC and routinely share information, most ICM efforts completed to date show that there is increased benefit in more detailed formal stakeholder agreements and cooperation, including the automation of data sharing and potentially even ICM response plan selection and approval during an ICM event. For the border crossing ICM deployment, even further collaboration between both nations' responsible agencies is needed to consider unified response plans to ICM events on either side of the border should be developed and formalized for a coordinated ICM system and streamlined responses to events along I-190, the Queen Elizabeth Way, and at each of the border crossing stations.

6.4 Performance Monitoring & Reporting Plan

Deployment should include a data driven process to continually monitor the performance of the ICM system and its response plans that are implemented in the field. The results of that performance monitoring should carry forward into a continuous improvement framework to ensure that the ICM response plans implemented in the field are as beneficial to the transportation system.

A series of performance measures were developed to track individual objectives and goals for an ICM system. Additional detail on the goals, objectives and associated performance measures is provided in Appendix F. These metrics are suited to tracking the goals and are generally measurable with minimal additional data collection efforts beyond the data collection and tracking already in place today. It is recommended that these field metrics be computed and tracked during the monitoring to assess the deployment, agency and stakeholder integration, and performance components of a future deployed ICM system. In addition, a monitoring should occur through a simulation-based approach to evaluate response plan impacts for the elements that cannot truly be measured in the field.

The operations-based performance metrics are designed to track the overall effects and impacts of an ICM system deployment. This cumulative impact of the ICM system is really the sum of the impacts of each action taken and each response implemented in response to each ICM triggering event. As can be seen in the analysis presented in Chapter 6, there is the potential for response plans to be implemented that have opposite impact of the intended effect on these system operations. This creates the need for a new category of performance measure to evaluate the impacts of the individual response plans, not just the system as a whole.

Second, the key to measuring the operational impacts of an ICM response plan to specific event is to assess the impacts on improving mobility (reducing travel times and improving travel time reliability), safety (reducing the severity of or outright preventing a crash), and environmental impacts (reducing emissions and fuel consumption). Unfortunately, some of these metrics can be exceedingly difficult or impossible to truly measure these changes in the field for specific ICM events. Even when surrogate measures can be used (e.g. corridor travel time or speed as an indicator of all vehicle hours traveled), they still cannot truly evaluate the difference between the performance measures when an action is taken and when an action is not taken by the ICM system. Since each event and the conditions surrounding an event are essentially unique and only one action can be taken in the field (enact a response plan or do nothing) at a time, a true comparison of a set of performance measurements for a different response for that event cannot truly be obtained.

To resolve these issues, two solutions can be deployed.

1. Tracked both over time, but in more detail and in consideration of the operating conditions present and when the ICM system implements a response plan.
2. Simulation based approach to evaluate response plan impacts for the elements that cannot truly be measured in the field.

The following describes in more detail the field and simulation monitoring.

6.4.1 Detailed Field Monitoring

The established performance metrics for monitoring include elements that can be directly measured in the field and many are already measured and reported in NITTEC's Annual Reports. These measures include:

- The number of crashes occurring by corridor strategy,
- The response time to incidents,
- Corridor specific travel times,
- Border crossing times and delays, and
- The number of different types of events that the TMC or partner agencies respond to.

These reported metrics are already excellent measures of the system performance and provide a valuable set of metrics to compare the system performance over time. It is highly recommended that this reporting continue to allow a comparison of these individual metrics through time to compare pre-ICM deployment metrics to those post-ICM deployment through a before and after comparison to estimate the impacts of the ICM deployment.

There are a number of confounding factors (economic activity, land use developments, roadway improvement projects, etc.), which can influence these metrics over time apart from the deployment of an ICM system. These combined with the relative rarity of crashes to the number of millions of vehicle miles traveled on the regions roadways can make a comparison over time difficult. That said, this set of performance metrics still provides an extremely valuable data set to track the performance of ICM deployment on improving the mobility, reliability, safety and environmental performance of the region.

It is also recommended that this performance tracking and reporting not only continue, but be expanded with additional details such as more robust recording of the location of the crash or congestion event, reporting of roadway volumes and throughput on the roadways (noted this will require additional sensing equipment), and details of the special event demand generators that are experienced and noted in the TMC. Additionally, once the ICM system is deployed, additional details of the nature of the ICM response plan(s) implemented in for each event should be recorded.

By having detailed records of corridor travel times and speeds, crash records, border crossing times, regional high demand events (e.g. sports events), weather data, and TMC events, a combined cluster analysis of these datasets can be undertaken to determine the interrelated aspects of these metrics (e.g. crash or weather impacts on travel times). This can help identify specific combinations of events and types which happen most frequently and which have the most impact on the performance of the transportation network, and thus potentially can see the most annual benefits from deployment on an ICM system.

This is a similar process to what was undertaken during this study to identify the specific base conditions, which were analyzed and potential benefits developed; however, having this database tied to the specific ICM responses plans implemented during each event can allow for a more robust analysis of the overall performance of the ICM deployment in the future under the wide variety of conditions that the region sees day-to-day throughout a year. By comparing the performance measures of when ICM response plans are implemented to when they are not or to pre-ICM conditions, it can also help identify which specific combination of events or response plans may be underperforming and may need to be revised in attempts to improve on the benefits from the ICM deployment under those conditions.

6.4.2 Simulation Monitoring

During day-to-day operations, only one specific ICM response plan (or set of plans) can be implemented by the TMC and its partner agencies in response to the specific congestion, crash, weather, or other type of event at hand. While data can be collected from field sensors during that event, it is impossible to truly know how operational conditions may have been different if a different response plan was initiated, or if no response plan was initiated at all during that specific event. As mentioned above, comparing performance metrics for similar events with different responses are one way to extract the relative performance, but the day-to-day variations of traffic demand, weather, and the infrequent nature of many crashes seen on the roadways means that two events are truly never identical. Such comparisons of field measured performance must then be taken with consideration of these differences in mind.

While not as accurate as true field-based performance measurements, the BNICM simulation models can provide a virtual testbed for various response plans under the same identical demand, weather, and crash conditions. Much as was done with this study to evaluate the ICM benefits, a robust comparison of simulated performance measures from two simulations with and without the ICM deployment in place can be used to estimate the impacts of the ICM response plan enacted. The simulation model can be used in this manner regardless of whether real-time predictive simulation is employed or if simulation models are used in a more purely planning capacity to develop response plans.

As exemplified by the ICM deployment in San Diego, the use of simulation models as a predictive engine in real-time can be used to evaluate different response plans in a simulated environment. The relative performance of these simulations run much faster than real-time can be used to help select a response plan to be pushed to the field at the time of an actual event. As part of the decision support system, real-time simulations provide estimation of the benefits of the selected response plan strategy; it is the nature of the design to provide such relative feedback of a ‘do nothing’ simulation compared to different response plan simulation. These differences are direct estimates of the impact of the ICM deployment. While the ultimate design for a decision support system (DSS) within a Buffalo-Niagara ICM is currently still to be determined, if a real time predictive simulation engine is included it is recommended the results are logged and reported on an ongoing basis to assess the benefits of the ICM deployment.

In addition, it is recommended that the accuracy of those real-time simulated predictions of response plans actually implemented in the field be measured against actual field sensor data and reported for evaluated ICM events. By comparing the accuracy of the predictive simulation versus the actual field data following the same response plan implementation, the accuracy of the predictions of the simulation model can be assessed. With this data tracked and reported, the simulation models’ accuracy can be examined and improved over time. This should lead to improved predictions of the response plan simulations used in real time within the ICM DSS, and a more beneficial ICM system.

Even if simulation models are not used in a real-time predictive manner, off-line or planning level simulation models can still be drawn upon to simulate observed ICM events and the response plans implemented in the field. The resulting comparison of the simulation results and the field observed conditions following the implementation of the response plan can be assessed along with the accuracy of the simulation. While not as streamlined as with a real-time predictive simulation engine, the same learning process can be applied to an offline simulation model to improve the accuracy of the models in simulating the events and responses that occurred, leading to a more accurate simulation model for assessment of future conditions. While the improved accuracy is not seen in the selection of the response plans as in a real-time simulation engine, the more accurate simulation models can still be used to evaluate ‘do-nothing’ or pre-ICM deployment conditions to estimate the impacts of the deployed ICM system.

Overall performance metrics of the accuracy of the prediction of a simulation engine should be developed and reported after the deployment of the ICM system, with the goal of increasing the accuracy of those predictions as the ICM system and the simulation models mature. While this may have more bearing if the simulation model is used in a real-time manner within the ICM DSS, improved simulation accuracy can still provide great benefits in testing and evaluating new and changing response plans over time, to improve the overall performance of the ICM system on improving operational conditions across the network.

Finally, the use of a simulation model can also provide insights and estimates for performance metrics that cannot realistically be measured in the field. Such estimates include total hours of travel or delay, tailpipe emissions, gallons of fuel consumed, and trip level variabilities of travel times. These performance measures are recommended to be produced in addition to the field-based performance metrics of the ICM system.

6.4.3 Performance Reporting Summary

To aid in the tracking of the performance of an ICM system deployment over time, it is recommended that the ICM performance metrics are reported as well as additional performance measures to be extracted from the simulation models in a manner similar the results presented in Chapter 6. To the extent possible, the metrics should be stratified by different operational conditions such as the base conditions used in this report, or through a more robust cluster analysis of operational conditions from a more robust collection of field conditions in the future. The ICM performance reporting should be shared with all ICM stakeholders on a regular basis, either quarterly or annually.

6.5 Future ICM Projects Considerations

The steps taken for this ICM project can assist other teams and jurisdictions in designing and deploying ICM systems. Future considerations for other ICM projects can be categorized under three main categories: study design and data needs, ICM strategies and implementation, and AMS.

6.5.1 Study Design & Data Needs

- **Narrowing the Scope of Analysis Conditions.** Several base conditions where ICM events could occur were analyzed in this study. There are many more events (e.g. different crash locations and severities, special events with abnormal demands) and conditions (e.g. mid-day or weekend conditions, additional weather conditions) that benefit from an ICM deployment; however, it is not feasible to address all conditions. To assess the full range of the benefits of an ICM deployment, the study conditions that occur most frequent to assess the scope and design of ICM deployment.
- **Historical Travel Demands.** Robust historic travel demands and operational conditions are important to an ICM study. While good historic weather and speed data are available, more widespread historic volume data for the same days would have aided in completing this study. While big-data sources are moving in the direction of being able to provide insights on travel demands for historic conditions, the sample rates are still relatively small and estimating full volume or demand

conditions is not reliable from these data sets. Additional permanent and reliable volume sensors deployed on the network can provide these data sets. While some regions have such volume sensors on freeways, both coverage and accuracy of those sensors should be considered. This coverage and accuracy is especially the case for arterials and lower volume roadways, which are generally less equipped with sensors and can be more difficult to assess given lower flow rates.

- **Historic Event Records.** Details of the historic event records are an important consideration. Simulating past crashes or other ICM events requires knowing the time and location of lane blockages and the presence of emergency responders. Details on events can help better replicate the conditions in the models. Some details can be inferred from the historic speed or weather data but making assumptions could also impact the potential benefits from ICM response plans. While the NITTEC TMC generally keeps good records for events occurring in their region, other agencies need to consider the quality of their TMC records before considering similar analyses.
- **Driver Reaction Data.** Estimating driver reactions to events is also an important consideration in determining the impact of ICM deployment. Assumptions can be made regarding the level and nature of driver reactions to an event without additional agency implemented ICM response plans. Driver surveys or mining of big-data sources could help in making assumptions on driver reactions to events.

6.5.2 ICM Strategies

- **Arterials Real-time Data and Communication.** For response plans aiming to encourage traffic to use arterials to bypass crashes and other incidents creating high delays on the freeway systems (or other key arterials), the deployed ICM system should have a real-time knowledge of the operational conditions on diversion arterials. This study showed that encouraging traffic to shift to arterials without adjustments of signal timing plans and coordination may not decrease the overall system delay, but rather shift delays from the freeway to the arterial system. For response plans to operate, the arterials should be better equipped to a) allow for both real-time and historic measurements of both demand loading and operational performance and b) have sufficient communications capabilities with the TMC (or similar for the operating agency) to allow for on-demand adjustments of timing control plans to implement response plan timing schemes. Many modern signal controllers have these capabilities through the addition of Automated Traffic Signal Performance Measures (ATSPM) and advanced communication systems but would likely require upgrades to signal controllers from older models in the field for diversion response plans to be effective. Costs for these signal controller upgrades should be considered as part of the deployment costs on all arterial corridors used for diversion traffic.
- **Weather Impacts on Travel Demand.** Winter weather conditions are common in the Buffalo-Niagara region. Research on the impacts of weather events on roadway capacity and throughput were leveraged to assess the impacts of winter weather conditions in this study; however, the impacts of weather conditions on demand are not well established. Further research on weather impacts on travel demand would help both the BNICM deployment and other ICM deployments in climates that have severe or winter weather conditions.
- **Physical Extent of ITS System.** The findings of the study indicate that the physical extent of the ITS systems needed to deploy ICM strategies and response plans should be considered as a parameter of the deployment design. By testing different extents of deployments for strategies, it allows for the comparison of the benefits from that deployment coverage versus the costs to install, operate, and

maintain the needed equipment. While overall benefits may be present for a corridor-wide approach, higher benefit-cost ratios could be seen from a targeted deployment for more costly systems. If a targeted approach is selected, the design should allow for future stages to expand the ICM deployments geographically as the need arises and as funding opportunities allow.

6.5.3 Analysis, Modeling, and Simulation

- **AMS Level of Effort Impacted by Model Type and Number of Base Conditions.** The model developed to analyze the potential BNICM deployment was an advanced simulation model capable of simulating the different ICM strategies under a wide variety of conditions. It was also designed for use in future real-time predictive means across the greater region as part of the decision support system of ICM deployment for the region. While this provides a high level of simulation analysis capabilities for different deployments, the time and costs associated with the development of a model with these capabilities should not be underestimated, and appropriate time and resources should be allocated accordingly. High cost and level of effort is especially true with more base conditions than the typical AM and PM peak periods such as the weather, demand, and crash conditions developed as part of the BNICM study.
- **Consider the Area Covered in the Model.** Having a large regional model allows for flexibility in the ranges of analysis that can be undertaken, but it also adds complexity and time required to run a large regional model. The larger the model, the stochastic noise present in any simulation model will increase, making it harder to isolate the impacts of the ICM response strategies from that model noise. While not completed for this study, running ICM strategy assessments simulations on smaller subarea models of the full regional BNICM model would reduce both the simulation run times and noise concerns as well as limit the ability of the model to predict impacts of the strategies outside of the subarea. If a subarea model analysis approach is undertaken, consider the correct balance of subarea size and predictive capabilities across the network.

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Appendix A. Project Management Plan

Buffalo-Niagara Integrated Corridor Management

Project Management Plan

final

report

prepared for

Niagara International Transportation Technology Coalition &
Greater Buffalo-Niagara Regional Transportation Council

prepared by

Cambridge Systematics, Inc.

June 5, 2017

report

Buffalo-Niagara Integrated Corridor Management

Project Management Plan

prepared for

Niagara International Transportation Technology Coalition &
Greater Buffalo-Niagara Regional Transportation Council

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date

June 5, 2017

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Acronyms and Definitions

Term	Definition	Term	Definition
AMS	Analysis, Modeling, and Simulation	NYSDOT	New York Department of Transportation
BOD	Board of Directors	NFBC	Niagara Falls Bridge Commission
CBSA	Canada Border Services Agency	NYSP	New York State Police
CCTV	Closed-Circuit Television	OPP	Ontario Provincial Police
ConOps	Concept of Operations	PBA	Buffalo and Fort Erie Public Bridge Authority
FHWA	Federal Highway Administration	PM	Project Manager
GBNRTC	Greater Buffalo-Niagara Regional Transportation Council	PMP	Project Management Plan
HAR	Highway Advisory Radio	PMBOK	Project Management Body of Knowledge
ICM	Integrated Corridor Management	RFP	Request for Proposal
INCOSE	International Council on Systems Engineering	SEMP	System Engineering Management Plan
IPDT	Integrated Product Development Team	SEP	Systems Engineering Processes
ITS	Intelligent Transportation Systems	USCBP	United States Customs and Border Protection
NFTA	Niagara Frontier Transportation Authority	USDOT	United States Department of Transportation
NITTEC	Niagara International Transportation Technology Coalition	VMS	Variable Message Sign
NYSERDA	New York State Energy Research and Development Authority		

Version History

Version	Developed by	Submittal Date	Revision Date	Approved by (Date)	Comments and Nature of Changes
1.0	Cambridge Systematics	06/30/2016			Initial Draft
1.1	Cambridge Systematics	7/27/2016			Revised based on received comments
1.2	Cambridge Systematics	06/05/2017			Revised version addressing all comments received, release as final report

Executive Summary

Partnering agencies and authorities in the Buffalo-Niagara metropolitan area have received a United States Department of Transportation (USDOT) grant support for deployment planning for the I-190 Integrated Corridor Management Corridor. Through the activities supported by this grant, the project will establish the Corridor's vision, goals, and objectives; identify operating agency, authority, and stakeholder issues and needs; identify concepts – technical, operational, and institutional – that can be deployed in the Corridor using an intensive stakeholder engagement effort; develop Analysis, Modeling, and Simulation decision support tools; and the develop an implementation plan for ICM for the I-190 Corridor.

This Project Management Plan (PMP) is the master planning document for the ICM project in the Buffalo-Niagara region. This document describes the activities in detail throughout the period of project development. The PMP defines the project management principles and procedures for the ConOps development. Guidelines from Project Management Body of Knowledge (PMBOK) were used to prepare the PMP. The PMP describes the overall program structure; project partners and participants; deliverables; related management plans and procedures; and the methods used to plan, monitor, control, and improve the project development efforts.

1.0 Introduction

The following report is the Project Management Plan (PMP) to support the Niagara Frontier Transportation Authority (NFTA), the Greater Buffalo-Niagara Regional Transportation Council (GBNRTC), and the Niagara International Transportation Technology Coalition (NITTEC) in advancing the Integrated Corridor Management (ICM) concepts towards development of the I-190 corridor in the Buffalo-Niagara region.

The Buffalo-Niagara metropolitan area has received a United States Department of Transportation (USDOT) grant support for the current I-190 ICM effort. Through the activities supported by this grant, the project will establish the I-190 ICM vision, goals, and objectives; identify operating agency, authority, and stakeholder issues and needs; identify concepts – technical, operational, and institutional – that can be deployed in the Corridor using an intensive stakeholder engagement effort; develop Analysis, Modeling, and Simulation decision support tools; and develop an implementation plan for ICM for the I-190 Corridor. This report is a product of the efforts made for the development of the I-190 ICM project concept, to provide a clear path towards a successful deployment.

The I-190 ICM deployment planning efforts are occurring in tandem with the development of the Border Crossing ICM initiative. The Border Crossing ICM project is funded through a separate grant awarded to NFTA by the New York State Energy Research and Development Authority (NYSERDA). This project resides in the same overall concept for ICM in the Buffalo-Niagara region, but focuses on the separate and larger regional border crossing corridor between the United States and Canada across the Niagara River.

1.1 SCOPE OF PMP

The PMP is the master planning document for the ICM project in the Buffalo-Niagara region. This document describes the activities in detail throughout the period of project development and defines the project management principles and procedures for the project. Guidelines from Project Management Body of Knowledge (PMBOK) were used to prepare the PMP. The PMP describes the overall program structure; project partners and participants; deliverables; related management plans and procedures; and the methods used to plan, monitor, control, and improve the project development efforts.

The PMP is a dynamic document and may be updated on a periodic basis to reflect all organizational changes, lessons learned, and advances in methodologies that occur throughout a project's life cycle. Agreement, and adherence, to these procedures is one of the keys to successful project delivery.

1.2 INTENDED AUDIENCE

This PMP is intended to provide the project partners, participants, and FHWA officers with detailed information on how the ICM project is being developed.

1.3 PMP UPDATE PROCESS

The PMP will be monitored and updated as needed during the project lifecycle. In case of major change to project scope, schedule or budget, an update of the PMP will be generated as well to document the changes.

2.0 Project Description

2.1 PROJECT PURPOSE

The overall purpose of the ICM project is to achieve the combined stakeholder vision of efficient transportation operations within the corridor. The ICM is intended to provide improved integration of operational procedures, facilitate improved emergency response, and improved dissemination of traveler information in the I-190 Corridor and in the larger Border Crossing corridor within the Niagara Frontier.

The Niagara Frontier is the border region that encompasses the Niagara River border crossings and is a strategic international gateway for the flow of trade and tourism between the United States and Canada. The Niagara River, flowing from Lake Erie to Lake Ontario, forms the border between the United States and Canada. On the Canadian side, the Niagara Region covers approximately two-thirds of the Niagara Peninsula and consists of twelve local municipalities. On the United States side, the Buffalo-Niagara Frontier region forms the western border of New York State with the province of Ontario. The City of Buffalo, the second largest city in New York State, is located at the easternmost end of Lake Erie, overlooking the Niagara River. The City of Niagara Falls, New York, is located 20 miles northwest of Buffalo in Niagara County opposite Niagara Falls, Ontario. Figure 2.1 shows a map of the region, the cities involved, and the primary corridor roadways to be considered in the combined I-190 and Border Crossing ICM project.

Figure 2.1 Map of the Buffalo-Niagara ICM Project Region

Background Map Source: ESRI ArcGIS StreetMap Data

2.2 PARTNERING AGENCIES AND AUTHORITIES

The Niagara region is a particularly complex area for transportation activities due to the interaction of different entities and activities. The ICM project is currently being led by the Niagara International Transportation Technology Coalition (NITTEC). NITTEC is coalition of transportation agencies in Western New York and Southern Ontario, allowing transportation agencies to collaborate and manage the multi-modal transportation systems, making it possible to reach mobility, reliability, and safety improvements in the region. NITTEC helps coordinate and facilitate communication between regional transportation agencies, in both Canada and the United States. Table 2.1 shows current NITTEC member agencies and related organizations.

Table 2.1 NITTEC Agencies

Member agencies	Other related organizations
Buffalo and Fort Erie Public Bridge Authority (PBA)	Canada Border Services Agency (CBSA)
City of Buffalo	Federal Highway Administration (FHWA)
City of Niagara Falls, New York	Greater Buffalo-Niagara Regional Transportation Council (GBNRTC)
City of Niagara Falls, Ontario	New York State Police (NYSP)
*Erie County	Ontario Provincial Police (OPP)
*Ministry of Transportation, Ontario (MTO)	United States Customs and Border Protection (USCBP)
*New York State Department of Transportation (NYSDOT)	State University of New York at Buffalo
*New York State Thruway Authority (NYSTA)	Other local and regional police and emergency services agencies
Niagara County	Recovery companies
Niagara Falls Bridge Commission (NFBC)	
*Niagara Frontier Transportation Authority (NFTA)	
Niagara Parks Commission	
Niagara Region	
Town of Fort Erie	

* Agencies included in the Policy Board

Source: NITTEC Transportation Operations Integrated Corridor Management Requirement Document, February 2010

2.3 PROJECT GOALS AND OBJECTIVES

The overall purpose of the ICM is to achieve the combined stakeholder vision of efficient transportation operations within the corridor. The ICM is intended to provide improved integration of operational procedures, facilitate improved emergency response, and dissemination of traveler information.

Based on this general purpose, Table 2.2 shows the specific goals set for each category of action.

Table 2.2 ICM Goals and Objectives

Category	Objective	Short Term Goal	Long Term Goal	Performance Measure
I. Agency Coordination	Improve center-to-center communications	1. Center-to-center (C2C) communications is functioning among all transportation related agencies in the corridor	1. Center-to-center (C2C) communications is functioning among all transportation related agencies in the corridor	1. Evaluate the use of established center-to-center communication links a. Number of agencies b. Monthly activity c. Monthly down time
II. Traveler Information	A. Improve accuracy of congestion (travel time) information reliability	1. Reduce the variation in travel times experienced by travelers throughout the corridor by 25 percent 2. Posted travel times are within 20 percent of measured travel times 3. Travel time information sources have an up-time of 99 percent 4. System element down time averages less than 12 hours per element failure 5. System (as a whole) down time averages less than four hours per system failure	1. Reduce the variation in travel times experienced by travelers throughout the corridor by 35 percent 2. Posted travel times are within 10 percent of measured travel times 3. Travel time information sources have an up-time of 99.9 percent 4. System element down time averages less than 10 hours per element failure 5. System (as a whole) down time averages less than four hours per system failure	1. Monthly variation for selected times and links 2. Compare posted travel times with measured travel times for selected time periods and links 3. Monthly up-time 4. Monthly down time per element 5. Monthly system down time
	B. Enable intermodal choices through improved traveler information	1. Transit information has been integrated into the highway information network 2. Traveler information usage has increased by 150 percent 3. An 85 percent customer traveler information satisfaction rating has been achieved among local commuters and border crossing commuters receiving information 4. Travelers are provided with various modal and route options to effectively travel throughout the corridor that enable them to make choices regarding: Departure time, Mode and route	1. Transit information has been integrated into the highway information network 2. Traveler information usage has increased by 200 percent 3. An 90 percent customer traveler information satisfaction rating has been achieved among local commuters and border crossing commuters receiving information 4. Travelers are provided with various modal and route options and are also provided with the current conditions facing each option	1. Traveler information is integrated 2. Evaluate the use of traveler information monthly a. Traveler surveys are conducted b. Web site hits c. 511 telephone service calls 3. Yearly traveler surveys 4a. Static traveler information is in place 4b. Dynamic traveler information is in place

Table 2.2 ICM Goals and Objectives (con't)

II. Traveler Information (con't)	C. Improve integration of weather information/data for traveler information, and for maintenance operations	1. Weather information/data sources is integrated into all traveler information services 2. Relationship with weather information/data sources has increased by 5 percent 3. Weather information/data is integrated into all maintenance call-out procedures and systems for managing operations	1. Weather information/data sources is integrated into all traveler information services 2. Relationships with weather information/data sources has increased by 10 percent 3. Weather information/data is integrated into all maintenance call-out procedures and systems for managing operations 4. Integration of the RWIS between the region and the province is functioning 5. RWIS is integrated into all traveler information services	1. Successful integration has been accomplished 2. Number of relationships with weather information/data sources 3. Successful integration has been accomplished 4. Successful integration has been accomplished 5. Successful integration has been accomplished
	D. Improve integrated operations based on real-time data	1. Use of real-time data has been determined 2. The system has an up-time of 99 percent 3. New technology is integrated at least every four years	1. Real-time data is used to improve operations 2. The system has an up-time of 99 percent 3. New technology is integrated at least every four years	1. Use of real-time data has been determined and is in use 2. Monthly up-time 3. Frequency of system element updates
III. Mobility (Arterial, Border, Freeway, Transit)	A. Maximize the free flow of traffic and reduce congestion	1. 50 percent of the identified arterials within the ICM corridor are coordinated across jurisdictions. 2. A central source directly or indirectly manages and operates 50 percent of the corridors in the ICM 3. Key signals in the corridor are retimed every three years	1. All identified arterials within the ICM corridor are coordinated across jurisdictions 2. A central source directly or indirectly manages and operates all corridors in the ICM 3. Key signals in the corridor are retimed every three years	1. The percentage of coordinated corridors 2. Percentage of the ICM corridors operated by a central source 3. Number of key signals retimed every three years
	B. Provide transit alternative and park-and-ride facilities	1. Transit ridership has increased 1 ½ times the percent of traffic volume increase 2. The number of park-and-ride facilities has increased by 10 percent	1. Transit ridership has increased 2 times the percent of traffic volume increase 2. The number of park-and-ride facilities has increased by 20 percent	1. Percentage of ridership increase 2. Number of park-and-ride facilities

Table 2.2 ICM Goals and Objectives (con't)

III. Mobility (con't)	C. Enhance border crossing clearance	1. Total border delay time has decreased by 5 percent from existing demand levels	1. Total border delay time has decreased by 15 percent from existing demand levels	1. Monthly total border delay time during selected times and periods
	D. Facilitate ITS and operational improvements that will facilitate ICM mobility	1. The VMS, Travel Time readers and CCTV have been deployed in accordance with the ICM	1. The VMS, Travel Time readers and CCTV deployed is maintained 2. The HAR system fully covers the ICM corridor	1. Number of VMS, Travel Time readers and CCTV deployed per year 2. HAR system coverage in the ICM corridor
	E. Enhance alternative route management capabilities	1. Develop one arterial signal system and integrate with related freeway management systems 2. Operate signals and freeways in one corridor as a system 3. Provide additional instrumentation on three primary arterials 4. Provide additional instrumentation on one parallel arterials that may be designated as diversion routes	1. Develop three arterial signal systems and integrate with related freeway management systems 2. Operate signals and freeways in three corridors as systems 3. Provide additional instrumentation on five primary arterials 4. Provide additional instrumentation on three parallel arterials that may be designated as diversion routes	1. Number of integrated systems 2. Number of corridors operating as a system 3. Number of arterials instrumented 4. Number of parallel arterials instrumented
IV. Incident Management	A. Establish incident classifications and severity guidelines	1. Develop agreed upon definitions for minor, intermediate, and major incidents 2. Define incident severity guidelines based on: Incident Severity, Field Conditions, Resources needed, and Estimated incident duration	1. Utilize agreed upon definitions for minor, intermediate, and major incidents 2. Utilize incident severity guidelines	1a. Incident definitions agreed upon 1b. Incident definitions universally used 2. Incident severity guidelines are defined

Table 2.2 ICM Goals and Objectives (con't)

IV. Incident Management (con't)	B. Improve and coordinate incident management	1. Meetings are held among transportation agencies monthly	1. Meetings are held among transportation agencies every month	1. The number of meetings held per year
		2. Average incident detection to arrival time is less than 8 minutes	2. Average incident detection to arrival time is less than 6 minutes	2. Monthly average incident detection to arrival time
		3. Average incident detection to lane clearance time is reduced by 20 percent	3. Average incident detection to lane clearance time is reduced by 30 percent	3. Monthly percentage reduction of average incident detection to lane clearance time
		4. Average time from detection to back to normal conditions is reduced by 15 percent	4. Average time from detection to back to normal conditions is reduced by 20 percent	4. Monthly percentage reduction of average time from detection to back to normal conditions
		5. All incident measures are uniform for all jurisdictions	5. All incident measures are uniform for all jurisdictions	5. Incident measures are uniform
		6. Responder training exists, which provides guidance on relaying accurate information on what equipment is needed for various incidents	6. Responder training exists, which provides guidance on relaying accurate information on what equipment is needed for various types of incidents	6. The number of training and exercise sessions held yearly
		7. An integrated corridor approach is established for: a. Incident management b. Special or planned events c. Emergencies within the corridor	7. An integrated corridor approach is provided during: a. Incident management b. Special or planned events c. Emergencies within the corridor	7. An integrated corridor approach is functioning for: a. Incident management b. Special or planned events c. Emergencies within the corridor

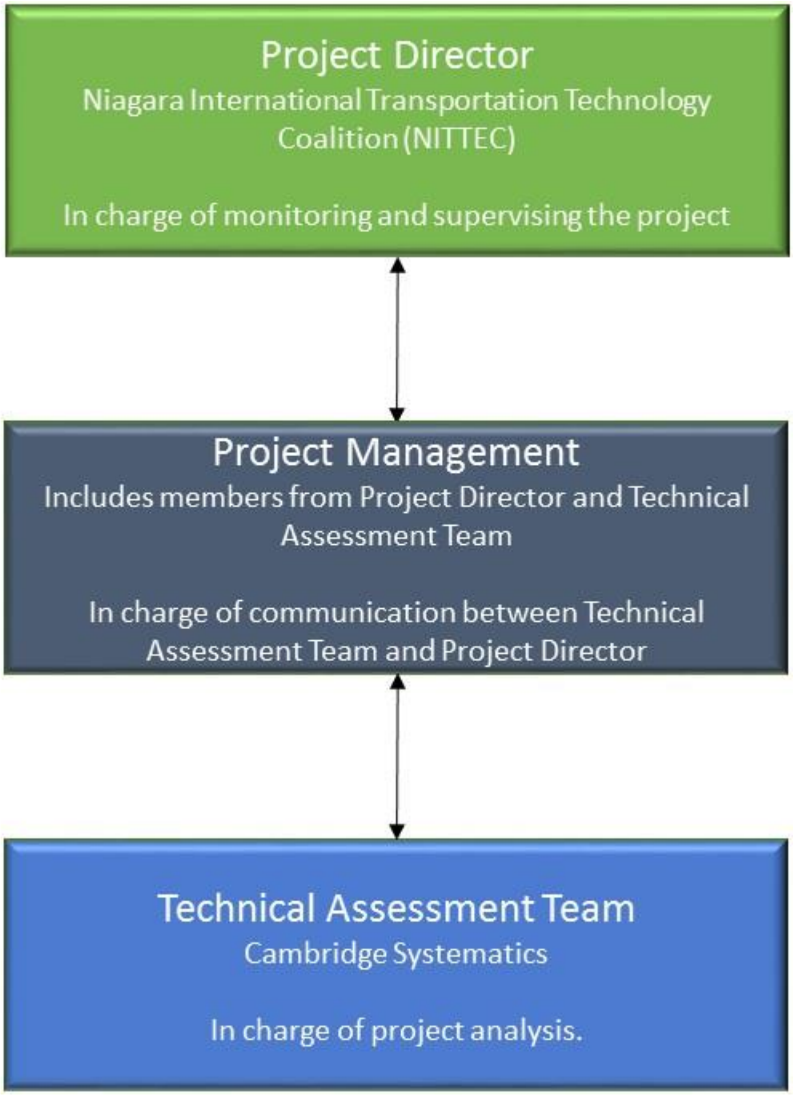
Source: NITTEC Transportation Operations Integrated Corridor Management Requirements Document, February 2010

3.0 Project Management Approach

3.1 ORGANIZATIONAL STRUCTURE

The ICM project is organized along the structure described in Figure 3.1.

Figure 3.1 Project Organization



Source: I-190 Integrated Corridor Management Project Proposal

3.2 STAKEHOLDER ROLES AND RESPONSIBILITIES

The Operational Concept of the ICM project defines the stakeholders listed in Table 3.1, as well as the corresponding responsibilities in ICM project.

Table 3.1 ICM Stakeholders and Responsibilities

Agency/Service	Responsibilities
NITTEC Traffic Operations Center	– Corridor coordinated operations – Corridor administration activities – Corridor performance monitoring – Corridor technical management and development – VMS – ITS device management (VMS, HAR, CCTV, etc.) – Enact/implement response plans
Bridge agencies • Buffalo and Fort Erie Public Bridge Authority • Niagara Falls Bridge Commission (NFBC)	– Daily corridor operations – Monitoring bridge traffic flow – Bridge surveillance – Enact response plans – Maintenance
Ministry of Transportation, Ontario (MTO)	– Daily corridor operations – Freeway management – Signal systems – ITS device management (VMS, CCTV, etc.) – Enact/implement response plans – Maintenance
New York State Department of Transportation (NYSDOT)	– Daily corridor operations – Freeway management – Signal systems – Maintenance
New York State Thruway Authority (NYSTA)	– Daily corridor operations – Freeway management – Maintenance
Niagara Frontier Transportation Authority (NFTA)	– Daily operations – Monitor bus on-time levels – Monitor train schedules – Monitor parking conditions – Enact response plans
Local municipalities within: • Erie County, New York • Niagara County, New York	– Daily Operations – Arterial surveillance – VMS on arterials

Agency/Service	**Responsibilities**
• Niagara Region, Ontario	– Enact response plans
Local municipalities that maintain traffic signals	– Daily Operations – Signal systems
Emergency agencies • Erie County Emergency Services • New York State Police (NYSP) • Niagara Falls Fire Department • Niagara Parks Police • Ontario Provincial Police (OPP) • NITTEC Incident Management Committee Members WNY & Ontario	– Emergency management – Coordination of law enforcement activities – Coordination of emergency services activities – Incident response management – Integration of Computer Aided Dispatch (CAD)

Source: NITTEC Transportation Operations Integrated Corridor Management System Operational Concept Final Report, January 2010

4.0 Scope Management

4.1 TECHNICAL TASK LIST

The scope of work is defined according to the following six tasks. While each task generally supports both the development of both the I-190 ICM initiative and the Border Crossing ICM initiative, some tasks are more geared towards one of the two ICM grants.

Task 1 – Project Management

Effective communication is essential to effective project management, both internally within the technical team and externally with the project leadership and stakeholders. To achieve a successful communication strategy, the following sub tasks have been defined:

- Subcontract for Data Collection.
- Meetings.
- ICM Project Plans and Progress Reports.
- Data Collection and Benefit Reporting.
- Final Report.

Task 2 – Establish Base Conditions

The establishment of the existing conditions is critical to ensure that the tool development efforts are realistic and can be used for scenario testing. In addition to the 'average' conditions typically analyzed, details on the non-recurring congestion events, including adverse weather impacts and special event generators will also be considered. This task will establish the base conditions which will be used in the subsequent model development and define the possible scenarios that will be undertaken in the scenario task. To reach this general objective, the following tasks have been defined:

- Identify Base Conditions for Analysis.
- Assemble and Review Available Resources.
- Assemble Available Data.
- Identify Data Gaps and Develop Data Collection Plan.
- Collect Data.
- Establish Base Conditions.

Task 3 – Develop Decision Support Tool

This task will create the analysis, modeling, and simulation (AMS) tools which will be used in the analysis of the selected analysis conditions, and the protocols for which they will be used to analyze potential future operating conditions for the selected analysis conditions in Task 4. To reach this general objective, the following tasks are considered:

- Select Modeling Methodology.
- Select Performance Measures and Evaluation Criteria.
- Network Development.
- Demand for Base Conditions.
- Calibration/Validation of Base Conditions.

Task 4 – Apply Decision Support Tool

Following the calibration to the baseline conditions, the developed decision support tool will be used to simulate traffic management strategy scenarios, and extract performance measures to assess potential improvements to operations under different traffic management strategies, and to evaluate the effectiveness of those strategies. These strategies are planned to be developed and performed in two different stages and in concert with workshops held in Task 5; the first set will examine 'existing technology' strategies, while the second set will examine new technology strategies or refined strategies based on review of the first set or results. To reach this general objective, the following tasks are considered:

- Identify Traffic Management Strategies.
- Simulate Scenarios.
- Calculate Performance Measures.
- Evaluate Strategies.

Task 5 – Develop Border Crossing Corridor Management Plan and I 190 ICM Implementation Plan

Based on the results obtained from the analysis tool, an implementation plan for the I-190 ICM concept can be developed, along with the border crossing corridor management plan. The following task are considered for this task:

- Workshops
- Development of the Border Crossing Corridor Management Plan
- Development of the I-190 ICM Implementation Plan

Task 6 – Performance Monitoring

In order to better track the performance of the border crossing and regional corridors and to assess the future changes and improvements in the corridor, a performance report template will be developed that can easily be populated from existing data collection sources used in this project.

4.2 PROJECT DELIVERABLES

Table 4.1 shows the project deliverables defined across the different tasks previously described. Progress on scope completion for each task will be identified in specified Project Progress Reports and Status calls. Submitted deliverables will be subject to Quality Control Process as described later in this PMP.

4.3 SCOPE CHANGES

Should the need for any changes to the scope be identified throughout the project, the following steps will be undertaken.

- Identification of the proposed change and documentation of the reasons for the change
- Preparation of change control form and documentation including any revised cost estimates resulting from the change
- Review and approval by the entire project team
- Identification of linkage to other PMP elements

Upon completion of the change, the PMP will be revised and updated to reflect the change.

Table 4.1 Project Deliverables

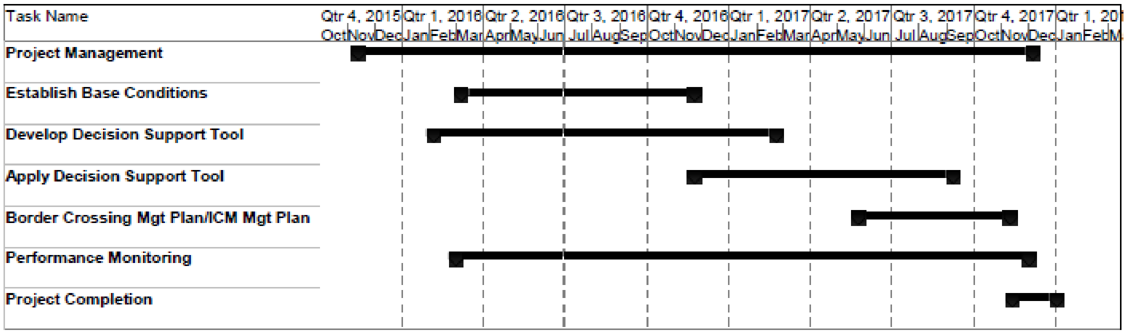
Task	Deliverable
Task 1 – Project Management	• Data Collection Subcontract Executed • Preparation and Participation in Kickoff Meeting (in-person) • Preparation and Participation in Project Meetings (bi-weekly phone conference or web-meetings project leadership meetings, quarterly in-person or web-meetings for entire project team) • Preparation and Participation in Wrap-Up Meeting (in-person) • Draft and Final Project Management Plan (PMP) • Draft and Final Systems Engineering Management Plan (SEMP) • Updates as needed to the existing NITTEC ICM System Operational Concept Report and the NITTEC ICM Requirements Document Report • Project Schedule • Monthly Progress Reports and Invoicing • Draft and Final Plan for Data Collection for Benefit Reporting and Report Template • Semi-Annual Performance Update Reports for the first year of the project • Draft and Final Project Report • Draft and Final Executive Summary
Task 2 – Establish Base Conditions	• Draft and Final Base Conditions Technical Memorandum
Task 3 – Develop Decision Support Tool	• Draft and Final Decision Support Model Development and Base Conditions Calibration Technical Memorandum • Calibrated Base Conditions Simulation Model Files
Task 4 – Apply Decision Support Tool	• Project Team Meeting/Workshop for Initial Strategy Discussion and Selection • Draft and Final Model Application Technical Memorandum
Task 5 – Develop Border Crossing Corridor Management Plan and I 190 ICM Implementation Plan	• Project Team Meeting/Workshop for Initial Strategy Discussion and Selection • Draft and Final Border Crossing Corridor Management Plan • Draft and Final I-190 ICM Implementation Plan
Task 6 – Performance Monitoring	• Process and Template for producing Quarterly Progress Reports • Quarterly Progress Reports

5.0 Schedule/Time Management

5.1 BASELINE PROJECT SCHEDULE

Figure 5.1 shows the high level summary of the project schedule by task. A detailed project schedule listing individual sub-tasks and tasks interdependencies is included in Appendix A. The included schedule was reviewed and agreed to by the project team on June 14, 2016.

Figure 5.1 High-Level Project Schedule



5.2 SCHEDULE MANAGEMENT

The process for managing the schedule and any proposed changes to that schedule will be completed as follows.

Schedule Reviews

Schedule status will be reviewed at regular bi-weekly project status call meetings through discussion of the ongoing and upcoming activities in the next month of the project. Any anticipated deviation from the schedule will be raised with the team as a schedule risk.

In addition to the bi-weekly status calls, the percent complete for schedule activities will be formally recorded in the schedule format monthly for reporting and review purposes.

Schedule Change Control

Schedule review cycles will include forecasts of potential schedule deviation and a proposed recovery plan will be presented

If required, changes to the project schedule that are proposed by the task owner will be subject to the change control process. Schedule activity changes will be entered and overall schedule impacts on subsequent tasks will be assessed. If required, re-baselining of the overall schedule will be completed with project team approval and signoff of the revised schedule.

Additionally, any impacts potential impacts on either project cost or scope will be identified and addressed according.

6.0 Cost/Budget Management

6.1 PROJECT COSTS

To generate efficiencies of scale, the I-190 ICM project is being completed in parallel with the Border Crossing ICM project. While the projects have similar objectives and methods and will both utilize the same regional AMS tool being developed, they address separate corridors within the Buffalo-Niagara region and require different analysis conditions, different management strategies, and require different deliverables. Therefore, some costs would be shared between the two grants, and some costs would be borne by only one grant.

Since the two projects are also funded through separate grants, throughout the project the cost reporting will be completed separately for the two projects. While time spent on certain tasks may be needed in both projects (e.g. developing the AMS tools), cost reporting will be split and tracked separately between both projects.

The following table breaks down the budget attributed from each of the ICM corridors (and respective grants) for each of the six tasks. Matching funds are not included in the totals shown.

Table 6.1 Project Costs By Task By Corridor

Task Name	I-190 ICM (USDOT)	Border Crossing ICM (NYSERDA)
Task 1: Project Management	$ 37,473	$ 32,576
Task 2: Establish Base Conditions	$ 35,886	$ 45,158
Task 3: Develop Decision Support Model	$ 37,532	$ 43,942
Task 4: Apply Decision Support Model	$ 72,821	$ 84,329
Task 5: Develop Border Crossing Management and ICM Implementation Plans	$ 16,288	$ 70,411
Task 6: Performance Monitoring	$ -	$ 9,239
Total:	$ 200,000	$285,655

6.2 COST REPORTING

Expenditures by task will be reported on invoices separately for each funding grant. Any cost issues will be identified in progress calls and the need to invoke change control will be determined.

6.3 COST CHANGE CONTROL PROCESS

Proposed revisions to the project cost baseline will be subject to the change control process and agreement by the project team. Possible workarounds will be identified in the process for maintaining the budget baseline.

7.0 Procurement and Staffing Management

7.1 PROCUREMENT PLAN

The lead agencies of the ICM project are the Niagara International Transportation Technology Coalition (NITTEC), the Greater Buffalo-Niagara Regional Transportation Council (GBNRTC), and the Niagara Frontier Transportation Authority (NFTA). These agencies have hired Cambridge Systematics Inc. as the consultant for the project.

As described in the project scope, Cambridge Systematics, Inc. will subcontract the activities related to data collection. Any subcontract agreements will be subject to the project team review and approval.

The subcontractor is still to be selected. While final details of the exact services of the subcontractor will be determined during the analysis of the gaps within the existing available data, the anticipated subcontractor will specialize in traffic count data collection. Efforts will be undertaken to select a subcontractor that is a registered Disadvantaged Business Enterprise (DBE) with the State of New York.

7.2 TEAM LEADERSHIP AND STAFFING

Table 7.1 shows the lead and support staff involved in the project for all project team members.

Table 7.1 Project Team Personnel

Team Member	Lead	Support Staff
NITTEC	Athena Hutchins	• Michael Smith • Timothy McGovern • Andrew Bartlett
GBNRTC	Hal Morse	• Mike Davis
Cambridge Systematics Inc.	Keir Opie	• Vassili Alexiadis • John Duesing • Daniel Krechmer • Sean Fitzgerald • Aldo Tudela Rivadeneyra • Sunil Dhuri • John Lewis
Traffic Data Subconsultant	TBD	• TBD

7.3 CONTINGENCY PLAN FOR PROJECT TEAM LEADERSHIP

Table 7.2 describes the contingency plan for the consultant team in case of unanticipated departures for key personnel on the consultant team.

Table 7.2 Team Leadership and Contingency Plan

Team Member	Current Leader	Contingency
NITTEC	Athena Hutchins	Michael Smith
GBNRTC	Hal Morse	Mike Davis
Cambridge Systematics	Keir Opie	John Duesing

Changes to the project team leadership personnel will be subject to review and concurrence by the project team.

7.4 TRAVEL AND OTHER EXPENSES

All travel and other allowable expenses will be subject to the guidelines set forth in the consultant agreements determined by NFTA, NITTEC and GBNRTC.

8.0 Quality Assurance and Control Management

The Consultant Project Manager (PM) will be responsible for the project development process and products, to ensure the project meets the quality standards and identify ways to mitigate risk or eliminate causes of unsatisfactory results. The Consultant PM will establish a QA/QC role to review project activities and inspect deliverables to ensure the project is adhering to its established plans, process and product quality standards prior to submittal to the project leadership.

8.1 QUALITY CONTROL

The Consultant PM and the Project Directors (NITTEC, NFTA, and GBNRTC) will provide a review approach for all project deliverables to ensure they meet the acceptance criteria for the deliverable. Formal FHWA acceptance is the performance standard that all deliverables are held to. Prior to completion, the consultant PM will establish a quality check-list for each deliverable. The completed checklist will be included in the draft submission of the document. The quality checklist will provide proof of completion of the following:

1. A self review from the document/product developer.
2. Acceptance and review by Project Director and core working group.
3. Acceptance and review by FHWA or NYSERDA, depending on deliverable.

The quality control process and checklists will consider and adhere to relevant technical guidance on modeling, including the FHWA's *Traffic Analysis Toolbox Volume III*: *Guidelines for Applying Traffic Microsimulation Modeling Software* (July 2004) and GBNRTC's own *Regional Simulation Modeling Guidelines and Technical Framework* (February 2011).

8.2 QUALITY ASSURANCE

The Consultant PM will support ongoing quality assurance, gathering lessons learned and identifying remedial actions to identified quality issues and document at project completion.

9.0 Communications Management Plan

The Communications Management Plan provides the framework for effective communications and stakeholder engagement throughout the life of the study. The plan will be updated as needed if communication needs change and/or if the stakeholders change. Building from the project management approach, this section identifies and defines the roles of people involved in this project. It also includes a table of scheduled communications as part of this project. A process for ensuring that the meetings and interactions are effective is also provided.

9.1 COMMUNICATION MANAGEMENT

The team will take a proactive approach towards engaging the stakeholders led by the Project Directors (NITTEC and GBNRTC leads) and supported by the Consultant PM. The roles of both parties are as follows:

- Project Directors
  - Be the single point of communication with USDOT and NYSERDA grant sponsors, along with other external parties
  - Support meeting requests and identify locations to host various scheduled meetings other project working groups
  - Ensure continued commitments to participate in the ICM planning process from stakeholders and members of the project working groups
  - Resolve conflicts between working group members and facilitate gathering of information by the consultant team
  - Present on the ICM project at various stakeholder forums identified by the project team
- Consultant PM
  - Organize all scheduled communications and meetings as part of the project including management team meetings, core working group meetings and other stakeholder engagement activities identified.
  - For each engagement, develop an agenda and provide minutes of the meeting to the project leadership
  - Identify opportunities for the project leadership to present and engage stakeholders on the ICM planning effort.
  - Provide monthly progress reports to the project leadership

9.2 SCHEDULED COMMUNICATIONS

Communications are planned as follows:

- Kick-off meeting at the beginning of the project.
- Regular Project meetings, held via phone conference or web meetings.
- Quarterly in person Progress Meeting and written monthly progress reports.
- Wrap up meeting at the end of the project

In addition to these means of communication, the Consultant will remain open to written communications when necessary. Critical communications will be accepted in written form, to provide a clear trail of decisions made throughout the project.

External Communications

Throughout the duration of the project, the project status will be communicated to parties external to the core project team as noted:

- NITTEC Border Crossing Subcommittee (each meeting)
- NITTEC Board of Directors (each meeting)
- GBNRTC Planning and Coordination Committee (PCC) (bimonthly)
- GBNRTC Policy Committee (each meeting)
- External Stakeholders including (MTO, NYSDOT, NYSTA, etc.) per monthly status updates

10.0 Risk Management

10.1 RISK PLANNING

Effective risk planning involves a clear process for identifying risks, analyzing the impacts, and developing a response plan to mitigate the impact of the risk. The following steps are necessary for clear approach to identifying, analyzing, responding, and monitoring risk:

1. Risk Identification. A Risk Register will be maintained by the consultant PM and will document the description, project stage, trigger, outcome, as well as the originating source of the risk. Once the trigger occurs, the risk becomes a problem to be solved.
2. Risk Analysis. Upon identification of the risks, the project leadership and the consultant PMs will conduct a risk analysis to identify the probability and impact of occurrence to develop a ranking of risk. Both probability and impact will be subjectively assessed using a "low to high" scale based on the team's understanding of the risk.
3. Response Planning. The team will develop a strategy to reduce the risk to a manageable extent focusing on the high-priority risks. Consistent with PMBOK, strategies considered will include avoidance, transfer, mitigation, and acceptance.
4. Monitoring and Control. The risk register will be reviewed to assess the current status of the risk, identify any new risks, and provide an update on the impact of the risk reduction strategy. As risks are resolved, they will be retired and no longer monitored.

10.2 ROLES

The Consultant PM will work with the Project Directors (NFTA, NITTEC, and GBNRTC) to identify sources of risk events and symptoms of risk. The Consultant PM will be responsible of developing and updating the Risk Register.

10.3 RISK REGISTER

The risk register will be tracked in a separate document on the project development report.

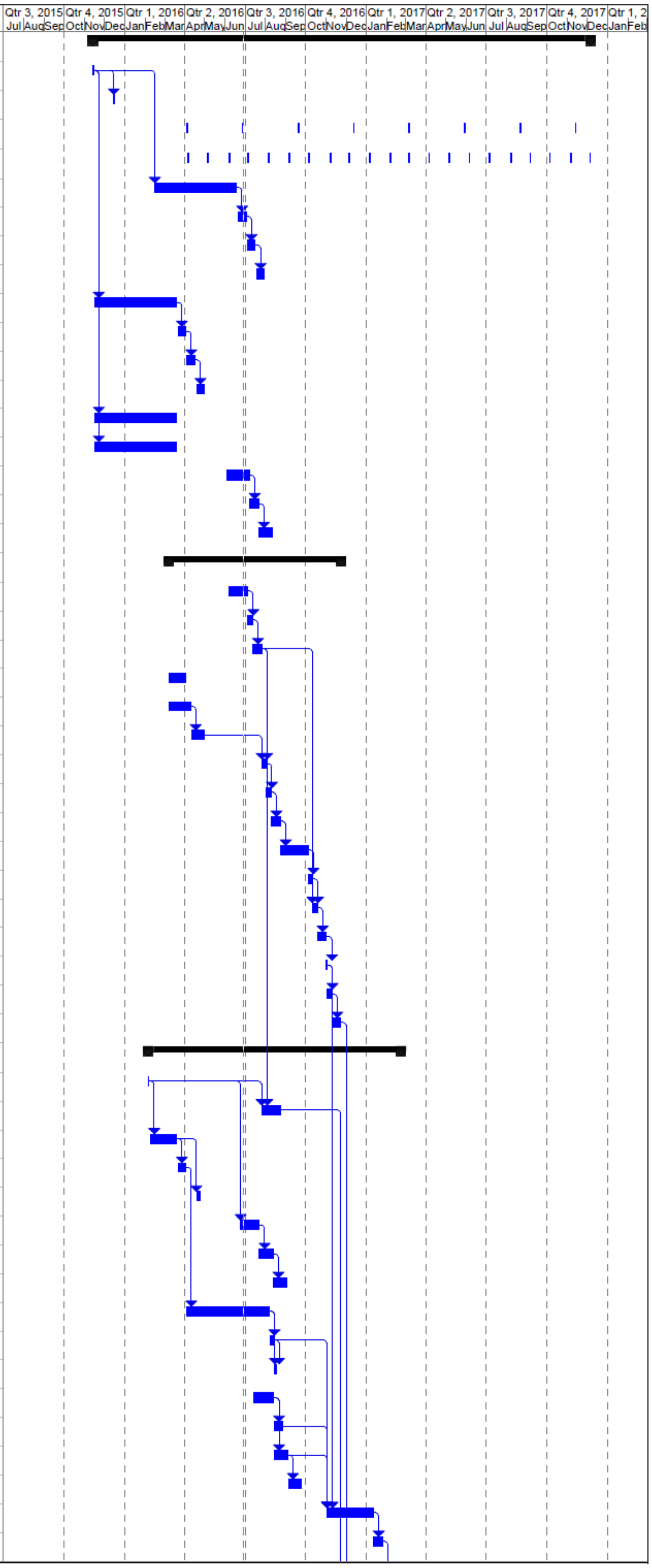
11.0 References

This section lists the applicable documents that are inputs to the project.

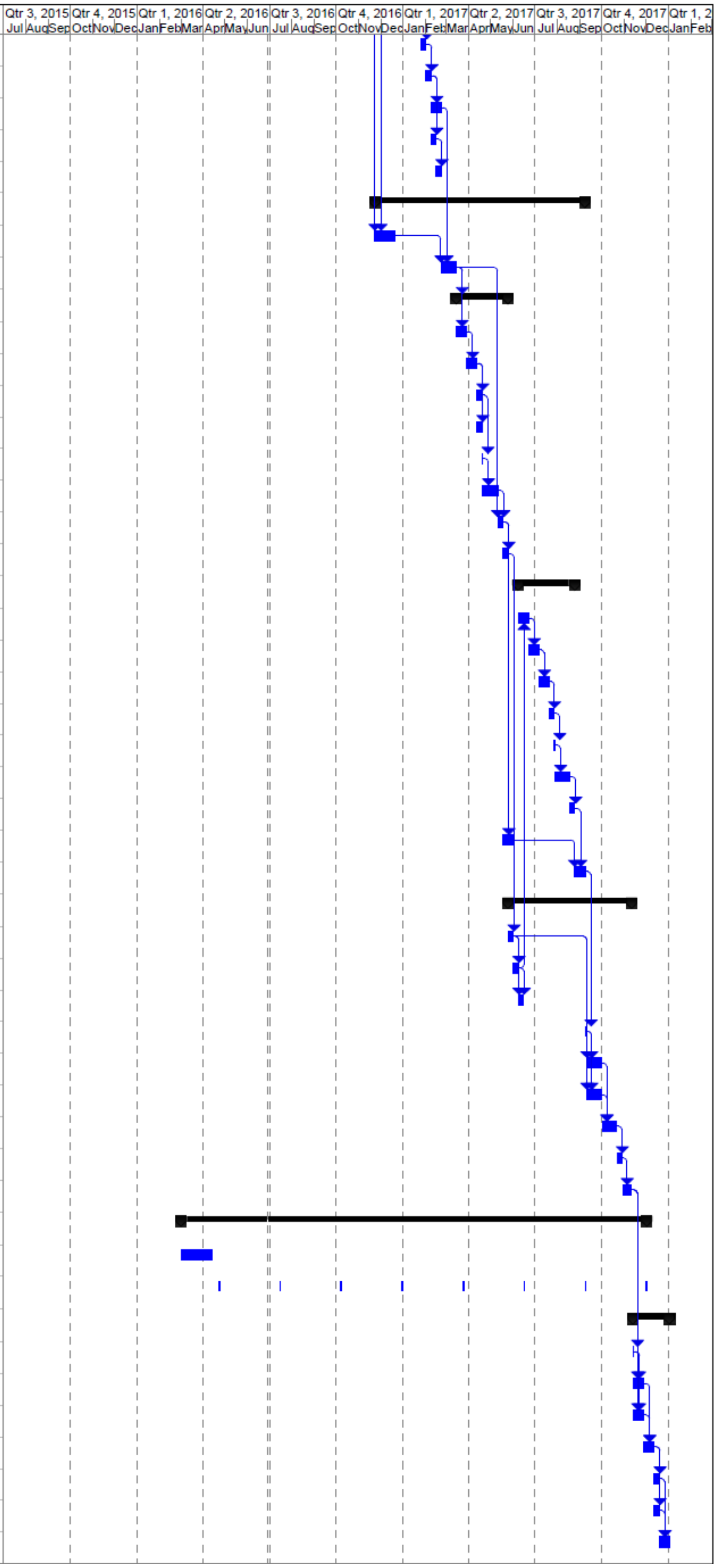
- NITTEC Transportation Operations Integrated Corridor Management Systems Operational Concept Final Report, September 2009.
- NITTEC Transportation Operations Regional Concept for Transportation Operations, January 2010.
- NITTEC Transportation Operations Integrated Corridor Management Requirements Document, February 2010.
- I-190 Integrated Corridor Management Project Proposal
- Buffalo-Niagara Integrated Corridor Management: System Engineering Management Plan.
- Buffalo-Niagara Integrated Corridor Management: Proposed Changes to Existing ICM Documents.
- GBNRTC Regional Simulation Modeling Guidelines and Technical Framework, February 2011
- FHWA, ICMS Concept of Operations for a Generic Corridor, April 2006, http://ntl.bts.gov/lib/jpodocs/repts_te/14281_files/14281.pdf
- FHWA, Integrated Corridor Management: Implementation Guide and Lessons Learned, February 2012, http://ntl.bts.gov/lib/47000/47600/47670/FHWA-JPO-12-075_FinalPKG_508.pdf
- USDOT, National ITS Architecture version 7.1, http://www.iteris.com/itsarch/index.htm
- Buffalo-Niagara Bi-National Regional ITS Architecture, November 2005, http://www.consystec.com/buffalo/web/_stakeholders.htm
- New York State Regional ITS Architecture, November 2009, http://www.consystec.com/newyork/web/index.htm
- FHWA System Engineering Management Plan Update, http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_2.cfm
- FHWA, Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software (FHWA-HRT-04-040), July 2004, http://ops.fhwa.dot.gov/trafficanalysistools/tat_vol3/vol3_guidelines.pdf

A. Detailed Project Schedule

Task Name	Duration	Start
Project Management	**538 days?**	**Fri 11/13/15**
Contract NTP	1 day?	Fri 11/13/15
Project Kickoff Meeting	1 day	Tue 12/15/15
Quarterly Status Meetings	**421 days**	**Mon 4/4/16**
Monthly Progress Reports	**436 days**	**Tue 4/5/16**
Draft Project Management Plan development	90 days	Mon 2/15/16
Team Review Draft PMP	10 days	Mon 6/20/16
Final PMP Development	10 days	Mon 7/4/16
PMP Team and NITTEC Approval	10 days	Mon 7/18/16
Draft Systems Eng Mgt Plan Development	90 days	Mon 11/16/15
Team Review Draft SEMP	10 days	Mon 3/21/16
Final SEMP Development	10 days	Mon 4/4/16
SEMP Team and NITTEC Approval	10 days	Mon 4/18/16
System Op Concept Report Update	90 days	Mon 11/16/15
Requirements Document Report Update	90 days	Mon 11/16/15
Draft Data Collection for Benefit Report & Template	24 days	Fri 6/3/16
Team Review Data Coll Benefit Report	10 days	Thu 7/7/16
Final Report and Approval	15 days	Thu 7/21/16
Establish Base Conditions	**187 days?**	**Mon 3/7/16**
Identify 8 Base Conditions	21 days	Mon 6/6/16
Consultant Review and Respond on 8 Base Conditions	5 days	Tue 7/5/16
Rank and Select 4 Base Conditions	10 days	Tue 7/12/16
Assemble/Review Resources	20 days	Mon 3/7/16
Assemble Available Data	25 days	Mon 3/7/16
Review all Collected Data Sets	15 days	Mon 4/11/16
Identify Data Gaps	5 days	Tue 7/26/16
Develop Data Collection Plan	5 days	Tue 8/2/16
Retain Data Collection Subconsultant	10 days	Tue 8/9/16
Collect Data	30 days	Tue 8/23/16
Review Data Quality Assurance/Release	5 days	Tue 10/4/16
Draft Base Conditions Technical Memo	5 days	Tue 10/11/16
Team Review Base Conditions Draft Memo	10 days	Tue 10/18/16
NITTEC BC Committeee Approve Base Conditions	1 day?	Tue 11/1/16
Final Base Conditions Technical Memo	5 days	Wed 11/2/16
Final Base Condiitons Memo Approval	10 days	Wed 11/9/16
Develop Decision Support Tool	**273 days?**	**Fri 2/5/16**
Select Modeling Methodology	1 day	Fri 2/5/16
Develop Protocols AMS Component Utilization	20 days	Tue 7/26/16
Acquire Model Software	30 days	Mon 2/8/16
Install and Test Model Software	10 days	Mon 3/21/16
GBNRTC Aimsum training at CS-NYC	5 days	Mon 4/18/16
Draft Performance Measures/Eval Criteria	20 days	Fri 6/24/16
Team Review Perf Meas/Eval Crit	15 days	Fri 7/22/16
Select Final Perf Meas/Eval Criteria	15 days	Fri 8/12/16
Network Development	90 days	Mon 4/4/16
Quality Control Review Networks	5 days	Mon 8/8/16
GBNRTC Signoff on Networks	2 days?	Mon 8/15/16
Complete Calibration of Travel Demand Model	22 days	Thu 7/14/16
Release TDM for Use	10 days	Mon 8/15/16
Demand Development from RTM	15 days	Mon 8/15/16
Fine Tune through ODME Processs	15 days	Mon 9/5/16
Calibration/Validation	50 days	Wed 11/2/16
Draft DSM Devt/Base Calibration Report	10 days	Wed 1/11/17



Task Name	Duration	Start
Team Review Draft Calibration Report	5 days	Wed 1/25/17
Final DSM Devt/Base Calibration Report	5 days	Wed 2/1/17
Calibration Report Approval	10 days	Wed 2/8/17
Install Calibrated Model at GBNRTC	5 days	Wed 2/8/17
Demonstrate Replicated Model Results	5 days	Wed 2/15/17
Apply Decision Support Tool	**207 days**	**Wed 11/23/16**
Assemble Current Traffic Management Strategies	20 days	Wed 11/23/16
Simulate "Do Nothing" Management Scenarios	15 days	Wed 2/22/17
Evaluate Existing Strategies	**51 days**	**Wed 3/15/17**
Identify Strategies - Existing Strategies	10 days	Wed 3/15/17
Team Prioritize Existing Strategies to Test	10 days	Wed 3/29/17
Develop Traffic Response Plan Existing Strategies	5 days	Wed 4/12/17
Methods/Protocols Existing Strategies in Simulation	5 days	Wed 4/12/17
NITTEC BC Committee Approve Strategies	1 day	Wed 4/19/17
Simulate Management Existing Strategy Scenarios	15 days	Thu 4/20/17
Calculate Performance Measures	5 days	Thu 5/11/17
Evaluate Existing Strategies	5 days	Thu 5/18/17
Evaluate New Strategies	**56 days**	**Thu 6/8/17**
Identify Strategies - New Strategies	10 days	Thu 6/8/17
Team Priorotize New Strategies	10 days	Thu 6/22/17
Develop Traffic Response Plan New Strategies	10 days	Thu 7/6/17
Methods/Protocols New Strategies in Simulation	5 days	Thu 7/20/17
NITTEC BC Committee Approve New Strategies	1 day	Thu 7/27/17
Simulate Management New Strategy Scenarios	15 days	Fri 7/28/17
Calculate Performance Measures	5 days	Fri 8/18/17
Develop Single User Benefit Dollar Value Methods	10 days	Thu 5/18/17
Evaluate All Strategies	10 days	Fri 8/25/17
Border Crossing Mgt Plan/ICM Mgt Plan	**122 days**	**Thu 5/25/17**
Workshop 1-Review Existing Strategy Evaluations	5 days	Thu 5/25/17
Workshop 1-Develop Second Set Strategy Scenarios	5 days	Thu 6/1/17
NITTEC BC Committee Review Workshop Results	5 days	Thu 6/8/17
Workshop 2 Incl NITTEC BC Committee	1 day	Fri 9/8/17
Draft Border Crossing Management Plan	15 days	Mon 9/11/17
Draft ICM Implementation Plan	15 days	Mon 9/11/17
Team Review Draft Plans	15 days	Mon 10/2/17
Final BCM and ICM Plans	5 days	Mon 10/23/17
BCM/ICM Plan Approvals	10 days	Mon 10/30/17
Performance Monitoring	**459 days**	**Tue 3/1/16**
Develop Performance Report Template	30 days	Tue 3/1/16
Quarterly Performance Reports	**421 days**	**Fri 4/22/16**
Project Completion	**36 days**	**Mon 11/13/17**
Wrap Up Meeting	1 day	Mon 11/13/17
Draft Project Report	10 days	Tue 11/14/17
Draft Executive Summary	10 days	Tue 11/14/17
Team Review Drafts	10 days	Tue 11/28/17
Final Project Report	5 days	Tue 12/12/17
Final Executive Summary	5 days	Tue 12/12/17
Team and NITTEC Final Approvals	10 days	Tue 12/19/17



Note: Approved schedule as of June 16, 2016

Appendix B. System Engineering Management Plan

Buffalo-Niagara Integrated Corridor Management

System Engineering Management Plan

final

report

prepared for

Niagara International Transportation Technology Coalition &
Greater Buffalo-Niagara Regional Transportation Council

prepared by

Cambridge Systematics, Inc.

June 5, 2017

www.camsys.com

report

Buffalo-Niagara Integrated Corridor Management

System Engineering Management Plan

prepared for

Niagara International Transportation Technology Coalition &
Greater Buffalo-Niagara Regional Transportation Council

prepared by

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38 East 32nd St, 7th Floor
New York, NY 10016

date

June 5, 2017

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Acronyms and Definitions

Term	Definition	Term	Definition
AMS	Analysis, Modeling and Simulation	NFTA	Niagara Frontier Transportation Authority
BOD	Board of Directors	NITTEC	Niagara International Transportation Technology Coalition
ConOps	Concept of Operations	NYSERDA	New York State Energy Research and Development Authority
FHWA	Federal Highway Administration	NYSDOT	New York Department of Transportation
GBNRTC	Greater Buffalo-Niagara Regional Transportation Council	PMP	Project Management Plan
ICM	Integrated Corridor Management	SEBoK	Systems Engineering Body of Knowledge
INCOSE	International Council on Systems Engineering	SEMP	System Engineering Management Plan
IPDT	Integrated Product Development Team	SEP	Systems Engineering Processes
ITS	Intelligent Transportation Systems	USDOT	United States Department of Transportation

Version History

Version	Developed by	Submittal Date	Revision Date	Approved by (Date)	Comments and Nature of Changes
1.0	Cambridge Systematics	03/2016			
1.1	Cambridge Systematics	06/2016			Revisions based on received comments
1.2	Cambridge Systematics	07/2016			Revised based on received comments
1.3	Cambridge Systematics	06/2017			Updated to final after inclusion of all comments

Executive Summary

Partnering agencies and authorities in the Buffalo-Niagara metropolitan area have received a United States Department of Transportation (US DOT) grant support for the development of the Concept of Operations (ConOps) for the I-190 Integrated Corridor Management Corridor. Through the activities supported by this grant, the ConOps will establish the Corridor's vision, goals, and objectives; identify operating agency, authority, and stakeholder issues and needs; and identify concepts – technical, operational, and institutional – that can be deployed in the Corridor using an intensive stakeholder engagement effort.

The System Engineering Management Plan (SEMP) establishes the systems engineering activities used on the I-190 ICM Corridor Concept of Operations Study project. The SEMP describes the framework for management and control of the systems engineering components during the ConOps development of the ICM corridor. The SEMP is a living document and continues to evolve as the project progresses beyond the ConOps into requirements, system design, and implementation.

1.0 Introduction

The following report is the Systems Engineering Management Plan (SEMP) which is a required to support Niagara Frontier Transportation Authority (NFTA), the Greater Buffalo-Niagara Regional Transportation Council (GBNRTC), and the Niagara International Transportation Technology Coalition (NITTEC) in advancing the Integrated Corridor Management (ICM) concepts towards development in the Buffalo-Niagara region.

The SEMP is the top-level plan for managing the systems engineering effort to produce a final operational system from initial requirements. This document follows guidelines established by the Federal Highway Administration (FHWA)[1]. These guidelines define a checklist of Critical Information that should be included in SEMP reports:

- **Are all the technical challenges of the project addressed by the systems engineering processes described in the SEMP?** This document addresses all technical challenges currently identified. As the project's Concept of Operations (ConOps) continues to develop, further technologies can be considered and included in the project, which will then be included in updated versions of this report.
- **Does the SEMP describe the processes needed for requirements analysis?** The SEMP process is clearly defined for this process in Chapter 3 – System Engineering Process. Analysis, Modeling, and Simulation (AMS) efforts are being undertaken to identify which alternatives best address the gaps and needs identified. This activity corresponds to the Concept Selection and Project Planning phases identified in the "vee" diagram and provide key components of the Concept of Operations document.
- **Does the SEMP describe the design processes and the design analysis steps required for an optimum design**? The design analyses considered for this project are clearly defined in Section 3.2 – System Requirement Analysis. The modeling and analysis activities and Concept of Operations document will provide the specific locations and technologies to be deployed, which will allow the both system and detailed requirements to be finalized and the design process to begin.
- **Does the SEMP clearly identify any necessary supporting technical plans, such as a Verification Plan or an Integration Plan? Does it define when and how they will be written?** This document identifies the stage of the project and clearly identifies the project's current needs. Once the project's ConOps, requirements, and design are developed, this document will be updated to include future technical plans, including Verification and Integration.

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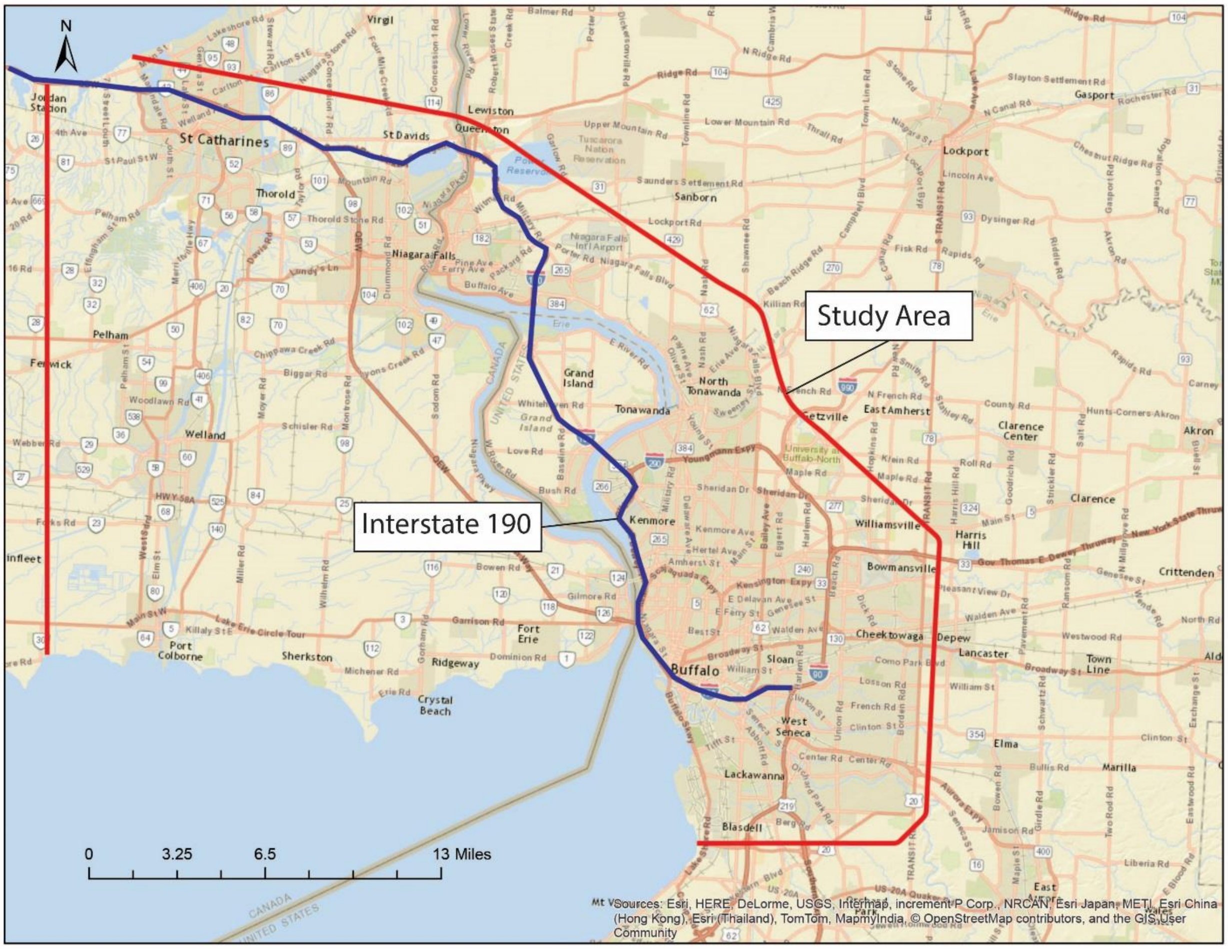
[1] ttp://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_2.cfm

- **Does the SEMP spell out stakeholder involvement when it is necessary?** This document describes all the stakeholders involved and their involvement in the project.
- **Does the SEMP identify all the required technical staff and development teams? Does it identify the technical roles to be performed by the system's owner, project staff, stakeholders, and the development teams?** Technical teams are identified and technical roles are described. Teams may be modified for later stages of the project.
- **Does the SEMP cover the interfaces between the various development teams?** The teams involved roles and responsibilities are described. As the project ConOps continues to develop, the SEMP will be updated accordingly.

The overall purpose of ICM is to achieve the combined stakeholder vision of efficient transportation operations within the corridor. The ICM is intended to improve integration of operational procedures between operating agencies and facilities, emergency response, and dissemination of traveler information.

The Niagara Frontier is the border region that encompasses the Niagara River border crossings and is a strategic international gateway for the flow of trade and tourism between the United States and Canada. The Niagara River, flowing from Lake Erie to Lake Ontario, forms the border between the United States and Canada. On the Canadian side, the Niagara Region covers approximately two-thirds of the Niagara Peninsula and consists of twelve local municipalities. On the United States side, the Buffalo-Niagara Frontier region forms the western border of New York State with the province of Ontario. The City of Buffalo, the second largest city in New York State, is located at the easternmost end of Lake Erie, overlooking the Niagara River. The City of Niagara Falls, New York, is located 20 miles northwest of Buffalo in Niagara County opposite Niagara Falls, Ontario. Figure 1.1 shows a map of the region and the cities involved.

Figure 1.1 Map of the Niagara Frontier Region



Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

1.1 PROJECT GOALS AND OBJECTIVES

The I-190 Integrated Corridor Management Project seeks to leverage the two ICM related grants from the Federal Highway Administration (FHWA) and the New York State Energy Research and Development Authority (NYSERDA) awarded to the region. This project will develop a decision support tool and perform the required Analysis, Modeling, and Simulation (AMS) assessments of the potential operational and environmental benefits of an ICM deployment in this area.

The System Engineering Management Plan (SEMP) establishes the systems engineering activities required for the I-190 ICM project. The SEMP describes the framework for management and control of the systems engineering components during the ConOps development of the I-190 ICM project. The SEMP is a living document and will continue to evolve as the project progresses beyond the ConOps into requirements, system design, and implementation.

1.2 INTENDED AUDIENCE

This SEMP is intended to provide the project partners, participants, and FHWA officers with detailed information on how the systems engineering process will be followed for the I-190 ICM project grant.

1.3 RELATIONSHIP TO THE PROJECT MANAGEMENT PLAN

The I-190 ICM project includes a Project Management Plan (PMP), which is being developed as a separate document. The PMP is the master planning document for the project that describes the activities in detail throughout the period of project development. The PMP includes sections on scope, schedule, cost, communications, risk, procurement, staffing, and quality control. This document, the SEMP, is the master planning document for the systems engineering technical elements during the ConOps. While it provides a high-level overview of the technical activities, it is intended to define the systems engineering process and methodologies in detail. Both the SEMP and PMP have been developed in concert for this project and are consistent with each other. As the project evolves, both planning documents will be updated periodically.

1.4 SEMP UPDATE PROCESS

The SEMP will be updated on a quarterly basis during the project lifecycle and at the end of the project. The project stakeholders will define the timing for the first update. Update version will be added to the project log at the beginning of this report.

2.0 Technical Planning and Control

The following sections present the corresponding technical planning activities considered for the I-190 ICM project. The PMP provides the master document on the technical planning and control activities and the following sections are replicated here to ensure stand-alone readability of the SEMP.

2.1 CRITICAL TECHNICAL OBJECTIVES

The ConOps describes in detail the technical and administrative framework so that stakeholders involved can ensure a corridor management program aligned to the following critical technical objectives:

- Improve center-to-center communications
- Improve accuracy of congestion (travel time) information reliability
- Enable intermodal choices through improved traveler information
- Improve integration of weather information/data for traveler information and for maintenance operations
- Improve integrated operations based on real-time data
- Maximize the free flow of traffic and reduce congestion
- Provide transit alternatives and park-and-ride facilities
- Enhance border crossing clearance
- Facilitate ITS and operational improvements that will facilitate ICM mobility
- Enhance alternative route management capabilities
- Establish incident classifications and severity guidelines
- Improve and coordinate incident management[2]

2.2 TECHNICAL TASK LIST

In order to reach this objective, the following tasks were considered for this study. Further detail for each task can be consulted in the PMP report:

- Project Management

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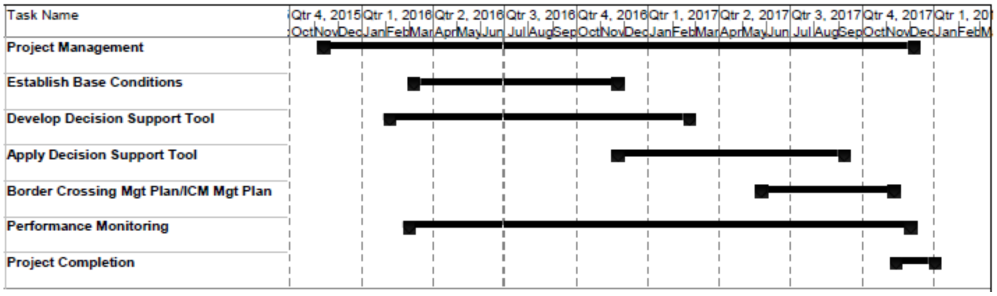
[2] Project objectives obtained from NITTEC Transportation Operations Integrated Corridor Management, System Operational Concept Final Report, September 2009.

- Establish Base Conditions
- Develop Decision Support Tool
- Apply Decision Support Tool
- Management and Implementation Plan
- Performance Reporting

2.3 WORK BREAKDOWN STRUCTURE

The work considered for this project follows the project structure as described in Figure 2.1. Further schedule details are included in the Project Management Plan.

Figure 2.1 Proposed High-Level Project Schedule



Source: Cambridge Systematics I-190 Project Management Plan

2.4 PROJECT DELIVERABLES

Table 2.1 shows a summary of all project deliverables considered for this project.

Table 2.1 Project Deliverables

Task	Subtask	Deliverable
1. Project Management	1.1 Subcontract for Data Collection	• Data Collection Subcontract Executed
	1.2 Meeting	• Preparation and Participation in Kickoff Meeting (in-person) • Preparation and Participation in Project Meetings (bi-weekly phone conference or web-meetings project leadership meetings, quarterly in-person or web-meetings for entire project team) • Preparation and Participation in Wrap-Up Meeting (in-person)
	1.3 ICM Project Plans and Progress Reports	• Draft and Final Project Management Plan (PMP) • Draft and Final Systems Engineering Management Plan (SEMP)

Task	Subtask	Deliverable
		• Updates as needed to the existing NITTEC ICM System Operational Concept Report and the NITTEC ICM Requirements Document Report • Project Schedule • Monthly Progress Reports and Invoicing
	1.4 Data Collection and Benefit Reporting	• Draft and Final Plan for Data Collection for Benefit Reporting and Report Template • Semi-Annual Performance Update Reports for the first year of the project
	1.5 Final Report	• Draft and Final Project Report • Draft and Final Executive Summary
2. Establish Base Conditions	2.1 Identify Base Conditions for Analysis	• Draft and Final Base Conditions Technical Memorandum
	2.2 Assemble and Review Available Resources	
	2.3 Assemble Available Data	
	2.4 Identify Data Gaps and Develop Data Collection Plan	
	2.5 Collect Data	
	2.6 Establish Base Conditions	
3. Develop Decision Support Tool	3.1 Select Modeling Methodology	• Draft and Final Decision Support Model Development and Base Conditions Calibration Technical Memorandum • Calibrated Base Conditions Model Files
	3.2 Select Performance Measures and Evaluation Criteria	
	3.3 Network Development	
	3.4 Demand for Base Conditions	
	3.5 Calibration / Validation to Base Conditions	
4. Apply Decision Support Tool	4.1 Identify Traffic Management Strategies	• Project Team Meeting/Workshop for Initial Strategy Discussion and Selection • Draft and Final Model Application Technical Memorandum
	4.2 Simulate Scenarios	
	4.3 Calculate Performance Measures	
	4.4 Evaluate Strategies	
5a. Develop Border Crossing Corridor Management Plan and	5.1 Workshops	• Project Team Meeting/Workshop for Initial Strategy Discussion and Selection
	5.2 Border Crossing Corridor Management Plan	

Task	Subtask	Deliverable
5b. I 190 ICM Implementation Plan	5.2 I-190 ICM Implementation Plan	• Draft and Final Border Crossing Corridor Management Plan • Draft and Final I-190 ICM Implementation Plan
6. Performance Monitoring		• Process and Template for producing Quarterly Progress Reports • Quarterly Progress Reports

Source: Cambridge Systematics I-190 Integrated Corridor Management Project Proposal

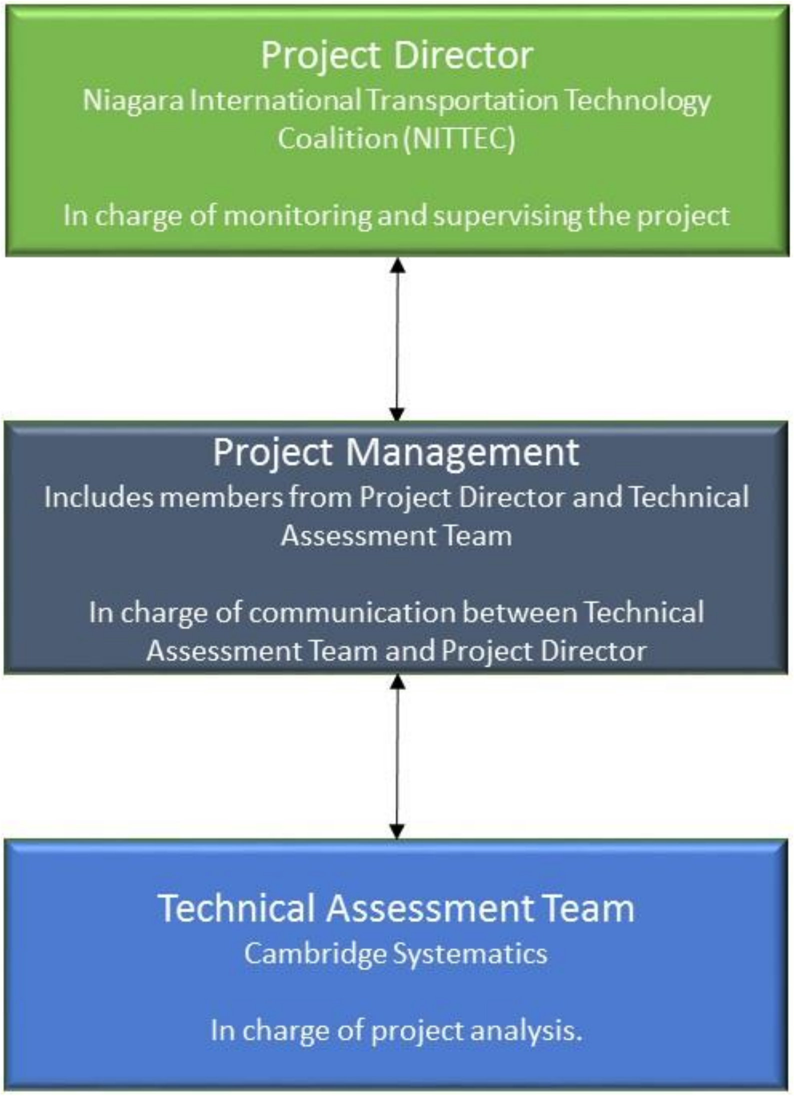
2.5 PROJECT MANAGEMENT PLANNING

The Technical Assessment team will work with the Project Management team to ensure that all system related activities are planned and coordinated with the Project Management activities of the project. This includes coordinating controls and processes, including change management, and risk management. The Systems Engineering Process activities map to the Project Management Plan.

2.6 PROJECT ORGANIZATION

Figure 2.2 shows the organization structure used for the I-190 ICM Project.

Figure 2.2 Project Organization



Source: I-190 Integrated Corridor Management Project Proposal

2.7 REVIEWS AND MEETINGS

In order to better track the performance of the border crossing and regional corridors and to assess the future changes and improvements in the corridor, a performance report template will be developed. Using this template, the Project Management and Technical Assessment team will prepare performance reports quarterly that summarize the performance of the corridor and region. The team will also coordinate with NFTA, NITTEC, and GBNRTC staff as needed to ensure the continuation the performance reporting after the conclusion of this effort to satisfy the needs of the NYSERDA funding grant.

2.8 APPLICABLE PLANS

This study is based on previous efforts made by NFTA, NITTEC, and GBNRTC to describe and structure the I-190 project. The following reports were used as a foundation for the current project:

- NITTEC Transportation Operations Integrated Corridor Management Requirements Document Final Report, February 2010
- NITTEC Transportation Operations Integrated Corridor Management System Operational Concept Final Report, September 2009
- NITTEC Transportation Operations Regional Concept for Transportation Operations Final Report, January 2010

3.0 System Engineering Process

This section describes the intended execution of the systems engineering processes (SEP) used to develop the system considered in this project. A robust SEP ensures that the ConOps and the ultimate design of the I-190 ICM Project is consistent with the vision of the corridor stakeholders and the resulting system of systems is developed in a fully integrated seamless, and multimodal manner.

3.1 SYSTEM ENGINEERING PLANNING PROCESS

The International Council on Systems Engineering (INCOSE) Systems Engineering Handbook v.3.2.2 was used as a reference in the development of this SEMP. Key processes that will be used in this project are:

- Stakeholder needs and requirements
- Trade-off studies, gap analyses, or technology assessments
- Technical reviews
- Risk identification, assessment, and mitigation
- Creation of performance measure metrics

A "Vee" process model is used for this project lifecycle. The life cycle for a system generally consists of stages regulated by a set of management decisions, which confirm that the system is mature enough to leave one stage and enter another. Figure 3.1 (adapted from the FHWA California Division ITS guide) illustrates the "Vee" Process model and identifies the portion of the diagram and the phases addressed by this project.

Through the systems engineering planning, all technical elements of the project are considered and a comprehensive integrated plan is developed. To support planning throughout the project, proven practices from the Systems Engineering Body of Knowledge (SEBoK) are used to guide the I-190 ICM corridor team, as shown in Table 3.1.

Figure 3.1 Project "Vee" Diagram

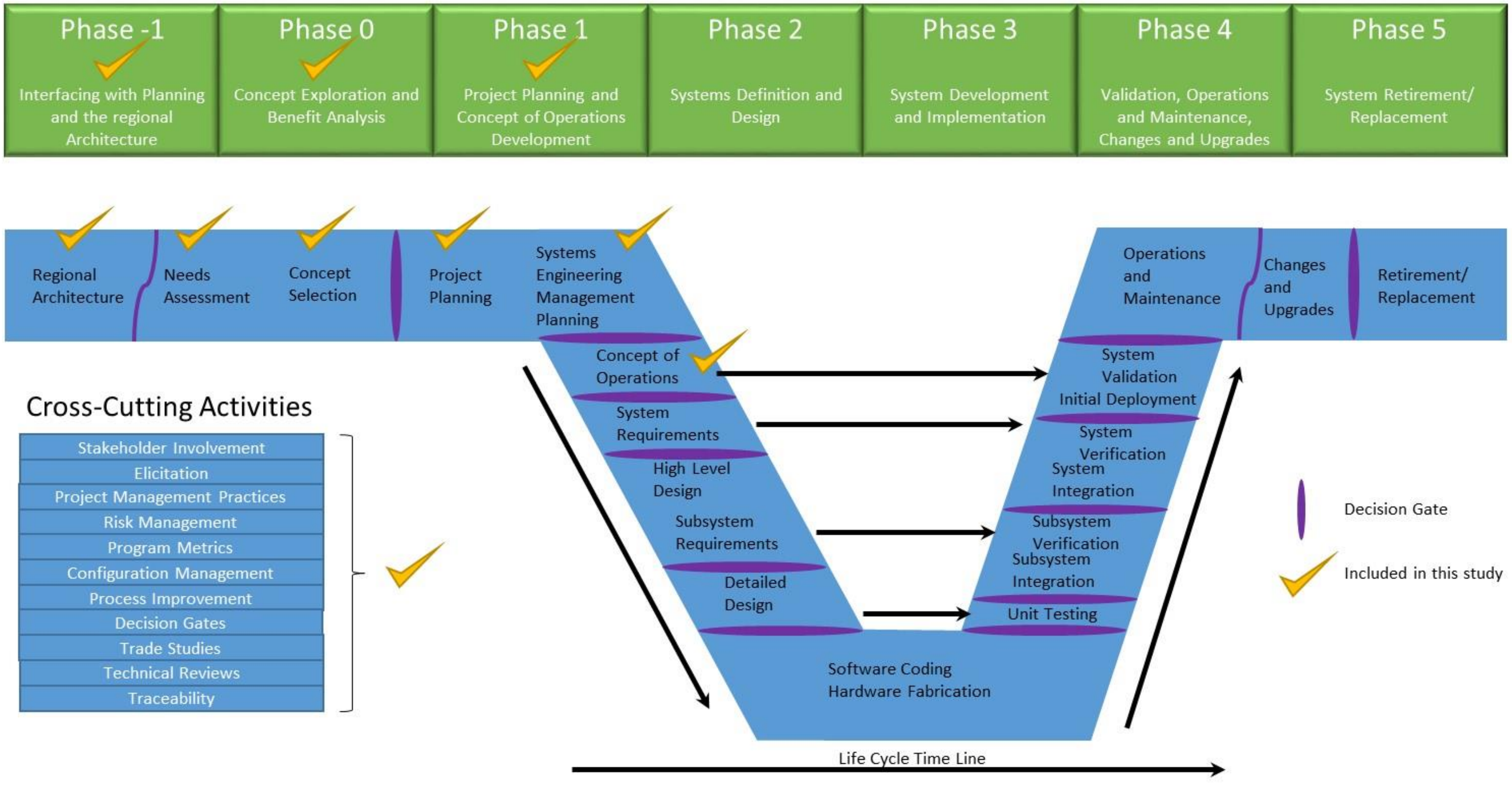


Table 3.1 Systems Engineering Planning Practices identified in SEBoK (First two columns replicated from SEBoK)

Name	Description	Adapted in I-190 ICM Project
Use Multiple Disciplines	Get technical resources from all disciplines involved in the planning process.	The staff involved is multi-disciplinary, and through workshops described in Task 5, different disciplines will be engaged.
Early Conflict Resolution	Resolve schedule and resource conflicts early.	Early identification or risks are included in the PMP document.
Task Independence	Tasks should be as independent as possible.	The project has identified and defined clear tasks and deliverables.
Define Interdependencies	Define task interdependencies, using dependency networks or other approaches.	Project team will ensure that any dependencies between tasks are captured in the project schedule.
Risk Management	Integrate risk management with the SE planning to identify areas that require special attention and/or trades.	The PMP Risk Management section identifies risks at an early stage.
Management Reserve	The amount of management reserve should be based on the risk associated with the plan.	Not applicable
Use Historical Data	Use historical data for estimates and adjust for differences in the project.	Both the ICM project concept, and the SEMP are a product of historical concepts and data.
Consider Lead Times	Identify lead times and ensure that you account for them in the planning (e.g., the development of analytical tools).	Stakeholders meetings, outreach, and supervision has been clearly stated in project proposal.
Update Plans	Prepare to update plans as additional information becomes available or changes are needed.	Both the PMP and SEMP are living documents and will be updated as the project concept is fully defined.
Use IPDTs	An integrated product development team (IPDT) is often useful to ensure adequate communication across the necessary disciplines, timely integration of all design considerations, as well as integration, testing, and consideration of the full range of risks that need to be addressed. Although there are some issues that need to be managed with them, IPDTs tend to break down the communication and knowledge stovepipes that often exist.	A ConOps with clearly defined scopes and services accompanies this study.

Source: Systems Engineering Body of Knowledge

3.2 SYSTEM REQUIREMENTS ANALYSIS

This section describes the methods used to prepare the ConOps and the top-level system requirements documents. Many robust analysis techniques will be applied for the development of this study. The primary approach will be through Analysis, Modeling and Simulation (AMS), but other common techniques will be employed, such as stakeholders' workshops, data collection, and performance measure analysis. This section also includes the process for approving the resulting documents, including who is involved, whether technical reviews are necessary, and how issues and comments are addressed.

Stakeholder Identification

The PMP defines the following stakeholders who will play vital roles in the study. Some of the project stakeholders are included in the project management and supervision; others will be involved in workshops and review. The PMP defines specific roles for each stakeholder identified:

- Niagara Frontier Transportation Authority (NFTA)
- Greater Buffalo-Niagara Regional Transportation Council (GBNRTC)
- Niagara International Transportation Technology Coalition (NITTEC)

Analysis Techniques

A multi-pronged approach is planned to gather needs and a system definition from a diverse set of stakeholders.

Analysis, Modeling and Simulation

The main objective of this technique is to develop a robust decision supporting tool, by performing the required Analysis, Modeling, and Simulation (AMS) assessments of the potential operational and environmental benefits that could be realized from an ICM deployment in the study area. With a robust analysis and assessment of the potential level of benefits, the groundwork will be laid to show which combination of ICM concepts will best improve the mobility and reliability of travel for the general public and freight through the Buffalo-Niagara region and provide the environmental and economic benefits related to reduced congestion.

Stakeholder Meetings and Data Collection

Due to the large number of stakeholders involved in this project, efficient and effective communication of progress will be critical to the success of the project's objectives. This task will include presentation materials for the Kick-Off, Wrap-Up, and regular Project Meetings with the Project Management team. Furthermore, a dataset of all existing data that is available from the region and relevant to the project will be developed. This will include available data sets about the region's roadway operations (including travel speeds or travel times, volumes, bottlenecks, and queues). Depending on the nature of gaps found in data collected, a data collection subconsultant will collect data to fill these gaps.

Stakeholders Workshops

Workshops will be conducted to engage stakeholders and obtain their input into the project. These workshops are envisioned to guide the definition of scenarios to be analyzed and evaluated by the decision support tool.

Performance Measures Analysis

In order to better track the performance of the border crossing and regional corridors and to assess the future changes and improvements in the corridor, a performance report template will be developed that can easily be populated from existing data collection sources used in this project. This template will be used to prepare performance reports quarterly that summarize the performance of the corridor and region. Furthermore, coordination activities will be ongoing between with NFTA, NITTEC, and GBNRTC staff as needed to ensure the continuation the performance reporting after the conclusion of this effort.

Review Approach

The review process consists of set meetings to review the project process. Progress meetings will be held via phone conference or web-meeting to keep all those in the Project Management team (including NFTA, GBNRTC and NITTEC staff) up to date on progress and to ensure that potential problems in the project are addressed quickly and efficiently to ensure the project plan stays on schedule and on budget. Additionally, quarterly meetings will be held with the entire project team either in-person and/or web-meeting as appropriate. Finally, at the conclusion of the technical deliverables and before the initiation of the performance reporting phase of the project, a Wrap-Up meeting will be held with the entire team to present the project findings, lessons learned, and the potential next steps in advancing the I-190 and cross-border ICM plans towards implementation.

3.3 SYSTEM ANALYSIS

This section describes the methods to be used for any required technical trade-off studies, cost/benefit decisions, and risk mitigation alternative analysis. At the ConOps stage, these trade-off studies and cost-benefit studies will be at the sketch planning level or subjectively assessed based on the expertise of the project working groups. As the project progresses and the preferred alternative emerges in detail, a more rigorous analysis, modeling, and simulation plan will be developed to conduct a rigorous analysis of the system.

3.4 REGIONAL SYSTEM ARCHITECTURE

The FHWA's Final Rule [23 CFR Part 940 part 11] places requirements on the minimum description of the systems engineering analysis for projects funded with highway trust funds. This section describes the following items as required by the Final Rule:

Identification of portions of the regional ITS architecture being implemented

The regional ITS architecture of interest are the following:

- New York State Regional ITS Architecture
- Buffalo-Niagara Bi-National Regional ITS Architecture
- Border Information Flow Architecture

The Buffalo-Niagara Bi-National Regional ITS Architecture is based on the generic National ITS Architecture used in the United States. The Architecture presents a roadmap for transportation systems integration for the metropolitan area of Buffalo, Niagara Falls, and the surrounding municipalities in New York as well as Region Niagara in Ontario, Canada over the next 15 years. The Buffalo-Niagara Bi-National Regional ITS Architecture has been developed through a cooperative effort by the region's transportation agencies, covering all surface transportation modes and all roads in the region.[3]

Because of the nature of the Integrated Corridor Management Program, which is multimodal and integrates a variety of traffic management and transit functions to provide improved monitoring, response and control capabilities, a significant portion of both regional ITS architectures will be impacted by the project.

The I-190 ICM corridor concept is envisioned as a “system of systems” that is in accordance to the vision of a regional integrated ITS program described in the architecture. Table 3.2 identifies the service packages directly pertinent to corridor-level traffic and transit operations through the ICM project. These packages will be part of the various transportation management strategies being explored as part of the ConOps. With the implementation of the ICM, the architecture interfaces between various ITS elements may change requiring an update to both the identified regional architectures.

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[3] http://www.consystec.com/buffalo/web/_regionhome.htm

Table 3.2 Core Service Packages from the regional architecture being considered as part of the ICM ConOps

Service Package	Service Package
AD1 – Data Mart	ATMS22 - Variable Speed Limits*
AD2 – Data Warehouse	ATMS23 - Dynamic Lane Management and Shoulder Use*
AD3 - ITS Virtual Data Warehouse	ATMS24 - Dynamic Roadway Warning*
APTS02 - Transit Fixed-Route Operations	ATMS26 - Mixed Use Warning Systems
APTS03 - Demand Response Transit Operations	CVO01 - Fleet Administration
APTS07 - Multi-modal Coordination	CVO02 - Freight Administration
APTS09 - Transit Signal Priority*	EM01 – Emergency Call-Taking and Dispatch
ATIS01 - Broadcast Traveler Information	EM02 – Emergency Routing
ATIS02 - Interactive Traveler Information	EM04 - Roadway Service Patrols
ATMS01 - Network Surveillance	EM05 - Transportation Infrastructure Protection
ATMS02 - Traffic Probe Surveillance	EM06 - Wide-Area Alert
ATMS03 - Traffic Signal Control	EM07 - Early Warning System
ATMS04 - Traffic Metering	EM08 - Disaster Response and Recovery
ATMS06 - Traffic Information Dissemination	EM09 - Evacuation and Re-entry Management
ATMS07 - Regional Traffic Management	MC03 - Road Weather Data Collection
ATMS08 - Traffic Incident Management System	MC04 - Weather Information Processing and Distribution
ATMS10 - Electronic Toll Collection	MC06 - Winter Maintenance
ATMS13 – Standard Railroad Grade Crossings	MC07 - Roadway Maintenance and Construction
ATMS15 – Railroad Operations Coordination	MC08 - Work Zone Management
ATMS16 - Parking Facility Management	MC09 - Work Zone Safety Monitoring
ATMS18 - Reversible Lane Management	MC10 - Maintenance and Construction Activity Coordination
ATMS21 - Roadway Closure Management	

Source: Buffalo-Niagara Bi-National Regional ITS Architecture, NITTEC Transportation Operations Integrated Corridor Management System Operational Concept Final Report, June 2009

*Note Not included in current Buffalo-Niagara Bi-National Regional ITS Architecture

Identification of participating agencies and their roles and responsibilities

The I-190 ICM Corridor stakeholders, identified in Table 3.3, will oversee and guide development of the ConOps. Roles and responsibilities as well as the project organization are described in the PMP. All the operations agencies identified in the table are identified in the sub-regional ITS architecture.

Table 3.3 I-190 ICM Participating Agencies

Policy Board Members	General Members	Affiliate Members
Erie County	Buffalo and Fort Erie Public Bridge Authority	Canada Border Services Agency
Ministry of Transportation Ontario	City of Buffalo	Federal Highway Administration*
New York State Department of Transportation	City of Niagara Falls (New York)*	Greater Buffalo Niagara Regional Transportation Council (GBNRTC)
New York State Thruway Authority	City of Niagara Falls (Ontario)*	John's Towing*
Niagara Frontier Transportation Authority	Niagara County*	New York State Department of Environmental Conservation
	Niagara Falls Bridge Commission	New York State Police
	Niagara Parks Commission	Ontario Provincial Police
	Niagara Region*	Rusiniak's Towing*
	Town of Fort Erie*	Town of Amherst*
		Town of Tonawanda*
		Town of Niagara on the Lake*
		University at Buffalo
		Rural Metro
		City of St. Catherine's
		Montgomery Services
		Twin City Ambulance
		United States Customs and Border Protection Agency

Source: NITTEC Regional Concept for Transportation Operations Final Report, January 2010

* Note: These agencies are not explicitly included in the Regional ITS Architecture, but they may be included in stakeholders groups.

Requirement Definitions

High-level stakeholder requirements are identified as part of the NITTEC Transportation Operations Requirements Document. Requirements are defined in three categories: Non-Functional Requirements (consisting of 20 requirements), Functional Requirements (consisting of 23 requirements), and Data Requirements (consisting of 23 requirements). Further information on each requirement can be seen in the aforementioned document.

Analysis of Alternate System Configurations

This activity will be undertaken as part of the development of the ConOps document for this project and details may be further refined during the design stage.

Procurement Options

This section will be developed in future phases of the I-190 ICM Corridor development since it relates to system procurement. The procurement and staffing needs will be outlined in general in the PMP report.

Identification of applicable ITS Standards and Testing Procedures

This section will be developed in future phases of the I-190 ICM Corridor development, once the system is completely defined and specific technologies identified.

Operations and Maintenance Procedures

This section will be developed in future phases of the I-190 ICM Corridor development, once the system is completely defined and specific technologies identified.

4.0 Transitioning Critical Technologies

As for the current state of the project, the main transition to a new technology is the implementation of Traffic Management System EcoTrafiX™. EcoTrafiX™ is a suite of equipment, software and services designed to manage traffic signals in a region with the objective to improve travel times, safety, and reduce emissions.

The objective of adapting EcoTrafiX™ as the Traffic Management System suite is to coordinate operational activities and events in the region, and serve as a potential platform for the Integrated Corridor Management initiative. This platform provides a user customizable platform, which allows users to geographically visualize all participating agencies' Intelligent Transportation Systems (ITS) equipment – including Closed Circuit Television (CCTV), Variable Message Signs (VMS), traffic sensors and detectors, and visualize dynamic system data in one central location.

Anticipated benefits include: Performance improvements for event management and response, including alarm and incident detection, and the status of action/response plans. Collaborative traffic management to increase the speed of event clearance, better traffic mitigation and recovery, and the potential to more easily make changes to construction plans that involve lane closures. Potential for energy and Greenhouse Gas emission reductions from increased mobility and promotion of public transportation services.

5.0 Integration of the System

High-level system integration is identified as part of the NITTEC Transportation Operations System Operational Concept, and will be specified in greater detail over the next phases of the ICM system design and development. This section will be revisited in the maintenance and the final update of the SEMP as the ConOps evolves.

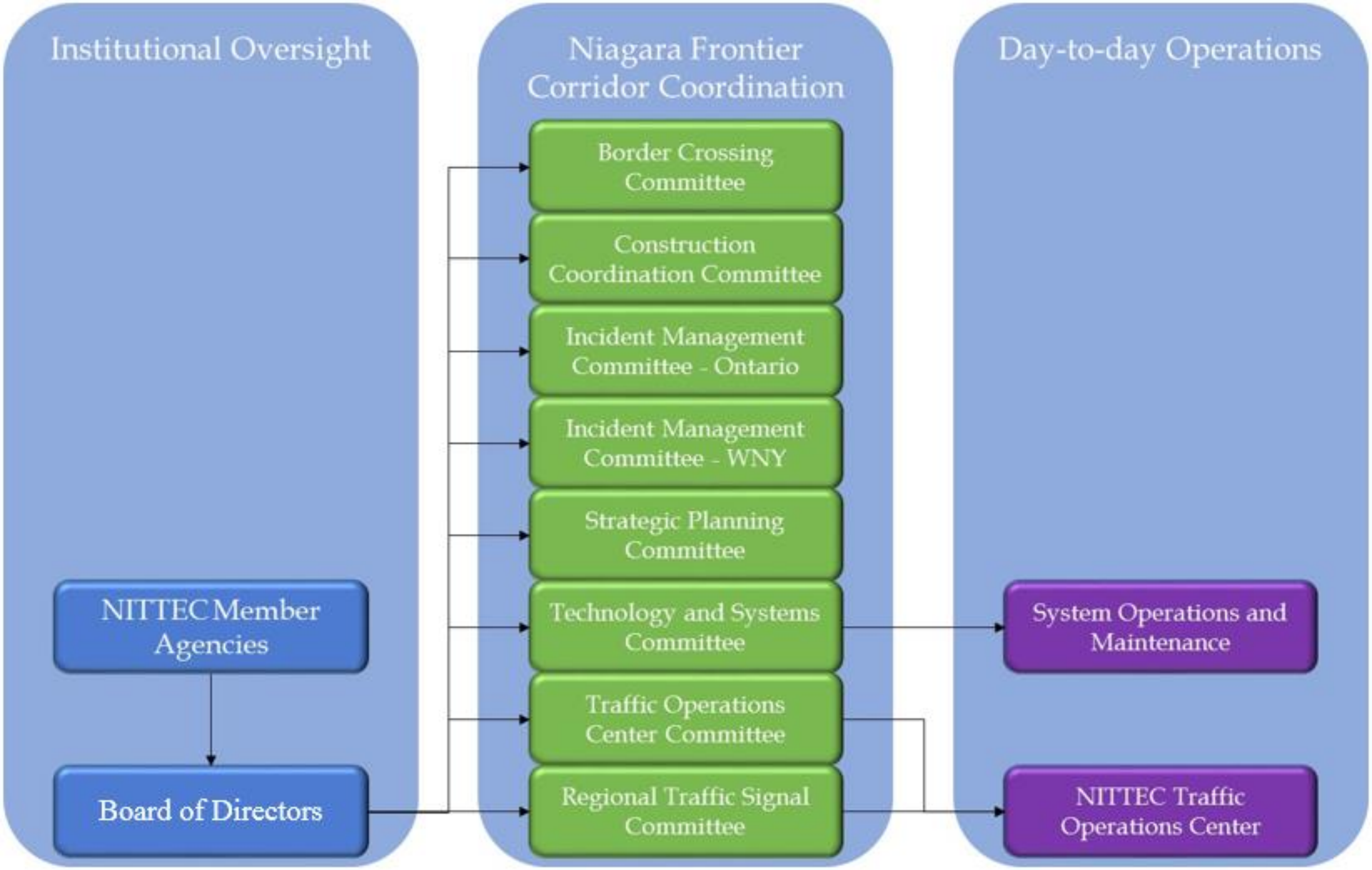
5.1 INSTITUTIONAL FRAMEWORK

The NITTEC Transportation Operations System Operational Concept identifies three key roles envisioned for the management of the ICM program:

- Institutional Oversight. This designation is responsible for the ICM concept leadership, overall management, commitment monitoring, and stakeholder relationships and will include NITTEC member agencies and the Board of Directors (BOD). The NITTEC member agencies and the BOD will be responsible for managing such things as the commitments of member agencies, providing direction and policy development for the corridor. The Technology & Systems Committee will continue to maintain and modify the Buffalo-Niagara Bi-National Regional ITS Architecture as necessary.
- Niagara Frontier Corridor Coordination. The institutional oversight of the BOD shall designate the corridor coordination to the respective NITTEC Committee. The designated Committee will manage the distribution of responsibilities, the sharing of control, and related functions among the corridor agencies. The body will also be responsible for recommending the necessary inter-agency and service agreements, budget development, project initiation and selection, corridor operations policies/procedures, and overall administration for the corridor.
- Day-to-Day Operations. This designation will include the NITTEC Traffic Operations Center as the central source for handling daily operations of the Niagara Frontier Corridor at the local level.

Figure 5.1 shows the Institutional Framework as described in the aforementioned document.

Figure 5.1 I-190 ICM Corridor Institutional Framework



Source: NITTEC Transportation Operations Integrated Corridor Management System Operational Concept Final Report, September 2009

6.0 Integration of the Systems Engineering Effort

This section addresses the integration of the multi-disciplinary organizations or teams that will be performing the systems engineering activities. Six primary activities serve to integrate the systems engineering effort.

6.1 SCOPE RESPONSIBILITY

Scope responsibility between the project's teams is provided in the Project Management Plan.

6.2 COMMUNICATION AND COLLABORATION

Communication and collaboration between stakeholders involved is key for the project success. To facilitate communication, progress meetings will be held via phone conference or web-meeting to keep all those in the Project Direction team (including NFTA, GBNRTC and NITTEC staff) up to date on progress and to ensure that potential problems in the project are addressed quickly and efficiently to ensure the project plan stays on schedule and on budget. Additionally, quarterly meetings will be held with the entire project team either in-person and/or web-meeting as appropriate.

6.3 CONFIGURATION MANAGEMENT

Configuration management ensures that project documentation accurately describes and controls the functional and physical characteristics of the end product being developed. Configuration Management deals with changes in product specifications rather than changes. For example changes to project scope, contract or project extent would be managed through the configuration management.

Configuration Management Planning and Identification of Configuration Items (CI)

The Technical Assessment team is responsible for planning and managing the configuration management required for this study. For this project, the following are identified as CIs for this phase of the study (further CIs can be identified as the project continues to develop):

1. Consultant Scope of Services

Configuration Control

Depending on the nature of the product change, the consultant PM will develop and submit a change request to the project leadership. After confirmation that this is a valid change request, the Project Manager will perform an analysis of the change identifying the impacts to other activities, schedules, and cost. Based on the analysis, the Project Manager will submit a change proposal to the Project Directors. The project leadership and the core working group will serve as a configuration control board and approve or reject the change.

6.4 CHANGE MANAGEMENT

Modification of the cost or schedule of the scope of services requires authorization by the Project Director (NITTEC) prior to performance of work related to any scope modifications. This authorization will be the only basis upon which budget modifications are made, change orders are issued, and applicable additional compensation may be claimed.

6.5 MASTER SCHEDULE AND COST TRACKING

The Technical Assessment Team will have responsibility for the master schedule and cost tracking throughout the project lifecycle. Schedule and cost tracking are reported to the Project Director and corrective actions, if necessary are undertaken as described in the PMP.

6.6 RISK MANAGEMENT

The risk management approach is described in the PMP.

7.0 Applicable Documents

This section lists the applicable documents that are inputs to the project.

- NITTEC Transportation Operations Integrated Corridor Management, Systems Operational Concept Final Report, September 2009.
- NITTEC Transportation Operations Regional Concept for Transportation Operations, Final Report, January 2010.
- NITTEC Transportation Operations Integrated Corridor Management, Requirements Document, February 2010
- FHWA, ICMS Concept of Operations for a Generic Corridor, April 2006, http://ntl.bts.gov/lib/jpodocs/repts_te/14281_files/14281.pdf
- FHWA, Integrated Corridor Management: Implementation Guide and Lessons Learned, February 2012, http://ntl.bts.gov/lib/47000/47600/47670/FHWA-JPO-12-075_FinalPKG_508.pdf
- USDOT, National ITS Architecture version 7.1, http://www.iteris.com/itsarch/index.htm
- Buffalo-Niagara Bi-National Regional ITS Architecture, November 2005, http://www.consystec.com/buffalo/web/_stakeholders.htm
- New York State Regional ITS Architecture, November 2009, http://www.consystec.com/newyork/web/index.htm
- System Engineering Management Plan Update, Federal Highway Administration (FHWA), http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_2.cfm

Appendix C. Concept of Operations and Requirements

Buffalo-Niagara Integrated Corridor Management

Proposed Changes to NITTEC's
ICM System Operations Concept Report

final
report

prepared for

Niagara International Transportation Technology Coalition &
Greater Buffalo-Niagara Regional Transportation Council

prepared by

Cambridge Systematics, Inc.

June 5, 2017

report

Buffalo-Niagara Integrated Corridor Management

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Greater Buffalo-Niagara Regional Transportation Council

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date

June 5, 2017

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1.0 Introduction

The I-190 Integrated Corridor Management (ICM) initiative can be traced back to 2007, when the Niagara International Transportation Technology Coalition (NITTEC) completed the Strategic Plan 2007. In this document, NITTEC described the long-term vision for the region's transportation future. One of the recommendations defined was the development of the concept of Transportation Operations for the Niagara region. In response to the Strategic Plan 2007, NITTEC initiated a Transportation Operations study. This study was divided in two parts:

- NITTEC Regional Concept for Transportation Operations (RCTO). This study describes a management tool, defining a path for a collaborative and sustainable operations and management strategy across different regional stakeholders.
- NITTEC Integrated Corridor Management (ICM). This study defines the region's initiative to promote operational coordination across multiple transportation networks and institutions, and to improve mobility and safety, among other transportation objectives for travelers and goods in the region.

As a result of this study, three different reports were developed in the 2009 to 2010 timeframe:

- NITTEC RCTO Final Report
- NITTEC ICM Requirements Document
- NITTEC ICM System Operational Concept

1.1 REPORT PURPOSE

This report provides a brief summary of the existing NITTEC ICM documents. It also identifies sections and topics to be considered important to be updated for the current I-190 Integrated Corridor Management AMS project

2.0 ICM Objectives

The overall objective of the current I-190 Integrated Corridor Management study is to develop a decision support tool and perform the required Analysis, Modeling, and Simulation (AMS) assessments of the potential operational and environmental benefits that could be realized from an ICM deployment in the region. This project is currently being supported by grants from the Federal Highway Administration (FHWA) and the New York State Energy Research and Development Authority (NYSERDA) grants.

To reach the aforementioned overall objective, this report aims to provide a brief description of the current institutional, operational, and management framework in the Niagara region, and the ICM initiative as initially conceived. This initial description will help identify sections, concepts, technologies, and measures that require changes to reflect the latest updates in the ICM concept and incorporate best-practices in cross-border activities.

Additional separate reports serving as the foundation for this project include the Project Management Plan (PMP) and the System Engineering Management Plan (SEMP).

3.0 Institutional Framework

An important characteristic of this region lies on the complexity of collaboration within multiple regional stakeholders involved. This section aims to provide a brief description of how current stakeholders are collaborating to provide transportation services. The institutional framework described is based on the NITTEC Regional Concept for Transportation Operations (RCTO). The purpose of this document is to describe the regional framework that allows transportation agencies in the area to work together, and determine future needs for the Buffalo-Niagara 2015 ICM study.

3.1 REGIONAL STAKEHOLDERS

The Niagara region is a particularly complex area for transportation activities due to the interaction of different entities and activities. One of the main characteristics of the region is that it encompasses the Niagara River border crossings, a strategic international gateway for trade and tourism flows between the United States and Canada. The Niagara River, flowing from Lake Erie to Lake Ontario, forms the frontier between both countries.

On the Canadian side, the Niagara region covers approximately two-thirds of the Niagara Peninsula, across twelve local municipalities, as shown in Table 3.1.

Table 3.1 Canadian Municipalities Included in the Niagara Region

Municipality	Population
Niagara Falls	82,997
Port Colborne	18,424
St. Catharines	131,400
Thorold	17,931
Welland	50,631
Fort Erie	29,960
Grimsby	25,325
Lincoln	22,487
Niagara-on-the-Lake	15,400
Pelham	16,598
Wainfleet	6,356
West Lincoln	13,837

Source: Statistics Canada Census Profile 2011

On the United States side, the Buffalo-Niagara Frontier region corresponds to the New York State border with Ontario. The region consists of three counties: Erie, Niagara, and Cattaraugus. The region can be further segregated in 64 local municipalities, and Native American lands. According to the United States Census Bureau, the Buffalo-Niagara Falls Metropolitan Area had a population of 1,135,509 in 2010. Table 3.2 shows the main U.S. Cities in the region, along with their population.

Table 3.2 United States Main Cities in the Buffalo-Niagara Frontier Region

City	Population
Buffalo	261,310
Lackawanna	18,141
Lockport	21,165
Tonawanda CDP	58,144
Niagara Falls	50,193
North Tonawanda	31,568
Olean	14,452
Tonawanda	15,130

Source: United States Census Bureau, 2010 Census Data.

The complexity of the transportation network in the region is not solely determined by the vast number of stakeholders involved, but by the interactions between transportation modes too, consisting primarily of 5 main transportation networks:

Border Crossings Network

The border crossings network in the region consists of 4 international border-crossing bridges across the Niagara River international border. All four bridges are tolled one-way in the Canada-bound direction.

Highway Network

The region contains an extensive highway network which includes Queen Elizabeth Way, Highway 405, Highway 420, among other important highways in Canada; and Interstate 190, Interstate 290, and Interstate 90, among other important State Routes in the United States.

Rail Network

The rail network in the region includes passenger and freight services, through a service provided by major rail carriers.

Bus Network

The existing bus network in the Niagara Frontier Corridor includes inter-urban transit and municipal transit service.

Air Transportation Network

The existing air transportation network within the corridor includes international and regional airports.

3.2 NIAGARA INTERNATIONAL TRANSPORTATION TECHNOLOGY COALITION

Niagara International Transportation Technology Coalition (NITTEC) is a road management system used in the Niagara Falls-Buffalo region, allowing transportation agencies to collaborate and manage the multi-modal transportation systems, making it possible to reach mobility, reliability and safety improvements in the region. NITTEC helps coordinate and facilitate communication between regional transportation agencies, in both Canada and the United States.

NITTEC Regional Concept for Transportation Operations

NITTEC was formed in 1995, with 14 members, each holding a Policy Board seat. In 2008, NITTEC set forth a new membership, committee, staff, and funding structure for the organization. Table 3.3 shows current NITTEC member agencies and related organizations.

Table 3.3 NITTEC Stakeholders

Member agencies	Other related organizations
Buffalo and Fort Erie Public Bridge Authority (PBA)	Canada Border Services Agency (CBSA)
City of Buffalo	Federal Highway Administration (FHWA)
City of Niagara Falls, New York	Greater Buffalo-Niagara Regional Transportation Council (GBNRTC)
City of Niagara Falls, Ontario	New York State Police (NYSP)
*Erie County	Ontario Provincial Police (OPP)
*Ministry of Transportation, Ontario (MTO)	United States Customs and Border Protection (USCBP)
*New York State Department of Transportation (NYSDOT)	State University of New York at Buffalo
*New York State Thruway Authority (NYSTA)	Other local and regional police and emergency services agencies
Niagara County	Recovery companies
Niagara Falls Bridge Commission (NFBC)	
*Niagara Frontier Transportation Authority (NFTA)	
Niagara Parks Commission	
Niagara Region	
Town of Fort Erie	

* Agencies included in the Policy Board

Source: NITTEC Transportation Operations – Integrated Corridor Management Requirement Document

Table 3.3 shows all member agencies of NITTEC, identifying the five current members of the Policy Board. The importance of the Policy Board members is that each has one vote on the Board of Directors (BOD). The rest of the member agencies are required to participate in the different Committees, and may attend BOD meetings as non-voting participants. Other related organizations may participate in Committees and BOD meetings as non-voting participants.

NITTEC's governing structure consists of the BOD and eight committees. The BOD provides overall program and policy direction to NITTEC. It also establishes operating procedures and oversees NITTEC's annual budget. It accepts new members to the Policy, General, and Affiliate Member classes.

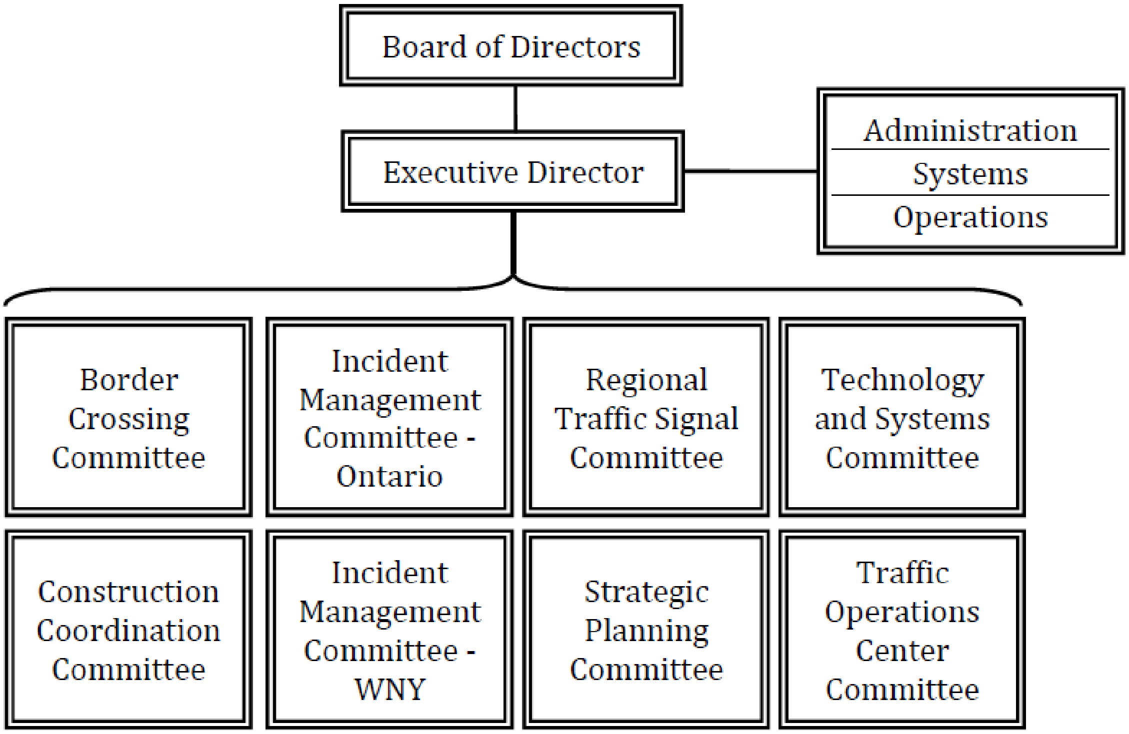
The BOD facilitates the coordination of capital and operational issues among the NITTEC Members. It provides oversight and approval responsibilities for the activities of the NITTEC Executive Director. The BOD provides oversight and approval responsibilities for the activities of all Committees.

There are eight Committees currently operating in NITTEC. Each Committee prepares and submits individual Committee accomplishments and work plans. The eight committees include:

- Border Crossing Committee,
- Construction Coordination Committee,
- Ontario Incident Management Committee,
- Strategic Planning Committee,
- Traffic Operations Center Committee,
- Technology and Systems Committee,
- Western New York Incident Management Committee.
- Regional Traffic Signal Committee

Figure 3.1 shows the organizational structure of NITTEC.

Figure 3.1 NITTEC Organizational Chart



Source: NITTEC Regional Concept for Transportation Operations

For funding, the NITTEC Executive Director prepares an annual budget for the fiscal year. The BOD reviews the proposed budget, and once approved, NYSDOT incorporates the budget into its presentation to the Greater Buffalo-Niagara Regional Transportation Council on behalf of NITTEC for inclusion in the region's Transportation Improvement Program (TIP).

A detailed description of NITTEC Transportation Operations functionality and activities can be reviewed in the NITTEC Regional Concept for Transportation Operations Report. This report shows operational goals and performance measures set for short and long-term horizons, as well as policies and procedures for day-to-day activities.

4.0 Integrated Corridor Management

An important product from the NITTEC Transportation Operations study, besides the aforementioned ***Regional Concept for Transportation Operations Report***, was the development of the Integrated Corridor Management (ICM) regional initiative. This initiative is described in detail in the ***ICM Requirements Document***, and the ***ICM System Operational Concept Report***. The objective of this section is to describe the ICMS initiative as it was initially conceived, identifying strengths and areas where concepts need to be updated to ensure a successful state-of-the-art ICM deployment strategy.

Generally, an ICM initiative consists of "the operational coordination of multiple transportation networks and cross-network connections comprising a corridor, and the coordination of institutions responsible for corridor mobility. The goal of ICM is to improve mobility, safety, and other transportation objectives for travelers and goods."[1] Based on this general vision, NITTEC developed specific goals and objectives for the Niagara Frontier ICM initiative

4.1 GOALS AND OBJECTIVES

The overall purpose of the ICM is to achieve the combined stakeholder vision of efficient transportation operations within the corridor. The ICM is intended to provide improved integration of operational procedures, facilitate improved emergency response, and dissemination of traveler information.

Based on this general purpose, Table 4.1 shows the specific goals set for each category of action.

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[1] From FHWA, FTA, Integrated Corridor Management – Concept Development and Foundational Research, Task 2.3 –ICMS Concept of Operations for a Generic Corridor (2006).

Table 4.1 ICM Goals and Objectives

Category	Objective	Short Term Goal	Long Term Goal	Performance Measure
I. Agency Coordination	Improve center-to-center communications	1. Center-to-center (C2C) communications is functioning among all transportation related agencies in the corridor	1. Center-to-center (C2C) communications is functioning among all transportation related agencies in the corridor	1. Evaluate the use of established center-to-center communication links a. Number of agencies b. Monthly activity c. Monthly down time
II. Traveler Information	A. Improve accuracy of congestion (travel time) information reliability	1. Reduce the variation in travel times experienced by travelers throughout the corridor by 25 percent 2. Posted travel times are within 20 percent of measured travel times 3. Travel time information sources have an up-time of 99 percent 4. System element down time averages less than 12 hours per element failure 5. System (as a whole) down time averages less than four hours per system failure	1. Reduce the variation in travel times experienced by travelers throughout the corridor by 35 percent 2. Posted travel times are within 10 percent of measured travel times 3. Travel time information sources have an up-time of 99.9 percent 4. System element down time averages less than 10 hours per element failure 5. System (as a whole) down time averages less than four hours per system failure	1. Monthly variation for selected times and links 2. Compare posted travel times with measured travel times for selected time periods and links 3. Monthly up-time 4. Monthly down time per element 5. Monthly system down time
	B. Enable intermodal choices through improved traveler information	1. Transit information has been integrated into the highway information network 2. Traveler information usage has increased by 150 percent 3. An 85 percent customer traveler information satisfaction rating has been achieved among local commuters and border crossing commuters receiving information 4. Travelers are provided with various modal and route options to effectively travel throughout the corridor that enable them to make choices regarding: Departure time, Mode and route	1. Transit information has been integrated into the highway information network 2. Traveler information usage has increased by 200 percent 3. An 90 percent customer traveler information satisfaction rating has been achieved among local commuters and border crossing commuters receiving information 4. Travelers are provided with various modal and route options and are also provided with the current conditions facing each option	1. Traveler information is integrated 2. Evaluate the use of traveler information monthly a. Traveler surveys are conducted b. Web site hits c. 511 telephone service calls 3. Yearly traveler surveys 4a. Static traveler information is in place 4b. Dynamic traveler information is in place

Table 4.1 ICM Goals and Objectives (con't)

Category	Objective	Short Term Goal	Long Term Goal	Performance Measure
II. Traveler Information (con't)	C. Improve integration of weather information/data for traveler information, and for maintenance operations	1. Weather information/data sources is integrated into all traveler information services 2. Relationship with weather information/data sources has increased by 5 percent 3. Weather information/data is integrated into all maintenance call-out procedures and systems for managing operations	1. Weather information/data sources is integrated into all traveler information services 2. Relationships with weather information/data sources has increased by 10 percent 3. Weather information/data is integrated into all maintenance call-out procedures and systems for managing operations 4. Integration of the RWIS between the region and the province is functioning 5. RWIS is integrated into all traveler information services	1. Successful integration has been accomplished 2. Number of relationships with weather information/data sources 3. Successful integration has been accomplished 4. Successful integration has been accomplished 5. Successful integration has been accomplished
	D. Improve integrated operations based on real-time data	1. Use of real-time data has been determined 2. The system has an up-time of 99 percent 3. New technology is integrated at least every four years	1. Real-time data is used to improve operations 2. The system has an up-time of 99 percent 3. New technology is integrated at least every four years	1. Use of real-time data has been determined and is in use 2. Monthly up-time 3. Frequency of system element updates
III. Mobility (Arterial, Border, Freeway, Transit)	A. Maximize the free flow of traffic and reduce congestion	1. 50 percent of the identified arterials within the ICM corridor are coordinated across jurisdictions. 2. A central source directly or indirectly manages and operates 50 percent of the corridors in the ICM 3. Key signals in the corridor are retimed every three years	1. All identified arterials within the ICM corridor are coordinated across jurisdictions 2. A central source directly or indirectly manages and operates all corridors in the ICM 3. Key signals in the corridor are retimed every three years	1. The percentage of coordinated corridors 2. Percentage of the ICM corridors operated by a central source 3. Number of key signals retimed every three years
	B. Provide transit alternative and park-and-ride facilities	1. Transit ridership has increased 1 ½ times the percent of traffic volume increase 2. The number of park-and-ride facilities has increased by 10 percent	1. Transit ridership has increased 2 times the percent of traffic volume increase 2. The number of park-and-ride facilities has increased by 20 percent	1. Percentage of ridership increase 2. Number of park-and-ride facilities

Table 4.1 ICM Goals and Objectives (con't)

Category	Objective	Short Term Goal	Long Term Goal	Performance Measure
III. Mobility (con't)	C. Enhance border crossing clearance	1. Total border delay time has decreased by 5 percent from existing demand levels	1. Total border delay time has decreased by 15 percent from existing demand levels	1. Monthly total border delay time during selected times and periods
	D. Facilitate ITS and operational improvements that will facilitate ICM mobility	1. The VMS, Travel Time readers and CCTV have been deployed in accordance with the ICM	1. The VMS, Travel Time readers and CCTV deployed is maintained 2. The HAR system fully covers the ICM corridor	1. Number of VMS, Travel Time readers and CCTV deployed per year 2. HAR system coverage in the ICM corridor
	E. Enhance alternative route management capabilities	1. Develop one arterial signal system and integrate with related freeway management systems 2. Operate signals and freeways in one corridor as a system 3. Provide additional instrumentation on three primary arterials 4. Provide additional instrumentation on one parallel arterials that may be designated as diversion routes	1. Develop three arterial signal systems and integrate with related freeway management systems 2. Operate signals and freeways in three corridors as systems 3. Provide additional instrumentation on five primary arterials 4. Provide additional instrumentation on three parallel arterials that may be designated as diversion routes	1. Number of integrated systems 2. Number of corridors operating as a system 3. Number of arterials instrumented 4. Number of parallel arterials instrumented
IV. Incident Management	A. Establish incident classifications and severity guidelines	1. Develop agreed upon definitions for minor, intermediate, and major incidents 2. Define incident severity guidelines based on: Incident Severity, Field Conditions, Resources needed, and Estimated incident duration	1. Utilize agreed upon definitions for minor, intermediate, and major incidents 2. Utilize incident severity guidelines	1a. Incident definitions agreed upon 1b. Incident definitions universally used 2. Incident severity guidelines are defined

Table 4.1 ICM Goals and Objectives (con't)

Category	Objective	Short Term Goal	Long Term Goal	Performance Measure
IV. Incident Management (con't)	B. Improve and coordinate incident management	1. Meetings are held among transportation agencies monthly 2. Average incident detection to arrival time is less than 8 minutes 3. Average incident detection to lane clearance time is reduced by 20 percent 4. Average time from detection to back to normal conditions is reduced by 15 percent 5. All incident measures are uniform for all jurisdictions 6. Responder training exists, which provides guidance on relaying accurate information on what equipment is needed for various incidents 7. An integrated corridor approach is established for: a. Incident management b. Special or planned events c. Emergencies within the corridor	1. Meetings are held among transportation agencies every month 2. Average incident detection to arrival time is less than 6 minutes 3. Average incident detection to lane clearance time is reduced by 30 percent 4. Average time from detection to back to normal conditions is reduced by 20 percent 5. All incident measures are uniform for all jurisdictions 6. Responder training exists, which provides guidance on relaying accurate information on what equipment is needed for various types of incidents 7. An integrated corridor approach is provided during: a. Incident management b. Special or planned events c. Emergencies within the corridor	1. The number of meetings held per year 2. Monthly average incident detection to arrival time 3. Monthly percentage reduction of average incident detection to lane clearance time 4. Monthly percentage reduction of average time from detection to back to normal conditions 5. Incident measures are uniform 6. The number of training and exercise sessions held yearly 7. An integrated corridor approach is functioning for: a. Incident management b. Special or planned events c. Emergencies within the corridor

Source: NITTEC Transportation Operations Integrated Corridor Management Requirements Document, January 2010

Recommendations

Table 4.1 shows a clearly defined set of goals and objectives for the ICM initiative. The short and long-term goals have been set based on the performance measures identified. In reviewing the existing goals and objectives with respect to the current I-190 ICM AMS effort, it is generally agreed that they are still valid.

However, as part of the current I-190 ICM AMS effort, there may be value in synthesizing the set goals across the different categories. Additionally, some categories have a large number of performance measures, increasing the complexity of the future evaluation procedures. It may be determined advisable that goals are further simplified for an easier implementation and evaluation strategy.

4.2 SYSTEM COMPONENTS

This section provides a brief summary of existing and planned systems that the ICM initiative considers for its operations. Table 4.2 provides the details of the stated existing and planned system devices, according to the Requirements Document.

Table 4.2 Existing and Planned System Devices

System Device	Owning Agency	Existing or Planned
Bridge Border Crossing Systems	CBSA/USCBP	Existing
Canadian Border Inspection Sensor Systems	CBSA	Planned
Canadian Border Inspection Systems	CBSA	Existing
City of Buffalo Coordinated Traffic Signal System	City of Buffalo	Planned
City of Buffalo Parking Management System	City of Buffalo	Existing
EcoTrafiX	NITTEC	Planned
Managed Reversible Lane System	PBA	Existing
MPO Data Collection and Reporting System	GBNRTC	Existing
Local Traffic Signal Control Systems	Local DPW	Planned
MTO Asset Management System	MTO	Planned
MTO TRIP (Traveler Road Information Project)	MTO	Existing
MTO TRIS (Traveler Roadway Information System)	MTO	Existing
COMPASS System	MTO	Existing
MTO Road Weather Information System (RWIS)	MTO/Niagara Region	Existing
Queue End Warning System	MTO	Existing
Managed Reversible Lane System	NFBC	Existing

System Device	Owning Agency	Existing or Planned
NITTEC TOC Archive Management System Communications Log	NITTEC	Existing
TRANSMIT (TRANSCOM's System for Managing Incidents & Traffic)	NITTEC	Existing
CROSSROADS (NITTEC's Advanced Traffic Management System)	NITTEC	Existing
NYSDOT Asset Management System	NYSDOT	Existing
NYSDOT Conditions Acquisition Reporting System (CARS)	NYSDOT	Existing
NYSDOT Public Information Office System	NYSDOT	Planned
NYSDOT Road Weather Information System	NYSDOT	Planned
NYSDOT Traffic Signal Inventory System and Maintenance System	NYSDOT	Existing
NYSDOT 511 System	NYSDOT	Existing
Queue End Warning System	NYSDOT	Planned
NYSTA Lane Closure Reporting System	NYSTA	Existing
NYSTA Maintenance Management System (MMS)	NYSTA	Existing
NYSTA Statewide Operations Center Archive Management System	NYSTA	Existing
NR Asset Management System	Niagara Region	Planned
ITS Field Elements	NYSDOT/NFBC/ NYSTA/MTO/ PBA	Existing

Source: NITTEC Transportation Operations Integrated Corridor Management Requirements Document, January 2010

Recommendations

A review of Table 4.2 was undertaken to understand the current state of the system, and to identify possible new systems that may be considered under the current I-190 ICM initiative. The following transportation systems can be considered for the I-190 corridor, as smart corridors across the country continue to implement them to enhance traffic operations:

- **Ramp Metering System**. "Ramp meters are traffic signals installed on freeway on-ramps to control the frequency at which vehicles enter the flow of traffic on the mainline."[2] Ramp metering reduces overall freeway congestion by

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[2] US Department of Transportation, Federal Highway Administration, Office of Operations, http://www.ops.fhwa.dot.gov/publications/fhwahop14020/sec1.htm

managing the amount of traffic entering the mainline and by breaking up platoons that make it difficult to merge onto the freeway.

- **Travel Time Monitoring System.** This system allows the continuous real-time monitoring of speeds and travel time on corridors that are not currently monitored through the TRANSMIT program. There are different alternatives to monitor travel times, including Bluetooth monitoring devices and probe vehicle information from public sources, such as the National Performance Management Research Data Set (NPMRDS), or private vendors like Inrix, HERE, and TomTom.
- **Vehicle Video-detection System**. Smart corridors across the US are currently implementing traffic vehicle video-detectors, substituting loop detection technology in particular. This technology provides a cost-effective solution to maintenance and construction activity or permanent changes in lane or road configuration.

4.3 INSTITUTIONAL FRAMEWORK

This section summarizes the proposed institutional framework described in the NITTEC Systems Operational Concepts Report. Three key roles were envisioned in the Operational Concepts report to manage the ICM initiative:

- **"Institutional Oversight** – Responsible for the ICM concept leadership, overall management, commitment monitoring, and stakeholder relationships and will include NITTEC member agencies, Board of Directors).
- **Niagara Frontier Corridor Coordination** - The institutional oversight of the BOD shall designate the corridor coordination to the respective NITTEC Committee. The designated Committee will manage the distribution of responsibilities, the sharing of control, and related functions among the corridor agencies. The body will also be responsible for recommending the necessary inter-agency and service agreements, budget development, project initiation and selection, corridor operations policies/procedures, and overall administration for the corridor.
- **Day-to-Day Operations** - This designation will include the NITTEC Traffic Operations Center as the central source for handling daily operations of the Niagara Frontier Corridor at the local level."[3]

The integration of the ICM institutional framework can be observed in Figure 4.1.

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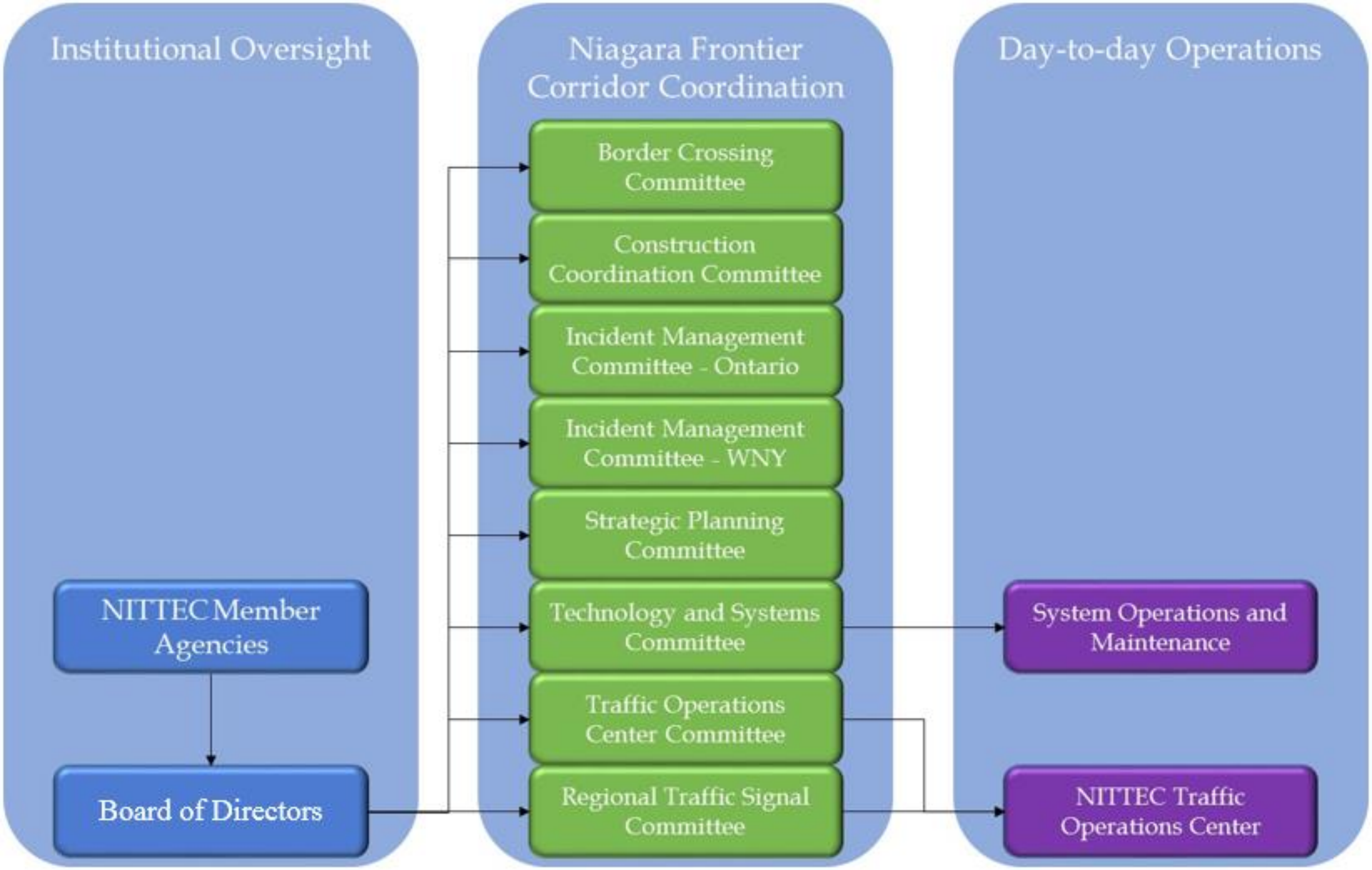
[3] The description of the institutional framework was obtained from the NITTEC Systems Operational Concepts Final Report.

Figure 4.1 Niagara Frontier ICM Institutional Framework



Source: Updated from NITTEC Transportation Operations Integrated Corridor Management System Operational Concept Final Report, September 2009

To further detail the operational concept of the ICM operations, the Operational Concept Report describes specific responsibilities for each agency/service involved. Table 4.3 shows a brief summary of these responsibilities; further detail can be seen in the Operational Concept Report.

Table 4.3 ICM Stakeholders' Responsibilities

Agency/Service	Responsibilities
NITTEC Traffic Operations Center	– Corridor coordinated operations – Corridor administration activities – Corridor performance monitoring – Corridor technical management and development – VMS – ITS device management (VMS, HAR, CCTV, etc.) – Enact/implement response plans
Bridge agencies • Buffalo and Fort Erie Public Bridge Authority • Niagara Falls Bridge Commission (NFBC)	– Daily corridor operations – Monitoring bridge traffic flow – Bridge surveillance – Enact response plans – Maintenance
Ministry of Transportation, Ontario (MTO)	– Daily corridor operations – Freeway management – Signal systems – ITS device management (VMS, CCTV, etc.) – Enact/implement response plans – Maintenance
New York State Department of Transportation (NYSDOT)	– Daily corridor operations – Freeway management – Signal systems – Maintenance
New York State Thruway Authority (NYSTA)	– Daily corridor operations – Freeway management – Maintenance
Niagara Frontier Transportation Authority (NFTA)	– Daily operations – Monitor bus on-time levels – Monitor train schedules – Monitor parking conditions – Enact response plans
Local municipalities within: • Erie County, New York • Niagara County, New York	– Daily Operations – Arterial surveillance – VMS on arterials

Agency/Service	Responsibilities
• Niagara Region, Ontario	– Enact response plans
Local municipalities that maintain traffic signals	– Daily Operations – Signal systems
Emergency agencies • Erie County Emergency Services • New York State Police (NYSP) • Niagara Falls Fire Department • Niagara Parks Police • Ontario Provincial Police (OPP) • NITTEC Incident Management Committee Members WNY & Ontario	– Emergency management – Coordination of law enforcement activities – Coordination of emergency services activities – Incident response management – Integration of Computer Aided Dispatch (CAD)

Source: NITTEC Integrated Corridor Management System Operational Concept Final Report

Recommendations

It is recommended through the current ICM AMS initiative that stakeholders involved review Table 4.3 and determine if stakeholders' responsibilities are still valid and appropriate, or if an update is required.

4.4 SYSTEM OPERATION

The NITTEC ICMS Operational Concept Report describe in detail not only the overall operational activities of the ICMS, but the day-to-day responsibilities for a successful operational strategy. This section presents an overall summary of this operational strategy. Further detail can be seen in the NITTEC ICMS Operational Concept Report.

The ICM operations can be summarized in the following strategies:

- Information Sharing/Distribution
  - Center-to-center (C2C) communications is functioning among agencies
  - Increase in traveler information services (web, 511, TV, radio)
  - Increase in traveler information usage
  - Reduce travel time variation
  - Integration of weather information into traveler information services
  - Integration of RWIS between the region and the province
  - Increase number of VMS, travel time readers, and CCTV deployed
  - Integrate transit information into the highway information network
- Improve the Operational Efficiency of Network Junctions and Interfaces

  - Facilitate ITS and operational improvements
  - Reduce system and system element down-time
  - Improve integrated operations based on real-time data
  - Integrate new technology
  - Develop uniform incident classifications and severity guidelines
  - Decrease detection, arrival, clearance and recovery times
  - Hold coordination meetings among agencies
  - Implement uniform incident measures
  - Conduct responder training
  - Utilize ICM approach for events
- Accommodate/Promote Cross-Network Route and Modal Shifts
  - Enable intermodal choices through improved traveler information
  - Provide travelers with various modal and route options
  - Increase transit reliability
  - Increase transit ridership
  - Increase the number of park-and ride facilities
- Manage Capacity/Demand Relationships within the Corridor on a "Realtime"/Short-term basis
  - Increase transit capacity
  - Increase corridor traffic signal coordination
  - Retiming of key signals in the corridor
  - Provide additional instrumentation on primary arterials
- Manage Capacity/Demand Relationships within the Corridor on a "Realtime"/Long-term basis
  - Enhance alternative route management capabilities
  - Appointment of a central source to manage and operate corridors in the ICM
  - Decrease total border delay time
  - Operate signals and freeways as a system

To follow these strategies, changes and additions have been set across the different set of stakeholder. Table 4.4 shows the changes and additions considered.

Table 4.4 Changes and Additions Considered for ICM Implementation

Stakeholder	Changes and Additions
Bridge agencies • Buffalo and Fort Erie Public Bridge Authority • Niagara Falls Bridge Commission (NFBC)	• Deployment of additional cameras • Vehicle processing technology for travel time reporting • Border Wait Time System reported wait times and delays on the Peace Bridge, the Queenston-Lewiston Bridge, and future deployment on the Rainbow Bridge, as a single source for real time traveler information.
Ministry of Transportation, Ontario (MTO)	• Additional CCTV coverage on the QEW, Highway 406, Highway 420 • Additional VMS sign locations on the QEW and Highway 406, and upstream of key decision points, especially on arterial highways • Additional TRANSMIT readers on Highway 406 • HAR on QEW • Automated data exchange interface with city, regions, and transit agencies • Expanded information dissemination system (increased information and corridor-wide view) • Expanded information dissemination (increased field dissemination devices) • GPS on service patrol/incident response/construction/maintenance vehicles (including subsystem for tracking) • Additional two-way communications linkages to support videosharing and other incident-related data • Border specific static/dynamic travel time signs
New York State Department of Transportation (NYSDOT)	• Additional CCTV coverage on I-190 • Additional VMS sign locations on I-190, Route 400, and upstream of key decision points, especially on arterial highways • Additional TRANSMIT readers on I-190, I-290, I-90, I-990, and Route 5, 400, 219 • Additional HAR on I-290 • Automated data exchange interface with city, county, and transit agencies • Expanded information dissemination system (increased information and corridor-wide view) • Expanded information dissemination (increased field dissemination devices) • GPS on service patrol/incident response/construction/maintenance vehicles (including subsystem for tracking) • Additional two-way communications linkages to support videosharing and other incident-related data • Border specific static/dynamic travel time signs
New York State Thruway Authority (NYSTA)	• Additional CCTV coverage

Stakeholder	Changes and Additions
	• Additional VMS sign locations, especially upstream of key decision points • Additional TRANSMIT readers • Additional HAR • Border specific static/dynamic travel time signs
Niagara Frontier Transportation Authority (NFTA)	• Monitor and communicate parking space availability within park-and ride facilities • Transit signal priority system • VMS for parking information dissemination • Interface with ATIS for providing and extracting real-time information • Additional spaces at park & ride lots • On-board devices for signal transit priority, including connection to schedule adherence system
Local municipalities within: • Erie County, New York • Niagara County, New York • Niagara Region, Ontario	• Enhanced controller software and communications with adjacent freeway ramp meters • Additional arterial VMS and cameras • Arterial VMS interface to freeway messages
Local municipalities that maintain traffic signals	• Upgrade traffic controllers and communications • New coordination timing of traffic signals
Emergency Agencies	• Enhancements to Computer Aided Dispatch (CAD) software to identify "best" routes • Interface to CAD, including protection/security of sensitive information
Corridor-wide	• Expanded travel information system to include additional information (transit travel times, arterial travel times, parking information, etc.) • ITS standards for center-to-center communications • Communications linkages between transportation management and emergency service centers (connect to existing subsystems)

Source: NITTEC Integrated Corridor Management System Operational Concept Final Report

Recommendations

It is recommended that stakeholders involved review Table 4.4 to confirm that all ICM operations are covered. If new ICM operations are being considered (such as ramp metering coordination or travel time collection via Bluetooth, among other possible technologies), they need to be added to the changes and additions required, and these changes need to be reflected on the I-190 ICM Plan and regional ITS Architecture.

4.5 SYSTEM EVALUATION

A set of performance measures has been defined to measure the ICM initiative's success.

Table 4.5 shows a list of all performance measures, and their short and long-term targets.

Table 4.5 Performance Measures and Targets

Performance Measures	Target
Accuracy of Travel Times	Short Term: • 25 percent reduction in travel time variation • Posted travel times within 20 percent of measured travel time • 95 percent up-time of travel time sources Long Term: • 35 percent reduction in travel time variation • Posted travel times within 10 percent of measured travel time • 98 percent up-time of travel time sources
System (as a whole) Down-Time (per system failure)	Short Term: Less than 4 hours (average) Long Term: Less than 3 hours (average)
System Element Down-Time (per element failure)	Short Term: Less than 12 hours (average) Long Term: Less than 10 hours (average)
Traveler Information Usage	Short Term: 150 percent increase Long Term: 200 percent increase
Customer Satisfaction	Short Term: 85 percent Long Term: 90 percent
Weather Information/Data Sources	Short Term: 5 percent increase in relationships Long Term: 10 percent increase in relationships
Transit Ridership	Short Term: 1 ½ times the percent of traffic volume increase Long Term: 2 times the percent of traffic volume increase
Park-and-ride Facilities	Short Term: 10 percent increase Long Term: 20 percent increase
Arrival Time (Average incident detection to arrival time)	Short Term: Less than 8 minutes Long Term: Less than 6 minutes
Clearance Time (Average incident detection to lane clearance time)	Short Term: 20 percent reduction Long Term: 30 percent reduction
Back to Normal Conditions Time (Average time from detection to back to normal conditions)	Short Term: 15 percent reduction Long Term: 20 percent reduction

Table 4.5 Performance Measures and Targets (con't)

Performance Measures	Target
Total Border Delay Time	Short Term: 5 percent decrease from existing demand levels Long Term: 20 percent decrease from existing demand levels
Arterial Coordination (within the ICM corridor)	Short Term: 50 percent are coordinated across jurisdictions Long Term: 100 percent are coordinated across jurisdictions
Signal Systems	Short Term: • One arterial signal system developed and integrated (with related freeway management systems) • Signals and freeways in one system operating as a system • Key corridor signals retimed every three years Long Term: • Three arterial signal systems developed and integrated (with related freeway management systems) • Signals and freeways in three systems operating as systems
Additional Instrumentation	Short Term: • On three primary arterials • On one parallel arterial (may be designated as a diversion route) Long Term: • On five primary arterials • On three parallel arterials (may be designated as diversion routes)

Source: NITTEC Integrated Corridor Management System Operational Concept Final Report

Recommendations

As suggested previously, the performance measures shown in Table 4.5 may be revisited with stakeholders and potentially reduced through the current ICM AMS efforts. Currently, there is a set of 15 performance measures. The ICM initiative may benefit from reducing the number of performance measures, but at the same time making sure that all modes of transportation are evaluated. As the current AMS effort proceeds, lessons learned from other ICM initiatives across the country regarding performance measures will be brought to the stakeholders for discussion. As part of these stakeholder discussions, the following suggestions for reducing and combining performance measures will be discussed:

- **Traveler Information Usage**. Although it is desirable to measure the effectiveness of traveler information systems, the set goals of 150% increase in the short-term horizon, and a 200% increase in the long-term horizon, maybe to be high considering the changing technology paradigm of wide-spread smartphones and with it increased access to traveler information. In the long-term traveler information is becoming increasingly available through private sources, and this is likely to continue as these capabilities are increasingly available in vehicle telematics systems. This performance measure also requires on baseline usage, which might be complicated to obtain from privately owned information distribution means. Through the current ICM AMS efforts, these goals may be recommended to be reconsidered.

- **Back to Normal Conditions Time.** This performance measure seeks to describe the overall average time from detection to back-to-normal conditions. Back-to-normal conditions may need to be defined more clearly, as conditions on different times of day may show different "normal" conditions. Instead, the metric may be renamed 'Time to Return to Acceptable Operations' or 'Time to Return to Expected Operations' or even another term may be considered. While other influences will certainly influence this time, it is noted that this metric is directly influenced by the 'Arrival Time' and 'Clearance Time' metrics that are already evaluating the effectiveness of incident management improvements.
- **Arterial Coordination.** This performance measure targets the number of jurisdictions coordinated, and acts as a metric of interagency collaboration. An additional metric more purely related to the performance of the arterial and/or signal system may be warranted or desirable.

Appendix D. ICM Strategies Primer

Buffalo-Niagara Integrated Corridor Management

ICM Strategies Primer

draft

report

prepared for

Niagara International Transportation Technology Coalition &
Greater Buffalo Niagara Regional Transportation Council

prepared by

Cambridge Systematics, Inc.

August 31, 2017

www.camsys.com

report

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1.0 Introduction

1.1 WHAT IS ICM?

ICM stands for Integrated Corridor Management. ICM can be defined as a set of transportation management and operations strategies, enabled by Intelligent Transportation Systems (ITS), that seek to optimize the use of existing infrastructure in a selected corridor network, while reducing the negative externalities associated to congestion, and enhancing safety. The United States Department of Transportation (USDOT) defines the ICM vision as a set of traffic operation strategies that "enables departments of transportation (DOTs) to optimize use of available infrastructure by directing travelers to underutilized capacity in a transportation corridor. Strategies include motorists shifting their trip departure times, routes, or modal choices, or DOTs dynamically adjusting capacity by changing metering rates at entrance ramps or adjusting traffic signal timings to accommodate demand fluctuations."(1)

The expected functionality of an ICM system typically involves three distinct yet interrelated types of integration:

- **Institutional integration** relates to coordination and collaboration between various agencies and jurisdictions that transcends institutional boundaries
- **Operational integration** refers to multiagency and cross-network operational strategies to manage the total capacity and demand of the corridor.
- **Technical integration** refers to sharing and distribution of information, and system operations and control functions to support the immediate analysis and response to congestion.

Figure 1.1 Functionality of an ICM System

Source: FHWA

This report presents a summary of ICM strategies for the Buffalo-Niagara ICM project's consideration. The objective of this report is to define and describe different traffic management and operations' strategies that can be part of the Buffalo-Niagara ICM project, as well as describing potential use cases and benefits.

It is not recommended that all these strategies be carried forward into the Buffalo-Niagara ICM project. The intention of presenting this material is instead to allow stakeholders to become more familiar with ICM operations and associated management strategies and the range of potential benefits and to spur a discussion as to which strategies should carried forward into the Buffalo-Niagara ICM project.

1.2 THE ICM INITIATIVE

The concept of ICM can be traced back to 2006, when the USDOT partnered with eight potential pilot sites to develop, deploy, and evaluate congestion management strategies as part of site-specific ICM project concepts. The initial sites considered included:

- Dallas, TX
- Houston, TX
- Minneapolis, MN
- Montgomery County, MD
- Oakland, CA
- San Antonio, TX
- San Diego, CA
- Seattle, WA

Of these sites, only two were selected to deploy, operate, and maintain the proposed ICM System: Dallas, TX and San Diego, CA. The following sections provide an overview of each pilot, as well as lessons learned from those deployments.

ICM US-75 Dallas, TX

The US-75 corridor in Dallas, Texas, was one of the two sites selected by the USDOT as part of the first ICM Initiative. The US-75 corridor is a north-south radial corridor that serves commuter, commercial, and regional trips, and is the primary connector from downtown Dallas to cities to the north. The ICM project was led by Dallas Area Rapid Transit (DART) in collaboration with U.S. DOT; the cities of Dallas, Plano, Richardson, and University Park; the town of Highland Park; North Central Texas Council of Governments (NCTCOG); North Texas Tollway Authority (NTTA); and the Texas Department of Transportation (TxDOT).

The US-75 project had four main objectives: improve incident management, enable intermodal travel decisions, increase corridor throughput, and improve travel time reliability. To reach these objectives, seven technology investments were considered for deployment:

- A Decision Support System (DSS), that utilized incoming monitoring data to assess conditions, forecast conditions up to 30 minutes in the future, and then formulate recommended response plans (including selecting from pre-approved plans) for consideration by operations personnel;
- Enhancement of the SmartNET regional information exchange network, a commercial data integration and dissemination tool with a common graphical

user interface (GUI). SmartNET provided a conduit for input, fusion and shared, multi-agency access to a variety of transportation data;

- A 511 telephone and web-based traveler information system for the region;
- Development of new, event-specific traffic signal timing plans;
- Arterial street monitoring system, including additional travel time detectors via Bluetooth;
- Using non-ICM funds, various supporting transit improvements including mobile data terminals and automatic vehicle location system replacement; and
- Parking management systems for key park-&-ride lots (2).

ICM I-15 San Diego, CA

The ICM I-15 project was the second corridor selected by the U.S. DOT as part of the initial ICM Initiative. This project included the involvement of a variety of local and State's authorities, being led by the San Diego Association of Governments (SANDAG), along with U.S. DOT; the California Department of Transportation; Metropolitan Transit System (MTS); North County Transit District (NCTD); the cities of San Diego, Poway, and Escondido; San Diego County Service Authority for Freeway Emergencies (SD SAFE); County of San Diego Office of Emergency Services (OES); and California Highway Patrol (CHP), in addition to private sector support.

I-15 is a primary artery for the movement of commuters, goods, and services from inland northern San Diego County to downtown San Diego. Weekday traffic volumes ranges from 170,000 to 290,000 vehicles on the general purpose lanes. The project had five primary goals: improve accessibility to travel options and enhance level of mobility for corridor travelers, enhance the corridor safety record, provide informational tools to make smart travel choices, integrate institutional partners across the corridor, and manage the corridor's network in a collaborative and coordinated way during normal and incident conditions.

For these purposes, the following solutions were considered:

- A Decision Support System (DSS) that utilized incoming monitoring data to assess conditions, forecast conditions up to 30 minutes in the future, and then formulate recommended response plans;
- Enhancement of the Intermodal Transportation Management System (IMTMS) regional information exchange network;
- Adjustments to ramp meter timing to support diversions to or from the freeway;
- Lane use modifications, namely the four configurable, managed (variably priced high occupancy toll) lanes in the I-15 median;

- Upgrade selected traffic signal systems, including new traffic signal coordination timings and responsive traffic signal control on two arterial streets paralleling I-15; and
- Arterial street monitoring system, including additional traffic detectors. (3)

Benefits & Lessons Learned

As part of the pre-deployment evaluation analysis of the ICM demonstrations, the USDOT published estimated benefits for each of the demonstration corridors. Table 2.1 shows a summary of these benefits:

Table 1.1 Estimated Benefits of ICM Initiatives

Evaluation Measures	I-15 San Diego, CA	US-75 Dallas, TX
Annual Travel Time Savings (person-hours)	246,000	740,000
Improvement in Travel Time Reliability	10.6%	3%
Gallons of Fuel Saved Annually	323,000	981,000
Tons of Mobile Emissions Saved Annually	3,100	9,400
10-year Net Benefit	$104 million	$264 million
10-year Cost	$12 million	$14 million
Benefit-Cost Ratio	10:1	20:1

Note: The values of safety benefits were not included.

Source: US DOT, Intelligent Transportation System, Joint Program Office, ITS Benefits, Costs, and Lessons: 2017 Update Report, http://www.itsknowledgeresources.its.dot.gov/its/bcllupdate/FreewayICM/

In addition to these estimated benefits, the following set of initial lessons learned were identified:

- ICM provides the opportunity to proactively improve and maximize the performance of the transportation system by serving as an alternate to traditional major infrastructure investments which may be more expensive or constrained by environmental issues.
- Regular communication and meetings with partner agencies are a valuable resource and critical throughout the project lifecycle, as they foster understanding and perspective.
- Following the systems engineering "V" process can be challenging at first, but provides an essential technical platform for building a robust design.
- Proactive management of incidents and congestion helps to minimize negative impacts to network performance when faced with unexpected or unusual events.

- Performance measures and evaluation criteria should be considered very early in the planning process and kept as a priority throughout design and implementation.
- Agencies should keep post-deployment operations and maintenance (O&M) in mind when designing their systems and identify funding sources and regional agreements and policies for O&M in advance. (4)

1.3 BUFFALO-NIAGARA ICM PROJECT

The Niagara Frontier is the border region that encompasses the Niagara River border crossing, and it is a strategic international gateway for the flow of trade and tourism between the United States and Canada. The Niagara River, flowing from Lake Erie to Lake Ontario, forms the border between the United States and Canada. On the Canadian side, the Niagara Region covers approximately two-thirds of the Niagara Peninsula and consists of twelve local municipalities. On the United States side, the Buffalo-Niagara Frontier region forms the western border of New York State with the province of Ontario. The City of Buffalo, the second largest city in New York State, is located at the easternmost end of Lake Erie, overlooking the Niagara River. The City of Niagara Falls, New York, is located 20 miles northwest of Buffalo in Niagara County opposite Niagara Falls, Ontario.

The Buffalo-Niagara ICM project is intended to provide a better integration of operational procedures, enhanced emergency response procedures, and improved dissemination of traveler information along the I-190 Corridor and in the larger Border Crossing corridor within the Niagara Frontier. The Buffalo-Niagara ICM vision is to "improve mobility through integrated management of transportation assets – freeways, arterials, transit, managed lanes – in the Niagara Frontier Corridor."(5) Based on this vision, the following ICM strategic objectives were adopted, along with specific project strategies to reach them:

- Enhance Information Sharing and Distribution
  - Improve Center-to-center (C2C) communications is functioning among agencies.
  - Increase in traveler information services (web, 511, TV, radio)
  - Increase in traveler information usage
  - Reduce travel time variation
  - Integration of weather information into traveler information services
  - Integration of RWIS between the region and the province
  - Increase number of VMS, travel time readers, and CCTV deployed
  - Integrate transit information into the highway information network
- Improve the Operational Efficiency of Network Junctions and Interfaces Frontier Corridor

  - Facilitate ITS and operational improvements
  - Reduce system and system element down-time
  - Improve integrated operations based on real-time data
  - Integrate new technology
  - Develop uniform incident classifications and severity guidelines
  - Decrease detection, arrival, clearance and recovery times
  - Hold coordination meetings among agencies
  - Implement uniform incident measures
  - Conduct responder training
  - Utilize ICM approach for events
- Accommodate/Promote Cross-Network Route and Modal Shifts
  - Enable intermodal choices through improved traveler information
  - Provide travelers with various modal and route options
  - Increase transit reliability
  - Increase transit ridership
  - Increase the number of park-and ride facilities
- Manage Capacity/Demand Relationships within the Corridor on a "Realtime"/Short-term basis
  - Increase transit capacity
  - Increase corridor traffic signal coordination
  - Retiming of key signals in the corridor
  - Provide additional instrumentation on primary arterials
- Manage Capacity/Demand Relationships within the Corridor on a "Realtime"/Long-term basis
  - Enhance alternative route management capabilities
  - Appointment of a central source to manage and operate corridors in the ICM
  - Decrease total border delay time
  - Operate signals and freeways as a system

2.0 Potential ICM Strategies

This section presents a summary of possible strategies to consider for ICM projects. The nature of a corridor's congestion patterns are often site-specific, as congestion can be caused by a variety of different factors. Many ICM strategies have been identified to deal with these congestion patterns. For this report, ICM strategies were identified for the following transportation areas:

- Freeway Management
- Arterial Management
- Traveler Information Systems
- Incident and Emergency Management
- Transit Management
- Commercial Vehicle Operations
- Bridge Operations
- Other Transportation Operations

A table identifying possible ICM strategies was prepared for each of these transportation areas. Each table presents a set of strategies, providing a brief description for each one, and identifying potential uses and benefits.

2.1 FREEWAY MANAGEMENT

This section presents different ICM strategies focused on improving mobility on freeways and highways, which are often the primary corridors targeted by ICM projects. Strategies in this section include potential ways to enhance capacity and manage demand for particular freeway corridor sections.

Table 2.1 Freeway Management ICM Strategies

Strategy	Description	Potential Use	Potential Benefits
High-Occupancy Vehicle (HOV) Lanes	HOV lanes are traffic lanes for the exclusive use of vehicles with two or more passengers. Other types of vehicles can be included as potential users, such as low-emissions vehicles, transit, and emergency vehicles. HOV lanes are often only applicable and enforced during peak hours.	HOV lanes seek to increase a corridor's efficiency by promoting carpooling and ridesharing. The use of HOV lanes is encouraged in corridors with recurrent high congestion. ITS equipment – such as cameras or transponders – can be used to enforce its correct use.	Benefits vary across sites. A study in California estimates that HOV lanes have increased people throughput by approximately 40% during peak hour. (6)

Strategy	Description	Potential Use	Potential Benefits
Dynamic HOV Lanes	Dynamic HOV lanes refer to HOV lanes that are managed according to traffic conditions along a corridor. When congestion is light, the HOV lane can be operated as a general purpose lane, and when congestion is severe, access can be limited to higher occupancy vehicles, or transit vehicles only.	Dynamic HOV lanes provide a much better use of HOV lanes, as it is responsive to traffic conditions, and not imposed, which might be counterproductive. This ICM strategy requires greater ITS involvement, such as traffic surveillance equipment, Dynamic Message Signs, and traffic detection systems.	Studies have found that this strategy could provide great benefits on transit services on a corridor, increasing ridership by 5% and on-time performance by 9%. (7)
High-Occupancy Toll (HOT) Lane	HOT lanes are HOV lanes that allow single-occupancy vehicles to use them by paying a toll.	HOT lanes provide a reliable alternative for travelers wanting to bypass congested lanes, and they can improve the use of previously underutilized HOV lanes. A HOT lane may also draw enough traffic off the congested lanes to reduce congestion on the regular lanes.	Travel times can be expected to be reduced from 8 to 20%, speeds from 8 to 20%, and total delay can decrease by 25 to 45%. (8)
Dynamic HOT Lane	Dynamic HOT lanes allow traffic managers to further control the use of HOT lanes by varying the toll prices by time of day, or congestion patterns.	This strategy seeks to further improve conditions on HOT lanes, particularly during peak hours, when HOT lanes may be over-utilized. Increasing or reducing tolls according to conditions can help keep HOT lanes as an attractive option, promoting a better use of the facility.	FDOT estimates that HOV lanes converted to dynamic HOT lanes increased the average speeds from approximately 20 to 50 mph at HOT lanes, during peak hour. (9) However, further research is needed to clearly define potential benefits.
Variable Toll Lane	Variable toll lanes are very similar to HOT lanes, except that tolls are applied to all vehicles, disregarding the number of occupants.	Variable toll lanes can be easier to enforce than Dynamic HOT lanes, as all vehicles are required to pay for its use, disregarding the vehicle's occupancy.	Expected benefits are similar to HOT and Dynamic HOT lanes.
Open Road Tolling	Open road tolling, commonly referred as congestion pricing, aims to reduce congestion by promoting road users to shift their trip off-peak periods; or to other transportation modes. There is a consensus among economists that congestion pricing represents the single most viable and sustainable approach to reducing traffic congestion. (10)	This strategy should be considered on highly congested networks exclusively, This strategy can be applied on corridors, usually through toll stations or bridges; or on network areas, by enforcing a toll on a selected area. Examples of this strategy can be seen in London and Singapore.	Congestion pricing efforts in Singapore have presumably reduced volumes by 15%, and increase average traffic speeds by 22%. (11) However, further research is needed to clearly define potential benefits.

Strategy	Description	Potential Use	Potential Benefits
Hard Shoulder Running Lanes	Hard shoulder running lanes seek to enhance a corridor's capacity by utilizing the hard shoulder designed for emergency stops during peak hour traffic. The shoulder use could be used exclusively for a particular vehicle type, like transit or HOVs.	Hard shoulder running can be considered at corridors with recurrent congestion during peak hours, or during an accident or other non-recurrent congestion event. This strategy requires sufficient right of way to safely accommodate traffic in shoulder, and may require further infrastructure investments.	International best practices have shown that hard shoulder running can increase a corridor's capacity by approximately 8%. (12) However, expected benefits will depend upon traffic demand profiles and operational conditions.
Dynamic Lane Management	This strategy refers to the capacity to open and close lanes on a facility based on real-time traffic conditions. This strategy implies that drivers are warned of open or closed lanes prior to the lane closure, commonly done through overhead signs or dynamic message signs.	This strategy can help manage traffic conditions resulting from traffic accidents or other non-recurrent congestion events. This strategy can also be considered to dynamically open hard shoulder running lanes during peak hour traffic.	Studies have estimated that delay can be reduced by 3 to 7% during congested periods (13). However, expected benefits will depend upon traffic demand profiles and operational conditions.
Dynamic Reversible Lane	A specialized and common form of dynamic lane management. This strategy involves the designation of a specialized lane (or lanes) on a facility to the direction of travel that would most benefit from its capacity according to time of day, and traffic conditions.	This strategy should only be considered when congestion patterns are directional. AASHTO states that reversible lanes are justified when "more than 65% of traffic moves in one direction during peak hours" with no fewer than two lanes for the minor-flow direction. (14)	Studies have found that a dynamic reversible lane strategy may improve traffic speeds by up to 40% (15). However, expected benefits will depend upon traffic demand profiles and operational conditions.
Dynamic Junction Control	This strategy focuses on the ability to modify the lane configuration at ramp merge or diverge junctions on Freeways.	When entrance volumes are high and mainline volumes are not, a dynamic junction control system may close the shoulder lane of the freeway upstream of the merge point to accommodate a higher volume of traffic from the entrance ramp. Alternatively, when exiting volumes are particularly high at a junction, the system may reallocate one of the through lanes as an exit lane to accommodate the excessive demand.	International best practices have estimated that mainline delay can be reduced by 4% and on ramps by 13% (16). However, expected benefits will depend upon traffic demand profiles and operational conditions.
Queue Warning	Queue warning's basic principle is to inform travelers of the presence of downstream stop-and-go traffic conditions, based on real-time traffic detection, using dynamic message signs.	Queue Warning should be used on corridors with frequent non-recurrent congestion events (such as accidents or weather hazards). Drivers can anticipate an upcoming situation of emergency braking and slow down, avoid erratic behavior, and reduce queuing-related collisions.	Benefits have shown that primary incidents can decrease from 15 to 25%. Secondary incidents can decrease from 40 to 50% (8). However, further research is needed to clearly define potential benefits.

Strategy	Description	Potential Use	Potential Benefits
Variable Speed Limit (VSL)	VSL are speed limits that are changed based on congestion patterns, road geometry, or weather conditions.	VSL can help amend speed limits that are often not followed, by providing realistic limits, enhancing the compliance rate. Reducing or increasing the speed limits accordingly can help lower speed variance and increase safety.	A study of VSL implementation in Missouri showed that VSL may have helped reduce crashes in the area from 4.5 to 8% (17)
Speed Harmonization	Speed harmonization is similar to VSL except that it seeks to deal with a corridor's performance, focusing primarily on congestion relief by gradually lowering speeds in a congested corridor to reduce stop-and-go traffic conditions. This strategy is currently being researched as Connected Vehicle technology could further enable its operation.	Speed harmonization has the potential to smooth traffic, increase the number of vehicles that a roadway can handle, and improve safety by making it easier for drivers to change lanes when necessary. This strategy should be considered in areas of heavy congestion, and requires a central control operations to optimize the network's speed.	Benefits are expected to improve system performance and sustainability. Current research is focused on quantifying potential benefits from speed harmonization. (18)
Automated Speed Enforcement (ASE)	ASE is a strategy to optimize speed enforcement with the use of cameras or other ITS equipment.	This strategy can be used in corridors with high speeds and high crash rates.	Different reports have shown that ASE can help recuse speeding by up to 30%, and crash rates by approximately 15%. (19)
Ramp Metering	Ramp metering seeks to improve a corridor's performance by managing on-ramp flow onto a corridor entrance, avoiding the entrance of large platoons of vehicles, helping reduce stop-and-go traffic on mainline lanes.	This strategy is commonly used on congested corridors, particularly during peak hours, and prioritizing on bottleneck formation areas. Ramp meters can be fixed-time, actuated, or centrally controlled.	Ramp meter can help increase mainline speed by 5 to 30%, increase mainline capacity by 5 to 15% during peak hour (and reduce it by 15 to 40% on ramps), and reduce crash rates by 20 to 30%, approximately. (8)
Mainline Metering	This strategy is similar to ramp metering, it involves controlling the flow of vehicles entering a specific freeway segment to reduce congestion and its associated inefficiencies farther downstream.	This strategy has typically been deployed only at entrances to tunnels and bridges, on heavily congested corridors.	Further research is needed to clearly define potential benefits.

Source: Cambridge Systematics, Inc.

2.2 ARTERIAL MANAGEMENT

This section focuses on potential improvements to consider on arterial corridors or networks, which can be used to improve mobility on a congested corridor. Strategies seek to enhance coordination and capacity on corridors, as well as transportation demand management strategies that seek to promote alternative transportation modes to reduce congestion on ICM corridors.

Table 2.2 Arterial Management ICM Strategies

Strategy	Description	Potential Use	Potential Benefits
Corridor Signal Coordination	This strategy refers to the preset coordination of traffic signal timings along a corridor. This coordination should take in consideration current traffic volumes and traffic directionality. The corridor signal timings will remain fixed for the duration of the plan.	This strategy can be considered for any uncoordinated corridors, presenting better benefits with high traffic volumes.	Expected benefits include a 7 to 25% delay reduction, a 12 to 25% reduction in stops, a 15 to 25 increase in the corridor's capacity, a 2 to 7% reduction in crash rates, and a 2 to 8% reduction in crashes. In general, the corridor's efficiency increases by 15 to 30 %, depending of the base scenario conditions. (8)
Adaptive Signal Coordination	This strategy refers to the coordination of traffic signal timings based on actuated traffic signals. This strategy allows corridors to have more flexibility to demand changes than the preset coordination plans.	This strategy can be considered for any uncoordinated corridors, or on corridors with fixed time coordination, presenting better benefits with high traffic volumes. The operation of this strategy requires vehicle detection technology at the coordinated intersections.	Expected benefits include a 25 to 45% delay reduction, a 8 to 20% reduction in travel time and speeds, a 20 to 35 increase in the corridor's capacity, a 5 to 10% reduction in overall emissions. (8) These benefits depend on the base scenario conditions.
Network Signal Coordination	This strategy refers to the implementation of signal control plans from a traffic management center. This control plans can be reactive, responding to incidents, or proactive, seeking to improve mobility not only on a corridor, but system-wide.	This strategy can be considered in congested corridors, which have a larger impact on a road network. To enable this strategy, there needs to be a Traffic Management Center, a highly covered network with detectors and cameras, and a communications network between these systems.	It is expected that this strategy can further improve conditions by decreasing travel times by 5 to 12%, reducing delay by 10 to 20%, increase capacity by 5 to 15%, and decrease emissions by 5 to 10% (8). These benefits depend on the base scenario conditions.
Freeway-Arterial Traffic Coordination	This strategy refers to the coordination of ramp meters and signal control systems, so that their operations complement, instead of possibly conflict with each other.	This strategy can be applied to heavily utilized ramps, where the queue might have an impact on downstream intersections on the feeding corridor.	Further research is needed to clearly define potential benefits.

Strategy	Description	Potential Use	Potential Benefits
Parking Management System	Parking management systems with information dissemination capabilities, most commonly deployed in urban centers or at modal transfer points such as airports, monitor the availability of parking and disseminate the information to drivers, reducing traveler frustration and congestion associated with searching for parking. Other management strategies include dynamic pricing and dynamic parking reservation. These last are still being researched and further defined.	Parking Management Systems are mostly used in urban centers, where parking demand is high.	Studies have found that Parking Management Systems may reduce travel time by up to 9% (20). Further research is needed to clearly define potential benefits.
Dynamic Pedestrian Signal Control	Current technologies, like the High intensity Activated crossWalK (HAWK) pedestrian crossing beacon, could improve pedestrian conditions on a corridor and encourage more users to walk. This strategy activates flashing beacons to alert coming traffic when a pedestrian requests it.	These solutions should be considered on corridors with significant pedestrian activity, on intersections with high incident rates, or where pedestrian activity needs to be encouraged. The use of this strategy may help calm traffic, reducing speeds and crash rates.	A recent study by the FHWA estimated that crashes can be reduced by approximately 30%, and pedestrian crashes by approximately 70%. Although benefits may vary according to the corridor's characteristics. (21)
Bicycle Corridor Signal Coordination	This strategy refers to the optimization of traffic signals along a corridor considering bicycle travel times. This strategy seeks to promote bicycling, ultimately reducing congestion.	This strategy can be considered for dense areas like downtown districts. Operations can be considered for peak or non-peak hours,	Researchers have estimated that this strategy may improve bicyclists' safety by reducing bicycle and pedestrian crashes by approximately 35%. (22) However, further research is needed to clearly define potential benefits.

Source: Cambridge Systematics, Inc.

2.3 TRAVELER INFORMATION SYSTEMS

This sections presents potential strategies and solutions to provide useful and updated traffic information to users, so they can re-schedule or re-route trips to avoid congestion. This effectiveness of these strategies rely on the quality and timeliness of the information provided.

Table 2.3 Traveler Information ICM Systems

Strategy	Description	Potential Use	Potential Benefits
Highway Advisory Radio (HAR)	This strategy, often referred as 5-1-1 radio, refers to the use of broadcast radio to inform travelers of particular incidents or traffic congestion. The purpose is to promote alternative routes, travel modes, and trip times during incident events or periods of heavy congestion.	This strategy can be considered for all type of corridors. It is often more useful in corridors with recurrent congestion patterns or high incident rates. This media can also be helpful to reach out during emergency situations.	Motorists that receive HAR information may reduce travel times by 20 to 25%, as expected travel time savings range between 0 to 5 minutes. (8)
Dynamic Message Signs (DMS)	This strategy uses DMS to inform users of traffic congestion and corridor travel times. If signs are located at key decision points to alternative routes, messages can promote users to deviate their route to avoid congestion.	This strategy is normally considered for corridors with recurrent congestion, or high incident rates. The location of these signs is important as the information provided could help users to take alternative routes before entering a congested corridor.	Expected travel time savings range between 5 to 25%, speeds may increase from 10 to 25%. Approximately 20 to 30% of motorists can save time by receiving this information. (8)
Telephone Multi-modal Traveler Information	This strategy, often referred as 5-1-1 phone number, seeks to disseminate traffic information using a designated phone number that users can dial to receive updated traffic conditions in a corridor. This service commonly includes traffic and transit information, when available.	This service is often used on any type of corridors where real time information is available. The structure of this service has been nationally standardized to the 5-1-1 service, and its use can be promoted across all users.	Potential benefits resemble HAR services. Studies have found that this service is often preferred across users than radio broadcast information. (23)
Web/Internet Multi-modal Traveler Information	This strategy, often referred as 5-1-1 service, refers to the use of web/internet pages and applications to broadcast information to users. Users can query this information for specific information, and on the go through mobile devices. This service commonly includes traffic and transit information, when available.	This service is often used on any type of corridors where real time information is available. The structure of this service has been nationally standardized to the 5-1-1 service, and its use can be promoted across all users. This service is often the most popular 5-1-1 service, and the most used.	It has been estimated that this service can help reduce delays by 2 to 5%, increase travel time reliability by 5 to 15%, reduce crash rates by 1%, and save motorists time by 10 to 20%. (8)
Dynamic Traveler Information	This strategy refers to the dissemination of real-time travel information through a DMS network from a TMC. This information can include incidents, events, or regular travel times.	This system can be considered for any corridor, and may have greater benefits for corridors with recurrent congestion. The application of this strategy requires a DMS, a communication network with the TMS, and reliable real-time data to inform users.	Potential benefits resemble the DMS strategy benefits. Further benefits include a potential reduction in crashes of approximately 3%. (24)

Strategy	Description	Potential Use	Potential Benefits
In-vehicle Traveler Information	This strategy refers to broadcasting information directly to vehicles. Technology for this strategy is currently being developed, as Connected Vehicle capabilities enable this type of communication.	This strategy can be considered for any type of corridor. However, technology continues to develop and the application of this strategy will likely be further defined in the coming years.	Studies have estimated that this technology could reduce travel times by 5 to 15%. (8) However, further research is needed to clearly define potential benefits.
Dynamic Routing	This strategy refers to the use of predictive traveler information to inform motorists of optimal routes, making a better use of the roadway capacity. Information is often disseminated using DMS.	This strategy can be applied to any corridor, as long as there is reliable real-time information, predictive traveler information capabilities, and a communication network to disseminate the information accordingly.	Further research is needed to clearly define potential benefits.
In-vehicle Route Guidance	This strategy refers to providing vehicles optimal routes to desired destination using real-time traffic data. Current providers includes the 5-1-1 service, and technology companies in the private sector, such as Google, or TomTom, among others.	This strategy can be considered for any type of corridor, as long as there is real-time data and a reliable routing mechanism to guide users across a network.	It is estimated that this strategy can reduce travel times by 5 to 15%, reduce vehicle stop time by 5 to 20%, reduce incident rates from 0 to 5%, and reduce fuel consumption by 0 to 10%. (8)

Source: Cambridge Systematics, Inc.

2.4 INCIDENT AND EMERGENCY MANAGEMENT

These strategies seek to consider the effect of incident and emergencies, and plan to reduce their effect on congestion on a network. These strategies rely on fast detection and agency preparedness to react to different incident events.

Table 2.4 Incident and Emergency Management ICM Strategies

Strategy	Description	Potential Use	Potential Benefits
Incident Response Plans	This strategy refers to the development of a systematic plan to use human and institutional resources responding to different types of incidents, seeking to quickly resume normal conditions, reducing congestion from incident events.	Incident response plans should be developed on all corridors. Greater benefits can be expected with higher volumes and high incident rates.	Expected benefits may include 40 to 60% delay reductions, 10 to 45% of travel time savings, a 12 to 27% of overall emissions reduction, and a reduction of incident duration times of approximately 15 to 40%. (8)

Strategy	Description	Potential Use	Potential Benefits
Incident Detection Systems	Incident detection refer to the implementation of surveillance technology to detect incidents on freeways in real time.	This strategy should be considered on corridors with a surveillance equipment installed. Benefits are greater on corridors with high volumes, high incident rates and/or long distances.	Expected benefits include a further decrease of incident duration by 2 to 10%, reducing delay by as much as 40 to 65%, depending on the efficiency of the incident response plan. (8)
Incident Management System	This strategy refers to the combination of incident detection systems and incident response plans.	This strategy should be considered on all corridors with an incident detection system. Greater benefits can be expected with higher volumes and high incident rates.	Expected benefits include an expected reduction in incident response time of 30 to 70%, an incident delay reduction of 15 to 45%, a decrease in travel time by 5 to 10%, a 15 to 50% reduction in crashes, and a 40 to 60% reduction in incident duration. (8)
Freeway Service Patrolling	This strategy refers to the implementation of freeway patrol vehicles that provide assistance to disabled vehicles, help remove obstructions, and help respond to incidents or emergencies. The	Patrolling vehicles are normally deployed on corridors, or subsections of corridors, driven by congestion patterns and incident rates, during peak hours. This strategy can help reduce mobility problems associated to non-recurrent congestion events.	Expected benefits include a reduction in incident duration of 17 to 70%, depending on type of incident and number of vehicles deployed. (8)
Emergency Vehicle Signal Preemption System	This strategy refers to the implementation of equipment on emergency vehicles to request and obtain the green light at signalized intersections, helping improve drivers' response to this situation and reduce conflicts.	This strategy should be considered on signalized corridors that are heavily utilized by emergency vehicles. The strategy involves installing equipment on vehicles, as well as on traffic control equipment.	Benefits may include a reduction of the emergency vehicle travel time by 10 to 20%, and a decrease in response time by 10 to 20% too. (8)

Source: Cambridge Systematics, Inc.

2.5 TRANSIT MANAGEMENT

These strategies seek to enhance transit services, making these services more reliable and attractive to promote their use further. This effect can help reduce congestion on a corridor, and provide different types of expected benefits from higher public transportation usage.

Table 2.5 Transit Management ICM Strategies

Strategy	Description	Potential Use	Potential Benefits
Transit Signal Priority (TSP)	TSP is a transit operations strategy to improve the service's on-time performance. Transit vehicles are equipped with a device that communicates to the upcoming signal control of its arrival, extending the green phase for the transit vehicle to pass, or reducing the red phase to reduce the vehicle's waiting time.	This strategy is often used on highly used transit corridors. Benefits increase significantly if transit vehicles have an exclusive lane.	Expected benefits include a travel time decrease of 5 to 25%, a decrease in passenger-delay of 5 to 14%, a bus delay decrease of 5 to 20%, a decrease of 0 to 10% in fuel consumption rates, and an increase in travel time reliability of 30 to 40%. (8)
Automatic Vehicle Location (AVL)	AVL is a strategy to provide transit agencies the location of vehicles via Global Positioning System (GPS) devices. With this strategy agencies are able to enhance services, not only by having a better understanding of overall operations, but having real-time information for users.	AVL is commonly used on fixed-route transit services, to enhance transit operations and improve the service reliability. Further benefits can be expected if combined with other ITS-related strategies for transit, such as Automatic Passenger Counter, and transit surveillance systems.	Expected benefits include travel time savings by 10 to 20%, a 0 to 5% decrease in the agency's general costs, and an increase in on-time performance of 10 to 25%. (8)
Computer-Aided dispatch (CAD)	CAD is a transit strategy that enables vehicle dispatch and communications through computer systems. This strategy aims to improve the service performance by enabling dynamic operations.	CAD systems are often integrated into transit operations with AVL systems, looking to enhance standard operations procedures and provide a faster and more reliable service.	Expected benefits include travel time savings of 10 to 20%, and a 2 to 10% decrease in the agency's general costs. (8)
Bus Rapid Transit (BRT) Lane Management	BRT lane management refers to the exclusive use of a corridor's lane for transit vehicles.	This strategy helps transit agencies run on-time, by reducing the effect of congestion on a corridor. This strategy is often only used on corridors with high transit demand.	Researchers have estimated that crash rates with transit vehicles can be reduced up to 40%, emissions can be reduced from 10 to 40% (25). However, further research is needed to clearly define potential benefits.

Source: Cambridge Systematics, Inc.

2.6 COMMERCIAL VEHICLE OPERATIONS

These strategies seek to enhance commercial vehicle operations and good movements. Strategies include optimization of inspection procedures, and network capacity through better use of the corridor's assets.

Table 2.6 Commercial Vehicle Operations ICM Strategies

Strategy	Description	Potential Use	Potential Benefits
Truck-lane Management	Truck-lane Management refers to lanes restrictions for Commercial Vehicle operations. Many States prohibit the use of right lanes for commercial vehicle use. Other States have experimented with truck-only lanes or bypasses to skip a corridor's bottleneck.	The purpose of truck-lane management is to separate slower moving trucks from the faster general traffic. For this strategy to be considered, there needs to be heavy commercial vehicle traffic, California recommends considering this strategy for corridors with over 30% of trucks in the vehicle mix. (26)	Further research is needed to clearly define potential benefits.
Electronic Credentialing	This strategy refers to the automation of the application, processing and issuance of motor carrier operating credentials	Electronic credentialing allows carriers to register with state agencies online to improve turn-around times and lower labor costs associated with permit processing and approval.	According to recent studies, 94% of motor carrier companies surveyed say that electronic credentialing is more convenient, 80% saw savings in staff labor time, and 58% achieved costs savings over manual methods, having a cost-benefit ratio of 2.6. (27)
Electronic Screening	This strategy refers to ITS-enhancements in the inspection of goods and legal status of commercial carriers.	Electronic screening equipment can be considered for installation at inspection stations.	Recent studies have found that electronic screening has a benefit-cost ratio of 1.9 to 7.5, depending on the site's characteristics.(27)
Weigh-In-Motion (WIM)	WIM are devices capable of weighing and estimating vehicle's weights in motion. This makes the weighing process more efficient, and, in the case of commercial vehicles, allows for trucks under the weight limit to bypass static scales or inspection.	WIM may be considered on corridors with congestion problems due to commercial vehicle inspections. WIM scales are often installed in current inspection stations, seeking to improve operations by targeting inspections to specific vehicles. WIM with electronic screening and credentialing provides the greatest benefit.	Studies have found that stations with WIM and pre-clearance technology may present benefit-cost ratios of approximately 9:1 to 13:1. (28). Different benefits can be expected from particular inspection station operations.
Freight Dynamic Routing Systems	This strategy aims to provide real-time traveler information to commercial vehicles and best routes to enhance commercial vehicles' operations.	This strategy is currently being researched further, it is expected to be appropriate for commercial vehicle operations on urban areas.	Past deployment of similar technology has shown that drayage costs could be reduced by 10%. (29) Further research is needed to clearly define potential benefits.

Strategy	Description	Potential Use	Potential Benefits
Commercial Vehicle Platooning	This strategy is currently under development, it considers the reduction of headways on commercial vehicle platoons, to enhance the corridor's capacity, and the improve speeds by reducing wind turbulence.	This strategy is currently being researched further, it is expected to be appropriate for commercial vehicle operations on long corridors.	Vehicle platooning could enhance capacity and reduce vehicle emissions by approximately 8% (30)

Source: Cambridge Systematics, Inc.

2.7 BRIDGE OPERATIONS

These strategies aim to enhance the efficiency of bridge operations. Strategies include the use of technology to expedite operating procedures at bridges, to provide a better service and potentially increase its capacity.

Table 2.7 Bridge Operations ICM Strategies

Strategy	Description	Potential Use	Potential Benefits
Electronic Toll Collection (ETC)	ETC is a strategy to collect tolls from users without the need of stopping at a toll booth. This is enabled by in-vehicle transponders, or license plate recognition cameras.	This strategy can be considered on toll bridges, to reduce queues formed by toll collection operations.	Studies have estimated that this technology could reduce delays at toll booths by as much as 85%. Having significant benefits on emission reductions too. (31)
Variable Toll Pricing	Variable toll pricing is a strategy to manage demand on a bridge or toll lane. Adjusting tolls by time of day or congestion patterns could entice users to travel in off-peak periods, or take alternative routes.	This strategy is often considered on corridors with heavy recurrent congestion. The strategy can be enhanced by combining it with ETC technology.	A static variable strategy showed a volume increase of 20% in off-peak periods, and a 13% decrease in peak periods. (32)
Bridge Border Crossing System	This strategy seeks to expedite safe and legal border crossings using ITS technology.	This strategy can be considered for border crossings that do not require special inspection procedures.	Studies have estimated that inspection times can be reduced by 50%, although benefits can vary significantly with the program's enrollment rate. (33)

Source: Cambridge Systematics, Inc.

2.8 OTHER TRANSPORTATION OPERATIONS

This section describes ICM strategies that can be applicable to many transportation modes, and that may include significant involvement from a variety of stakeholders.

Table 2.8 Other Transportation Operations ICM Strategies

Strategy	Description	Potential Use	Potential Benefits
Data Management System	ICM strategies are often bind to large amount of data, either from equipment or vehicles, across a variety of stakeholders. A Data Management System structures a data framework that facilitates data storing, access, and analysis for its use in operations and strategy evaluation.	Data Management Systems are often developed for ICM corridors to state the roles and responsibilities of different stakeholders, and consider the framework and operation procedures to store, access, and analyze data generated.	Evaluations of data management systems have found that these systems improve planning and policy-decision-making. (34)
Asset Management System	Asset management systems are business processes defined to operate, monitor, maintain, upgrade, and expand physical assets on a transportation network. These systems help maintain good conditions, ease capital investments, and plan for future conditions.	Asset management systems are normally implemented for ICM, given that most ICM strategies rely on ITS equipment and infrastructure to operate.	The greatest benefits of asset management systems are related to supporting strategic decision taking, improve communications among stakeholders, and enable reliable evaluations of ICM strategies.
Road Weather Information System (RWIS)	RWIS monitors weather conditions on a transportation network, providing valuable information to agencies regarding potential weather hazards, and infrastructure condition. This information can be used to alert users of such hazards, and help maintain infrastructure in good conditions.	RWIS are often used in locations with extreme weather patterns. These systems are comprised of Environmental Sensor Stations (ESS), a data communication system, and a central system to collect and monitor these data.	Studies have estimated that RWIS can have a benefit-cost ratio of 5:1, depending on the location's weather conditions. (35)
Winter Maintenance	This strategy refers to active response to winter weather hazards. Strategies often include weather monitoring through RWIS and anti-icing techniques.	These strategies are often considered in location with heavy snow or rain.	Studies have estimated that these strategies can have benefit costs ratio from 1.8:1 to 36.7:1, and reduce crashes by up to 20%, depending on the location's weather. (36)
Work Zone Management System	This strategy seeks to provide information to motorists regarding active work zones, promoting alternate routes, lane closures and lower speeds, to increase safety and reduce congestion.	Work zone management systems often rely on portable message signs to alert motorists, and traffic management equipment to close lanes and diverge traffic.	Studies have found that mainline volume diverging traffic at workzones can reduce traffic volumes from 10 to 52%. (37)

Source: Cambridge Systematics, Inc.

3.0 ICM Equipment

This section refers to ITS equipment needed to deploy the ICM strategies previously described. ICM strategies are often reactive or proactive to particular traffic conditions. ITS can help detect these conditions in the network, and trigger the ICM strategies, to obtain the expected benefits. Based on this premise, the following categories of ICM equipment are described:

- Traffic Management Equipment
- Communications Technologies

3.1 TRAFFIC MANAGEMENT EQUIPMENT

This section describes a set of ITS equipment and devices that focus on monitoring and managing traffic – whether aggregating information from multiple users, or detecting the presence of a particular vehicle of interest. This devices enable different ICM strategies, as most of the strategies require monitoring capabilities to trigger, operate and/or enforce their operations. Table 3.1 presents a summary of commonly used ITS technology for this purposes, as well as a brief description and its potential use in ICM.

Table 3.1 Traffic Management ICM Equipment

Strategy	Description	Potential Use
Traffic detection technology	This equipment is used to detect vehicles. The most common technologies used for this purpose include traffic detection cameras, and in-pavement loop detectors, although other technologies are available.	Traffic detection equipment is used in the majority of ICM strategies presented. This equipment can help collect traffic data – like volume, speed and vehicle classification. Furthermore, this equipment can be used to activate traffic signals or other ICM strategies.
Traffic surveillance technology	This equipment is mostly referring to Closed-Circuit Television (CCTV) cameras. This equipment monitors and records activities on field, and communicates them to a Transportation Management Center (TMC) for its proper use.	CCTV is commonly used for incident detection, ICM strategies monitoring, and to archive operations data.
Information system technology	This equipment refers to different type of physical signs and signals used to inform users of strategies operations. These signs include fixed information signs, such as fixed signs alerting users of HOV conditions, or dynamic, which refers to the use of dynamic message signs (DMS), traffic signals, and beacons to alert users of certain operational conditions.	Information system technology is often used to enable most dynamic ICM strategies. Their proper placement and use is vital for the successful operation of ICM strategies. Strategies depending on this equipment include Dynamic Lane Management, Speed Harmonization, and Ramp Metering, among many others.

Strategy	Description	Potential Use
In-vehicle equipment	There are a variety of ITS in-vehicle equipment that can be used for ICM strategies. Popular technologies include GPS equipment and RFID transponders. This technology is continuously developing, with the advent of Connected Vehicle and its communication capabilities through DSRC or 4G/5G communications.	This technology is mostly used in ICM operations to detect the location of the vehicle in a particular position of interest – like a toll lane or a signalized intersection; and triggers a particular response from the system – like charging a toll on the equipment, or requesting signal priority. This equipment is also used to monitor vehicle fleet, like patrols or transit vehicles.
Other Vehicle Detection Equipment	Certain ICM strategies require more specific equipment, specializing in a particular characteristic of the vehicle. These technologies include speed detection, through speed radars, Bluetooth detectors, or License Plate Recognition cameras. Other technologies focus on certain types of transportation modes, like Bicycle/Pedestrian detectors, or commercial vehicle scales.	Certain ICM strategies require more precise equipment for their operation. Examples of this type of strategies are Commercial Vehicle Screening, Automated Speed Enforcement, or RWIS.
Probe Vehicle Surveillance	Traffic conditions and roadway information can also be obtained from probe vehicle surveillance. Among the most common uses are speed and incident detection. Sources of information include private and public entities, like Google traffic or NPMRDS information, respectively.	ICM strategies that can use this type of information are incident management systems, or network signal coordination.

Source: Cambridge Systematics, Inc.

3.2 COMMUNICATIONS TECHNOLOGIES

Another important set of equipment needed to implement ICM strategies is the communication network that enables data transfers from ITS equipment to the transportation management centers. This communication network allows agencies to deploy the described strategies in real-time. Table 3.2 shows a brief description of possible solutions to construct these communication networks, as well as describe their potential use in ICM implementation.

Table 3.2 Communications Equipment ICM Equipment

Strategy	Description	Potential Use
Wire Communications Network	This solution refers to physical network, often referring to cable wiring such as Fiber optic or Ethernet cable network, which connect ITS equipment with central controllers. This solution is often consider more reliable than wireless communication, but it may also be more expensive.	This type of communication network is often implemented to connect devices that are expected to have a long life-cycle – such as traffic signals, DMS, CCTV cameras, with the control center.
Wireless Communication Network	Wireless communication networks, such as RFID communication (referring to vehicle transmitters) and TCP/IP (which enables Local Area Network or LAN, among network connections), are commonly used in ICM strategies, and their use is becoming more common as their implementation cost can be lower than wire networks. Furthermore, research in this area continues to investigate other type of wireless technology that could enhance this type of communications, with technology such 4G/5G networks. However, safety concerns regarding this type of communication continue to be an important deterrent.	Currently this type of communications are often used in ICM strategies that are vehicle-specific, such as toll collection via transponders or TSP in transit buses. However, it can be expected that this type of communication networks will have further uses, as Connected Vehicle technology and the Internet of Things (IoT) technology continues to develop.

Source: Cambridge Systematics, Inc.

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Appendix E. Performance Measures

CAMBRIDGE
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Think Forward

Technical Memorandum

TO: Buffalo-Niagara ICM Project Team

FROM: Keir Opie

DATE: June 5, 2017

RE: BNICM AMS Performance Measures and Evaluation Methods

The overall purpose of the Buffalo-Niagara ICM (BNICM) project is to achieve the combined stakeholder vision of efficient transportation operations within the corridor. The ICM is intended to provide improved integration of operational procedures, facilitate improved emergency response, and improved dissemination of traveler information in the I-190 Corridor and in the larger Border Crossing corridor within the Niagara Frontier.

Part of the current ICM project is to develop an Analysis, Modeling, and Simulation (AMS) tool to forecast impacts on the system operations under potential ICM strategies that could be implemented. This tool, an Aimsun hybrid (mesoscopic & microscopic) DTA simulation tool is currently being developed to better evaluate the operational impacts of the ICM strategies or packages of strategies. This memo serves to document the performance measures and evaluation methods for the AMS evaluation will utilize the Aimsun AMS tool for the various ICM strategies to be analyzed.

It is noted that the GBNRTC Travel Demand Model is also available for regional analysis of travel patterns and mode split estimation for the AMS evaluation, although this tool is limited in its usability to assess short term operational conditions from non-recurring events or under dynamically changing conditions. As such, the following recommendations generally refer to the use of the Aimsun AMS tool for the derivation of performance measures.

Performance Measures and Evaluation Criteria

The selection of performance measures and evaluation criteria is a key element of the planning phases for an ICM project, and should be tied to the goals and objectives that the potential ICM deployment aims to meet. The following performance measures are produced from the simulation model and are frequently used to assess the network operational performance under varying conditions.

Network Usage

Performance measures like volume and VMT are good indicator of magnitude of traffic and throughput under congested conditions in the region. Network usage performance measures can be gathered on a single link or roadway, a corridor, or on a systemwide regional level. One of the goals of ICM is to help balance network capacity and demand to improve the corridor and network throughput of vehicles and persons.

Throughput Volumes

Traffic volume is a basic performance measure that can be obtained from the results of the Aimsun simulation model. Traffic flow volumes can be recorded on network links for different mode of travel or type of vehicle, by time period, and by direction. When measured across finite time periods under congested (queued) conditions, the volume is representative of throughput and is less than demand. By comparing throughput volumes across different ICM strategies and most likely across a screenline representing the entire ICM corridor, the overall ability of the management strategies on increasing the corridor throughput can be measured.

Vehicle Miles Traveled (VMT)

VMT is another good aggregate measure of the amount of systemwide network usage within a specific time period. The link level VMT data can be aggregated for a corridor, by functional class, or at a systemwide regional level. Under an ICM analysis, VMT by functional class or by roadway provides valuable insights into the effectiveness of strategies at encouraging route shift behavior in an attempt to increase overall corridor throughput.

Mobility

One of the major objective of ICM is to balance network capacity and demand to improve corridor and network mobility by improving travel time and overall mobility.

Travel Times

Many ICM strategies center upon providing accurate travel time estimates to travelers both in terms of pre-trip and en-route travel information. The travel time on the individual links can be aggregated to corridor level to represent a point to point travel time along a known route. Alternatively, travel times can be reported by OD pairs. This allows the comparison of travel times for the same trip regardless of the route taken to complete that trip.

Speeds

Speed is an important metric to gauge corridor performance under different operations management strategies. Point speed can be collected at various locations in the network by using detectors and compared between scenarios. In addition, although more qualitative in nature, space-time diagrams (also know as speed contour maps or congestion heat maps) of speeds along specific roadways can be produced to illustrate the overall operation of the roadway throughout the analysis period, including the duration and length of bottlenecks queues or impacts. Speeds are anticipated to be reported from the models on either 5 or 15 minute levels.

Delay

Delay (or the lack thereof) an ideal measure of the efficiency of the transportation system. Delay directly relates to the magnitude of congestion experienced by a traveler in the network. Many ICM strategies are focused to reduce traveler delays. Delay can be broadly defined as travel time in excess of some subjective minimum travel time threshold. When delay is calculated for roadway-only modes, posted speed limits or 85th percentile speed limits are commonly used to calculate minimum travel time thresholds. In the case of Aimsun, each individual simulated driver has a desired free-flow speed given the posted speed limit on the roadway, and delay is calculated as any travel time in excess of this travel time, regardless of the causation of that delay (queued congestion or signal timings). Delay will be reported in terms aggregate terms of vehicle-hours of delay (VHD) or person-hours of delay (PHD) and in per vehicle units (seconds per vehicle).

Border Crossing Delays

Reduction of border crossing delays is an important goal of the cross-border ICM corridor. Within the ICM project area there are three major roadway border crossings between USA and Canada. Delays at these border crossing stations will be measured in the simulation models as the travel time in excess of an established minimum crossing time to enter the border queue, progress through the border screening process, and cross the border. For consistency, the border crossing delays in the simulation model will be measured in the simulation model using the identical entry and exit points and minimum threshold travel time as the implemented Bluetooth based delay monitoring system does.

Travel Time Reliability

Travel Time Reliability captures the relative predictability of travel time. Unlike mobility, which measures how many people are moving at what rate, the reliability/variability measures focus on how much mobility varies from day to day or from the normal conditions.

Planning Index

For this ICM AMS effort, as in many studies with a travel reliability measure a threshold of the 95th percentile travel time is selected to calculate the planning index. The planning index represents the extra time cushion needed during peak traffic periods to prevent being late 95% of the time. It is the ratio of the total time needed to ensure 95 percent on-time arrival compared to free-flow travel time.

$$\boldsymbol{Planning\ \ Index} = \frac{\boldsymbol{95th\ Percentile\ Travel\ Time}}{\boldsymbol{Free\ Flow\ Travel\ Time}}$$

Travel Time Index

The Travel Time index is the ratio of peak period travel time compared with free flow travel time, during peak periods. The Travel Time Index represents the additional time needed to be added during peak hours, compared with conditions of light traffic.

$$\textbf{Travel Time Index} = \frac{\textbf{Peak Period Travel Time}}{\textbf{Free Flow Travel Time}}$$

Variance in Travel Time

Variance in travel time is another indicator for travel time reliability over time. It describes how travel time varies over time and the impacts of this variance on corridor users versus the mean travel time. Variance in travel time is expressed in terms of standard deviation of travel time.

Environmental

Various environmental performance measures can be gathered from the results of the simulation model to assess the impacts of the ICM strategies on operations. While Aimsun does have emission model add-ins that can be integrated with the microsimulation, no such tool exists for the mesoscopic simulation framework, nor are these models approved for use by the US EPA. As such, post processing methods of simulation model outputs can be used to estimate environmental impacts of ICM strategies.

Fuel consumption

Fuel consumption rates can be assumed for different vehicle types at different operating speeds. Total fuel consumption can then be computed using the VMT stratified by vehicle type and operating speed.

Vehicle Tailpipe Emissions

The tailpipe emissions can be computed for vehicle based on different emission rates for different vehicle types and various pollutants (COx, NOx, SOx, PM & VOCs) at different operating speeds. Tailpipe emission rates can be assumed for different vehicle types and pollutants based on published research from the EPA.

Relation to NITTEC's Established Performance Metrics

In addition to the above performance metrics to assess the changes in operational performance of the ICM corridor using the AMS tool, it is important to tie these measures to NITTEC's established performance metrics for operational performance of an ICM system. The following section builds upon these goals and performance measures by presenting a strategy to assess these performance measures with the AMS tool. For this purpose, the performance measures were first classified in three different groups:

- **AMS Output**. This category includes performance measures that can be obtained directly from the simulated conditions, including the metrics identified in the previous section. These metrics can either be explicitly simulated in the AMS tool and captured as model outputs, or can be estimated using post processing tools or techniques based directly on model outputs.

- **AMS Input**. This category includes performance measures for which assumptions will need to be made for each analyzed scenario and can be used as inputs into the AMS evaluation. These may refer to data being incorporated to the analysis from external sources or current practices and the desired changes that would be seen under an ICM deployment to better manage and adapt to real-time operational conditions. Alternatively, these assumptions on various agency performance measures like incident response times or traveler information dissemination that can not be directly simulated in the AMS tool, but the impacts of changes in those performance measures will have impacts on other metrics which can be explicitly simulated.

- **Non-AMS Metric**. The final category includes performance measures that can not be directly included in the AMS evaluation of the potential ICM strategies, either implicitly or explicitly. Performance metrics in this category relate to implementation, management, or maintenance of assets in the field, or otherwise not able to be assessed in the AMS evaluation.

The following table presents the strategy that will be used to evaluate the performance measures in the AMS evaluation.

Table 1: Performance Measurements Integration with AMS

Category	Performance Measure	Type	Proposed Action
I. Agency Coordination	1. Evaluate the use of established center-to-center communication links a. Number of agencies b. Monthly activity c. Monthly down time	1. Non-AMS Metric	1. N/A
II Traveler Information – Objective A. Improve accuracy of congestion (travel time) information reliability	1. Monthly travel time variation for selected times and links	1. AMS Output	1. Evaluate travel times in Aimsun across scenarios and determine variability in travel times.
	2. Compare posted travel times with measured travel times for selected time periods and links	2. AMS Output	2. Evaluate travel times in selected links on Aimsun and compare with set goals. Travel Time Index is an optional to report.
	3. Monthly up-time	3. Non-AMS Metric	3. N/A
	4. Monthly down time per element	4. Non-AMS Metric	4. N/A
	5. Monthly system down time	5. Non-AMS Metric	5. N/A
II Traveler Information – Objective B. Enable intermodal choices through improved traveler information	1. Traveler information is integrated	1. Non-AMS Metric	1. N/A
	2. Evaluate the use of traveler information monthly a. Traveler surveys are conducted b. Web site hits c. 511 telephone service calls	2. Non-AMS Metric	2. N/A
	3. Yearly traveler surveys	3. Non-AMS Metric	3. N/A
	4a. Static traveler information is in place 4b. Dynamic traveler information is in place	4. AMS Input	4. Assume improved use of dynamic traveler information under appropriate ICM strategies.

Category	Performance Measure	Type	Proposed Action
II Traveler Information – Objective C. Improve integration of weather information/data for traveler information, and for maintenance operations	1. Weather information/data and traveler information services have been successfully integrated	1. Non-AMS Metric	1. N/A
	2. Number of relationships with weather information/data sources	2. AMS Input	2. Assume integration of weather information/data sources with AMS tool evaluation for improved dissemination of weather conditions to travelers.
	3. Weather information/data and maintenance call-out systems have been successfully integrated	3. Non-AMS Metric	3. N/A
	4. Successful integration of the region's RWIS with the province has been accomplished	4. Non-AMS Metric	4. N/A
	5. Successful integration of RWIS into all traveler services has been accomplished	5. Non-AMS Metric	5. N/A
II Traveler Information – Objective D. Improve integrated operations based on real-time data	1. Use of real-time data has been determined and is in use	1. AMS Input	1. N/A
	2. Real-time data system monthly up-time	2. Non-AMS Metric	2. N/A
	3. Frequency of system element updates for real-time data	3. Non-AMS Metric	3. N/A
III. Mobility (Arterial, Border, Freeway, Transit) – Objective A. Maximize the free flow of traffic and reduce congestion	1. The percentage of coordinated corridors	1. AMS Input	1. Assume percentage of arterial network coordination in the AMS tool under different ICM strategies as appropriate.
	2. Percentage of the ICM corridors operated by a central source	2. Non-AMS Metric	2. N/A
	3. Number of key signals retimed every three years	3. Non-AMS Metric	3. N/A

Category	Performance Measure	Type	Proposed Action
III. Mobility (Arterial, Border, Freeway, Transit) – Objective B. Provide transit alternative and park-and-ride facilities	1. Percentage of ridership increase	1. AMS Output or AMS Input	1. Depending on ICM strategies being tested, either a) Evaluate changes in ridership either from output of a Travel Demand Model run (for recurring condition changes), or b) Assume revision of auto/transit mode shifts as an input to Aimsun (for incident or dynamic conditions)
	2. Number of park-and-ride facilities	2. AMS Input	2. Assume changes under different ICM strategies as appropriate.
III. Mobility (Arterial, Border, Freeway, Transit) – Objective C. Enhance border crossing clearance	1. Monthly total border delay time during selected times and periods	1. AMS Output	1. Evaluate border-crossing delay with Aimsun tool across scenarios
III. Mobility (Arterial, Border, Freeway, Transit) – Objective D. Facilitate ITS and operational improvements that will facilitate ICM mobility	1. Number of VMS, Travel Time readers and CCTV deployed per year	1. Non-AMS Metric	1. N/A
	2. HAR system coverage in the ICM corridor	2. Non-AMS Metric	2. N/A
III. Mobility (Arterial, Border, Freeway, Transit) – Objective E. Enhance alternative route management capabilities	1. Number of integrated arterial and freeway management systems	1. AMS Input	1. Assume different integrations under different ICM strategies as appropriate.
	2. Number of signal and freeway corridors operating as a system	2. AMS Input	2. Assume different integrations under different ICM strategies as appropriate, including ramp metering strategies.
	3. Number of arterials instrumented	3. AMS Input	3. Assume different integrations under different ICM strategies as appropriate.
	4. Number of parallel arterials instrumented	4. AMS Input	4. Assume different integrations under different ICM strategies as appropriate.

Category	Performance Measure	Type	Proposed Action
IV. Incident Management – Objective A. Establish incident classifications and severity guidelines	1a. Incident definitions agreed upon 1b. Incident definitions universally used 2. Incident severity guidelines are defined	1. Non-AMS Metric 2. AMS Input	1. N/A 2. N/A
IV. Incident Management – Objective B. Improve and coordinate incident management	1. The number of meetings held per year	1. Non-AMS Metric	1. N/A
	2. Monthly average incident detection to arrival time	2. AMS Input	2. Assume different incident response and clearance times based on changes in incident definitions under different ICM strategies as appropriate
	3. Monthly percentage reduction of average incident detection to lane clearance time	3. AMS Input	3. Assume different incident response and clearance times based on changes in incident definitions under different ICM strategies as appropriate
	4. Monthly percentage reduction of average time from detection to back to normal conditions	4. AMS Output	4. Evaluate return to normal conditions given detection and lane clearance time improvement assumptions for ICM strategies as appropriate.
	5. Incident measures are uniform	5. Non-AMS Metric	5. N/A
	6. The number of training and exercise sessions held yearly	6. Non-AMS Metric	6. N/A
	7. An integrated corridor approach is functioning for: a. Incident management b. Special or planned events c. Emergencies within the corridor	7. AMS Input	7. Assume different responses for different conditions based on ICM strategies being evaluated.

ICM Strategy Evaluation

The impacts of the various packages of ICM strategies will be assessed in a simulation model analysis of a particular event or condition and the above performance metrics can be quantified to estimate the performance of the entire corridor. These performance metrics can be compared to the same metrics for a simulation model of the exact same event or condition that *does not* include those ICM strategies, but instead includes the normal operating conditions and responses that may exist. For example, a simulation analysis of an ICM strategy which targets improved coordination regarding incident response may be model the lane clearance time of a particular crash as 45 minutes, where under normal conditions the lane clearance time on the same crash would be 60 minutes.

The overall impacts of the ICM strategies on any particular performance metric can then be assessed by looking at the changes in that performance metric between the 'Without ICM' simulated scenario and the 'With ICM' scenario, along with the percent change of each metric, according to the following formulas:

$$ICM\ Impacts\ on\ Metric\ X = Metric\ X_{With\ ICM} - Metric\ X_{Without\ ICM}$$

$$Percent\ chage\ of ICM\ Impacts\ on\ Metric\ X = \frac{Metric\ X_{With\ ICM} - Metric\ X_{Without\ ICM}}{Metric\ X_{Without\ ICM}}\ X\ 100$$

This therefore provides a mechanism to assess the overall impacts of the ICM strategies for each metric. The assessment of the overall impacts of the ICM strategies evaluated will return the net change in that performance measure for each of the tested scenarios for the entire corridor as a whole, as well as the magnitude of each improvement compared with previous conditions.

While the overall goal is to provide net benefits to the overall corridor, it is possible that the benefits of the system operations may not be shared equally by all, and in fact some strategies may have possible impact on some but negative impacts on others. For example, a ramp metering system can be expected to improve operations on the freeway mainline, but it may also degrade conditions on the ramp and possible parallel arterials if the meter truly do meter access to the freeways. To assess who may see the benefits of the ICM strategies, the metrics will also be further stratified by the class of roadway (e.g. freeway vs. arterial), the class of vehicle (e.g. autos vs. trucks), the OD of the trips (e.g. cross-border trips or CBD trips), or to a defined corridor or subcorridor or subset of roadways. This will allow the breakdown of which users or areas of the network see the most benefits from ICM deployment and who, if any one, sees disbenefits.

Benefit Cost Analysis

To further assess the overall benefits of the system across multiple performance metrics, it is recommended that the metrics monetized to dollar values. The monetization of these metrics will be based on the current research and previous ICM efforts undertaken, and are expected to include the following methods by overall metric type:

- **Mobility:** Apply the mean user's value of time ($/hr) to the overall vehicle hours of time saved. Higher values of time may be appropriate for truck versus the general traveling public.

- **Reliability:** Apply the mean user's value of time ($/hr) to the change in the standard deviation of the travel times for the traveling public. Higher values of time may be appropriate for truck versus the general traveling public.

- **Environmental:** Apply the average retail fuel costs ($/gal) can be applied to the estimated change in gallons of fuel consumption; estimated average cost of treatment ($/ton of pollutant) can be used to monetize changes in tailpipe emissions.

While the performance measures and benefits calculated will apply only to the particular scenario being simulated, the overall annual benefits to be expected can be approximated by scaling those benefits to an annual level. For example, benefits seen during a simulated recurring congestion event can be annualized by multiplying by 250 to represent the approximately 250 typical weekday commute days in a year. Similarly, an incident of a particular severity and type that happens on average 20 times per year can be scaled up by 20, and so on, to arrive at an annualized benefit. While this is an approximate method, it is required to estimate annual benefits as the analysis of every possible event to occur within a typical year is infeasible.

Overall costs to build and deploy the ICM systems can also be estimated. Costs to be estimated would be split into one-time capital (procurement and installation) and ongoing annual operation and maintenance costs for the life of the ITS equipment. These values can be combined into an annualized present year life-cycle cost estimate for the ICM strategy.

Finally, the overall benefit-cost ratio for the ICM strategies can be estimated by dividing annual benefits by annualized costs to arrive at the B/C ratio for the envisioned ICM system as a whole. This can help provide important information into the viability of the envisioned ICM system.

Appendix F. Analysis, Modeling and Simulation

Buffalo-Niagara Integrated Corridor Management

Final Report

final

report

prepared for

GBNRTC & NITTEC

prepared by

Cambridge Systematics, Inc.

and

Transpo Group

Updated August 2020 by Transpo Group

March 2020

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draft report

Buffalo-Niagara Integrated Corridor Management

Final Report

prepared for

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March 2020 (Updated August 2020)

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Executive Summary

Many transportation agencies across the country are realizing that continued expansion of their region's roadways to alleviate congestion is becoming more difficult. Often faced with reduced budgets and increased project development costs, as an alternative to expanding the roadway's physical capacity more agencies are turning to leveraging technology to better manage the operations of their roadways to reduce congestion levels, improve the reliability of travel times, and prevent crashes. The concepts of Integrated Corridor Management (ICM) fundamentally strive for these operational improvements through improved coordination between varying agencies operating transportation systems within the region, improved incident or event response strategies during congestion or non-recurring events, and improved use of Integrated Transportation Systems (ITS) technologies to improve the operations in the corridor. These concepts are also best applied not to a specific facility, but the larger corridor of alternative parallel or nearby roadways or alternative travel models.

The Buffalo-Niagara region is well positioned for the consideration of an ICM deployment. Numerous agencies are involved in operating roadways on both sides of the border, and the long history of development in the region has created roadways which can be difficult and exceedingly expensive to physically expand. This Buffalo-Niagara ICM (BNICM) project built upon previous ICM planning efforts completed for the region and aimed to develop decision support tools needed to complete the required Analysis, Modeling, and Simulation (AMS) assessments of potential ICM deployments in the region and to conduct those AMS assessments and to prove the feasibility of an ICM deployment to provide the overall benefits to improve operational and environmental conditions on the region's transportation network. Throughout this planning level BNICM project, the previously established goals for a successful ICM deployment were kept in mind for the ICM system to improve agency coordination, improve traveler information, improve mobility for all transportation network elements, and to improve incident management capabilities.

This project was completed for the Niagara Frontier Transportation Authority (NFTA), the Greater Buffalo-Niagara Regional Transportation Council (GBNRTC), and the Niagara International Transportation Technology Coalition (NITTEC) and made possible through grant funding of both the United States Department of Transportation (USDOT) and from the New York State Energy Research and Development Authority (NYSERDA).

Model Development

At the onset of the BNICM project, it was evident that a robust analysis tool would be needed to simulate the various conditions under which ICM response plans could be deployed, as well as to simulate the various potential ICM strategies that would need to be tested and analyzed. While GBNRTC had various existing simulation models already developed, none of them were ideal for the combined need of both regionwide analysis and local operations details that would be needed for analysis of the BNICM project.

To fill this gap, the BNICM project's first charge was to develop an Aimsun hybrid microscopic – mesoscopic simulation model that could simulate traffic conditions at the regional level with a mesoscopic simulation framework while simultaneously simulating localized details and technologies needed to evaluate key freeway corridors and certain ITS strategies. The framework for the BNICM analysis tool was also selected to potentially be expanded into use as a near real-time predictive element of a future ICM decision support system (DSS) tool for real-world ICM deployments, as has been done in previous ICM deployments in the U.S. and in other countries.

The BNICM model covers the entirety of the I-190 corridor from I-90, through downtown Buffalo, across Grand Island, through the Niagara region, and terminating at the Lewiston-Queenston Bridge crossing between United States and Canada. The model includes all parallel freeway and arterials, and the larger bi-national corridor comprised of the three major bridge crossings between Canada and the United States in the Buffalo-Niagara region and all connecting roadways between those crossings on both sides of the border.

The model was first constructed and calibrated to represent existing conditions. This involved an exhaustive effort to compile all available traffic counts for the region. In addition to the traffic count database maintained by GBNTRC, additional counts were compiled from the New York State Department of Transportation (NYSDOT), the New York State Thruway Authority (NYSTA), the Ministry of Transportation of Ontario (MTO), the Buffalo and Fort Erie Public Bridge Authority, and the Niagara Falls Bridge Commission. After review of those collected traffic counts, as part of this study additional field counts were collected to fill in identified key gaps in the available traffic count data.

The traffic counts were then used to revise and improve upon the regional travel demand estimates from the GBNRTC regional travel demand model through an Origin-Destination adjustment process. These demands were then simulated in the BNICM model for the typical weekday AM peak period (7-10 AM) and the PM peak period (3-6 PM) and compared to the observed count data as well as against historic roadway speeds as extracted from the National Performance Measurement Research Data Set (NPMRDS). Further changes and improvements to the roadway representation in the model, the regional travel demands, and the models representations of route choices made by drivers were iteratively improved upon through the calibration phase of the project until the resulting simulations well represented the existing typical weekday peak period conditions.

Base Conditions

While typical weekday peak period conditions do often occur, a number of other non-typical conditions are also frequently seen on the region’s roadways. These conditions needed to be included in the evaluation of the future ICM deployment as ICM strategies can often provide greater benefits when conditions are not typical but include non-recurring events such as disruptions from crashes, unusual demand conditions, or from adverse weather conditions. To serve in the evaluation of the potential benefits from an ICM deployment, five additional observed or base conditions were selected, and the AM and PM peak period models were adapted and further calibrated to represent these non-typical conditions. The final set of base conditions included the following:

- Typical AM and PM peak period conditions
- Major crashes in each of the AM and PM peak periods
- Snow conditions in the AM peak period
- High cross-border demand Canada Day & Independence Day holiday traffic during a PM peak
- High demand for a Sabres hockey game in Downtown Buffalo during a PM peak

For each of these conditions, an actual representative day from recent years was selected, and any date specific count and speed data for that day were compiled. These additional non-typical base condition models were developed by altering the typical peak period condition models to include the non-typical conditions. These base conditions models were similarly calibrated to represent the available speed and count data for those representative non-typical conditions.

ICM Strategies Benefits

To select which specific ICM strategies should be considered for inclusion in a future ICM deployment, a review of the larger universe of potential ITS deployments was reviewed and a candidate list of ICM strategies was developed that were best suited to the Buffalo-Niagara region considering it's roadway network, the goals of the ICM deployment, and the base conditions under which the ICM deployment would be evaluated. The following ICM strategies were advanced for further consideration and evaluation:

- Improved Dynamic Traveler Information
- Freeway Incident Detection and Service Patrol
- Ramp Metering
- Variable Speed Limits and Queue Warnings
- Variable Toll Pricing
- Signal Coordination
- Parking Intelligent Transportation Systems (ITS)
- Dynamic Lane Controls
- Road Weather Information System (RWIS) and Plow Management

For each of the strategies, a plan for what a deployment of each of those systems within the I-190 and the cross-border corridors would consist of was developed. Given this expected deployment of each of these systems, estimated initial deployment costs as well as the annual operating and maintenance costs were used to create annualized life-cycle costs for each of the ICM strategy deployments.

To evaluate the impacts of the ICM strategy deployment under the different base conditions, methods were developed to include these ICM strategies implicitly within the BNICM simulations so that the impacts on operations could be estimated. By comparing the results of two simulations with and without the ICM strategies active, the differences in the performance metrics could be taken as the impacts of the ICM strategy deployment. The primary metric used to evaluate the operational impacts was the change in the total vehicle hours traveled (VHT). This provided a good overall metric to evaluate the impacts on all relevant regional roadways, including both freeways and arterials. The changes in VHT were then converted into monetary values using assumed driver's value of time estimates.

Where the simulation tool could not feasibly estimate impacts, off-model estimates of the benefits of ICM strategy deployments were developed. These benefits were generally in the form of savings from improved safety conditions and resulting prevented crashes. Previous studies presenting the observed impacts of the similar ICM strategy deployments on reducing crash rates were leveraged along with existing crash statistics for the study corridors to estimate the number of prevented crashes that could be expected. These values were then converted into a dollar values using crash cost estimation methods.

Benefit-Cost Analysis Results

As the permutations of the number of ICM strategies and the base conditions would result in a significantly large number of scenarios, two key sets of packages of strategies were developed to streamline the evaluation process. The first 'Package A' set of strategies focused on improving freeway conditions and included the first five strategies in the above list. The second 'Package B' included those same strategies, but also added real-time signal coordination to better include the arterials in the ICM deployment. The final three strategies were not included in the ICM deployment evaluations at this stage of the ICM planning.

Under the Package A ICM deployment, an annual savings of over half a million VHT could be expected, or when converted into dollars a savings of over $7.5 million. Savings from reduced Vehicle Miles of Travel (VMT) and Carbon Emissions are valued at $2.5 million and $65,000 respectively. The deployment could also be expected to prevent approximately 5 medium to major peak period crashes per year and 22 minor peak period crashes per year. The estimated mobility benefits of the additional VHT savings from those prevented crashes added another three quarters of a million dollars in benefits, and the societal savings of those prevented crash costs was estimated at over $2.7 million per year. Collectively, a Package A ICM deployment was estimated to produce benefits of over $13 million per year. Compared to the estimated annualized costs of the Package A deployment of $4.9 million per year, the benefit to cost ratio is estimated to be 2.77.

Under the Package B ICM deployment, the annual savings in VHT were estimated to increase to over 617,000 hours per year, equivalent to over $9.2 million in user time savings. VMT and Emissions savings are estimated to be $4.4 million and $128,000. As the Package B deployment was not predicted to further improve safety benefits over the Package A ICM deployment, the Package B safety benefits remained unchanged from Package A. The total benefits of the Package B ICM deployment was then estimated at over $17.2 million per year. When compared to the estimated $5.1 million annualized costs of a Package B deployment, the benefit to cost ratio improved to 3.37.

Implementations Plans

Both evaluated ICM deployment plans showed a positive return on investment and should be considered feasible for deployment within the region. The next step towards an ICM deployment within the region would consist of a more detailed design and a more robust analysis of the costs to deploy, operated, and maintain the ICM system components within the region. In particular, attention should be made to the addition of real-time volume sensors. While real-time speed data is generally available, a future ICM system will need to use the detection of both the speeds and volumes of both freeway and arterial facilities as inputs into the ICM system decisions.

A further review of the deployment assumptions for the ICM strategies made as part of this project should also be revisited in more detail. While overall the analyses of the ICM deployments showed that they would produce benefits, the analysis of events under which an ICM system would be deployed showed varying degrees of benefits. Further review, investigation, and analysis of those conditions and strategy deployments returning lower than average benefits should be re-examined to determine the potential for improved response plan performance under those conditions to improve benefits.

An additional next step would be to consider the potential for ICM benefits outside of the weekday peak period conditions. While higher levels of benefits should be expected during the peak period when congestion is higher, potential for additional benefits outside of the peak periods is very much present, especially for safety benefits and travel time benefits during crash conditions. Operating an ICM system during off-peak weekday and weekend conditions should have minimal impacts on the deployment costs but could yield further benefits and improved benefit to cost ratios.

The next stages of analysis should also consider the potential benefits and costs of a staged deployment. Deploying the entire ICM system as analyzed under this project may be prohibitively expensive in terms of initial deployment costs. A staged deployment approach would allow those high initial capital costs to be distributed over years. However, further analysis should be completed on the potential staged deployments to ensure that the different stages operate effectively without the inclusion of potential future later stage deployment components of the ICM system.

Specific to the I-190 corridor, the next steps towards implementation should include more robust design considerations for the ICM strategy deployments. For the ramp metering, the design of a ramp metering timing algorithm should be developed and evaluated versus the more generalized algorithm applied under this project, both for normal operating conditions and as part of a response plan where ramps may see significantly different volumes. Further attention should also be made to the variable speed and queue warning system as tested in this project. The high costs associated with deployment may suggest a staged deployment design, with the first stage of deployment focusing on those areas with more frequent crashes and slow congested operations.

Specific to the cross-border corridor, next steps towards implementation should include a more detailed examination of the possibility of trucks changing their crossing locations on short notice to improve travel times from an incident on either side of the border. Further communication and coordination are also recommended between NITTEC and MTO on an international approach to ICM to coordinate actions taken during an ICM event, and to ensure that the events are designed to complement each other, and not conflict each other. Further coordination with U.S. Customs and Border Protection (CBP) and the Canada Border Services Agency (CBSA) so that the operations of the border crossings are included in the determination of an appropriate response plan. While these lines of communication are already established, further agreements and cooperation in the automated sharing of data and potentially jointly developed ICM response plans for both countries could further improve the ICM system performance.

Performance Monitoring

While the previous simulation and benefit-cost analysis demonstrates the feasibility and viability of an ICM deployment within the region, any potential deployment should also include a data driven process to continually monitor the performance of the ICM system and its response plans that are implemented in the field. The results of that performance monitoring should also carry forward into a continuous improvement framework to ensure that the ICM response plans implemented in the field are as beneficial as they can be for the given conditions as an ICM system operates over time.

Once the ICM system is deployed, a detailed reporting of the performance of the system under the ICM response plan should be developed and tracked over time. While it is impossible to truly know how the roadway system would have performed if a different response plan was undertaken, the comparison of the different performances of different response plans under similar conditions should provide meaningful insights into the relative performance of the response plans. Given these reviews and comparisons, efforts should be made under an ICM deployment to routinely revisit the components of the response plans with the goal for continuous improvement of their benefits.

The use of the BNICM simulation tool can also be leveraged for this performance reporting in a future ICM system. The model was developed with a framework that allowed the possibility of a future expansion and conversion into a real time prediction simulation engine that could be used in real-time to help evaluate different response plans' effectiveness under any given situation. Even if in the ICM system detailed design the decision is made not to include a real-time simulation based predictive input to the DSS, an off-line simulation tool can still be leveraged to evaluate different response plans in a post-implementation manner to estimate if further enhancements could have been made to the response plan implemented to maximize benefits. In either real-time or off line use, the reporting of the performance of the simulation models and their accuracy as a predictive tool in estimating the real world system performance should be included as part of an ICM system deployment. This performance reporting provides the data needed to enhance and improve the simulation model over time, which should in turn lead to more accurate predictions of the impacts of an ICM response plan under varying conditions and improved response plan performance in the real-world.

1.0 Introduction

The following report is the final project report documenting the activities completed at part of the Buffalo-Niagara Integrated Corridor Management (BNICM) planning study. The study was completed for the Niagara Frontier Transportation Authority (NFTA), the Greater Buffalo-Niagara Regional Transportation Council (GBNRTC), and the Niagara International Transportation Technology Coalition (NITTEC). The overall objective of this BNICM study was to develop decision support tools needed to complete the required Analysis, Modeling, and Simulation (AMS) assessments of potential Integrated Corridor Management (ICM) deployments in the region and to conduct those AMS assessments and to prove the feasibility of an ICM deployment to provide the overall benefits to improve operational and environmental conditions on the region's transportation network. The study ultimately aimed at advancing the ICM concepts towards deployment both in the Buffalo-Niagara region.

This project was built upon the previous foundations for exploring ICM concepts in the region, including the ICM Systems Operational Concepts Report[1], the ICM Requirements Report[2], and the Regional Concept for Transportation Operations Report[3], all three of which were previously prepared by NITTEC. These documents established the goals and potential framework of how ICM concepts could be leveraged within the Buffalo-Niagara region, and were the starting point for this current ICM Planning Study.

The planning study was made possible through the grant funding of both the United States Department of Transportation (USDOT) and from the New York State Energy Research and Development Authority (NYSERDA). Supported by these grants, the project revisited and refined the previously establish regional ICM vision, goals, and objectives; identified operating agency, authority, and stakeholder issues and needs; identified potential ICM strategy concepts that could be deployed in the Corridor; developed Analysis, Modeling, and Simulation decision support tools to facilitate the evaluation of the potential ICM deployment; and developed implementation plans for ICM for the I-190 Corridor and the larger regional cross border corridor.

1.1 Buffalo-Niagara Region Background

The Niagara Frontier is the border region that encompasses the Niagara River border crossings and is a strategic international gateway for the flow of trade and tourism between the United States and Canada. The Niagara River, flowing from Lake Erie to Lake Ontario, forms the border between the United States and Canada. On the Canadian side, the Niagara Region covers approximately two-thirds of the Niagara Peninsula and consists of twelve local municipalities. On the United States side, the Buffalo-Niagara Frontier region forms the western border of New York State with the province of Ontario. The City of Buffalo, the second largest city in New York State, is located at the easternmost end of Lake Erie, overlooking the Niagara River. The City of Niagara Falls, New York, is located 20 miles northwest of Buffalo in Niagara

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[1] NITTIEC Transportation Operations, Integrated Corridor Management System Operational Concept, June 4, 2009 https://www.nittec.org/download/file/11713669

[2] NITTEC Transportation Operations, Integrated Corridor Management, Requirements Document, January 29, 2010, https://www.nittec.org/download/file/8759

[3] NITTEC Transportation Operations, Regional Concept for Transportation Operations, January 6, 2010, https://www.nittec.org/download/file/8755

County opposite Niagara Falls, Ontario. Figure 1.1 shows a map of the region, the cities involved, and the primary corridor roadways considered in the ICM project.

Figure 1.1 Map of the Buffalo-Niagara ICM Project Region

Background Map Source: ESRI ArcGIS StreetMap Data

The Niagara region is a particularly complex area for transportation activities due to the interaction of different entities and activities. The ICM project is currently being co-led by the Niagara International Transportation Technology Coalition (NITTEC). NITTEC is coalition of transportation agencies in Western New York and Southern Ontario, allowing transportation agencies to collaborate and manage the multi-modal transportation systems, making it possible to reach mobility, reliability, and safety improvements in the region. NITTEC helps coordinate and facilitate communication between regional transportation agencies, in both Canada and the United States.

Table 1.1 shows current NITTEC member agencies and related organizations. The project was also supported with efforts by the Greater Buffalo-Niagara Regional Transportation Council (GBNRTC). GBNRTC is the Metropolitan Planning Organization (MPO) for the Erie and Niagara Counties, which cover the U.S. portion of the region, and are one of NITTEC's partner agencies.

Table 1.1 NITTEC Agencies

Member Agencies	Other Related Organizations
Buffalo and Fort Erie Public Bridge Authority (PBA)	Canada Border Services Agency (CBSA)
City of Buffalo	Federal Highway Administration (FHWA)
City of Niagara Falls, New York	Greater Buffalo-Niagara Regional Transportation Council (GBNRTC)
City of Niagara Falls, Ontario	New York State Police (NYSP)
*Erie County	Ontario Provincial Police (OPP)
*Ministry of Transportation, Ontario (MTO)	United States Customs and Border Protection (USCBP)
*New York State Department of Transportation (NYSDOT)	State University of New York at Buffalo
*New York State Thruway Authority (NYSTA)	Other local and regional police and emergency services agencies
Niagara County	Recovery companies
Niagara Falls Bridge Commission (NFBC)	
*Niagara Frontier Transportation Authority (NFTA)	
Niagara Parks Commission	
Niagara Region	
Town of Fort Erie	

* Agencies included in the Policy Board
Source: NITTEC Transportation Operations Integrated Corridor Management Requirement Document, February 2010.

1.2 ICM Goals

The overall purpose of the ICM project was to advance the combined stakeholder vision of efficient transportation operations within the region corridor. Overall, the BNICM is intended to provide improved integration of operational procedures and transportation network management, facilitate improved emergency response, and improved dissemination of traveler information in the I-190 Corridor and in the larger Border Crossing corridor within the Niagara Frontier.

The ultimate goals an ICM deployment within the region was documented in the previously reference ICM Requirements Report. These goals were maintained throughout this ICM Planning Study, and helped drive the overall objectives of what a potential ICM deployment should aim to achieve for the region.

Table 1.2 ICM Goals

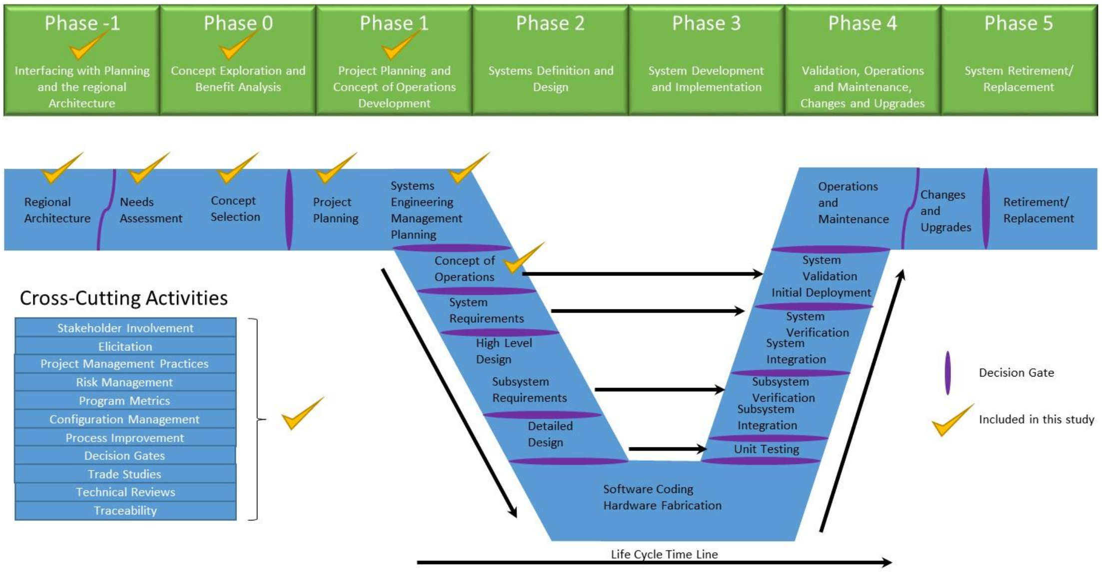
Goal Category	Goal Objective
Agency Coordination	Improve center-to-center communications
Traveler Information	Improve accuracy of congestion (travel time) information reliability
	Enable intermodal choices through improved traveler information
	Improve integration of weather information/data for traveler information, and for maintenance operations
	Improve integrated operations based on real-time data
Mobility (Arterial, Border, Freeway, Transit)	Maximize the free flow of traffic and reduce congestion
	Provide transit alternative and park-and-ride facilities
	Enhance border crossing clearance
	Facilitate ITS and operational improvements that will facilitate ICM mobility
	Enhance alternative route management capabilities
Incident Management	Establish incident classifications and severity guidelines
	Improve and coordinate incident management

Source: NITTEC Transportation Operations Integrated Corridor Management Requirement Document, February 2010

1.3 Project Activities

The ICM Planning Study fit into the larger systems development process, commonly illustrated using the ‘Vee’ diagram. As shown in Figure 1.2, the specific efforts under this study belong in the first half of the Vee, and start to approach the system design stages of the project. The efforts undertaken here were meant to lay the groundwork for future design and deployment of an ICM deployment in the region by examining the types of ICM strategies that could yield significant benefits versus the costs to deploy such strategies. The following outlines the high level activities that were completed during this study, and reference other documents or chapters within this final report that provide more information.

Figure 1.2 Project "Vee" Diagram



1.3.1 Review Previous ICM Documents

At the onset of this study, the previously completed ICM foundation documents referenced above were reviewed and potential updates to the documents were identified. While no significant updates were suggested as part of this review, the resulting document[4] provides a summary of those previous ICM documents, identifies areas for potential updates, and draws attention to elements that are important to the AMS activities which were undertaken in this study. Additionally at this stage of the project, a Systems Engineering Management Plan was developed to guide the activities of this study.

1.3.2 BNICM Simulation Model Development

In order to evaluate the potential benefits of different strategies that might be undertaken as part of an ICM deployment, the development of an AMS tool capable of analyzing these different strategies was required to be developed. After a review of the potential platforms for the AMS tool, an Aimsun Simulation model capable of hybrid mesoscopic and microscopic traffic simulation at both the regional level and the detailed operations level of the ICM strategies was selected. The details of the development of this tool, the BNICM model, are presented in Chapter 2 of this report.

1.3.3 Base Condition Selection and Model Calibration

ICM can be expected to provide benefits under a wide variety of operational conditions, including normal recurring congestion as well as under non-recurring congestion events created by crashes, inclement weather, or abnormal demand conditions. In order to determine the potential benefits of an ICM deployment under these varying conditions, several of these operational conditions were selected for analysis as part of this study. These 'base conditions' were selected by reviewing previous actual events which occurred on the region's roadways, and included both AM and PM peak period typical recurring congestion conditions, a crash condition occurring in each of the AM and PM peak periods, a snow event impacting morning

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[4] Buffalo-Niagara Integrated Corridor Management, Proposed Changes to NITTEC's ICM System Operations Concept Report, Cambridge Systematics, June 5, 2017, https://www.nittec.org/download/file/8758

commute, a PM peak period commute impacted by additional demands from holiday travel, and a PM peak commute impacted by additional demand headed towards a Buffalo Sabres hockey game at the downtown Keybank Center. For each of these base conditions, observed conditions were established and documented through the examination of traffic counts and speed data. Individual BNICM traffic simulation models were then developed and calibrated to and validated against those observed conditions. Chapter 3 of this report presents the summary of those efforts.

1.3.4 ICM Strategy Review and Selection

In order to identify what ICM strategies could be implemented within the region to advance the overall identified ICM goals, thorough review of potential strategies was undertaken, and a short list of potential strategies was selected for potential deployment and evaluation within this ICM study. The selected strategies, along with their envisioned deployment within the I-190 and Cross-Border corridors and estimates of their potential life cycle costs are presented in Chapter 4 of this report.

1.3.5 Strategy Simulation and Impact Assessment

Following the identification of specific strategies that could be deployed within the study corridors, a series of simulations were undertaken for each of the base conditions under both current operations without ICM deployment and potential future conditions with an ICM system deployed and operational. The impacts of the different ICM strategies on improving operational conditions were assessed from those simulation results and the resulting computation of a benefit-cost ratio proving the feasibility and viability of such an ICM deployment are presented in Chapter 5 of this report.

1.3.6 Recommended Deployment and Implementation Next Steps

Based on a review of the evaluated ICM strategies and the positive return on investments have on an ICM deployment, a series of recommendations and next steps towards deployment and implementation of ICM within the I-190 and Cross Border corridors is presented in Chapter 6 of this report.

1.3.7 Framework for Performance Monitoring of ICM

While the material contained within this report demonstrates the feasibility of an ICM deployment within the region, any successful ICM deployment must also include a framework for continual performance monitoring and response plan strategy improvements. Chapter 7 of this report presents such a framework.

2.0 Simulation Model Development

At the onset of the BNICM project, it was evident that a robust analysis tool would be needed to simulate the various conditions under which ICM strategies could be deployed, as well as simulate the various potential ICM strategies that would need to be tested and analyzed. While GBNRTC had various existing simulation models developed, none of them were ideal for the combined need of both regionwide analysis and local operations details that would be needed for analysis of the BNICM project.

After reviewing options for a BNICM analysis tool, the team opted for the Aimsun modeling platform. Specifically, an Aimsun based hybrid simulation model approach was selected with microscopic simulation of key freeway corridors and mesoscopic simulation of the remainder of the freeway and arterial network. There was a proven history of using the Aimsun modeling platform for ICM planning studies, and using Aimsun also allows a clear transition into potential future deployment phases of the BNICM by using real-time predictive simulations with Aimsun Live to support a real-time decision support system (DSS) as part of a potentially deployed BNICM in the future through an Aimsun Live application.

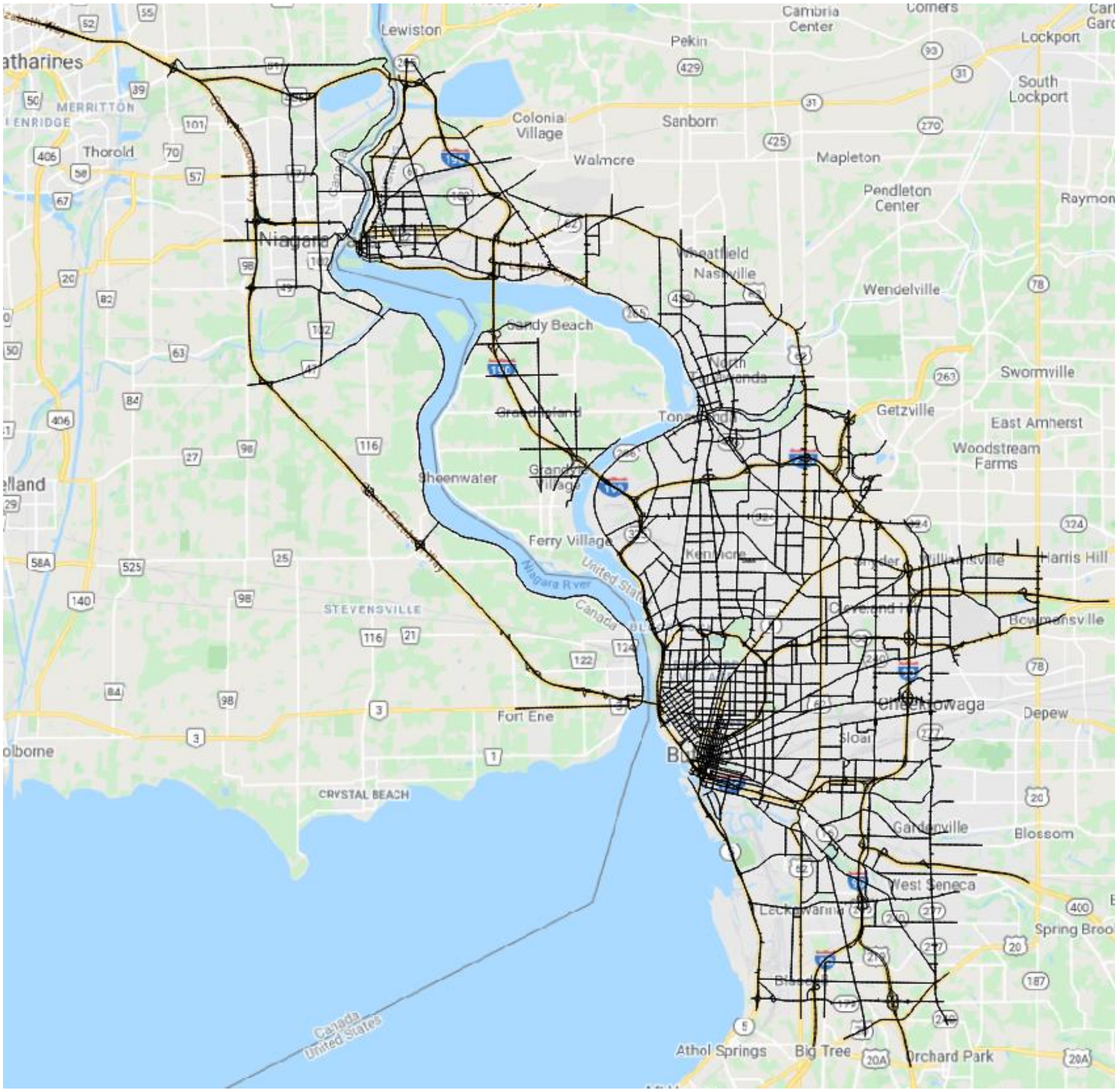
A multi-resolution modeling approach consistent with the existing GBNRTC simulation framework was adopted. The GBNRTC Regional Travel Demand model, a TransCAD-based model, provides the regional travel patterns while an Aimsun hybrid model simulates the regional traffic in mesoscopic and microscopic resolutions to provide an understanding of the regional traffic diversions and to assess the traffic operations in congested environments under different potential conditions and deployed ICM strategies.

2.1 Base Model Development

As illustrated in Figure 2.1, the BNICM model covers the entirety of the I-190 corridor from I-90, through downtown Buffalo, across Grand Island, through the Niagara region, and terminating at the Lewiston-Queenston Bridge crossing between US and Canada. The model includes all parallel freeway and arterials, and the larger bi-national corridor comprised of the three major bridge crossings between Canada and the United States in the Buffalo-Niagara region and all connecting roadways between those crossings on both sides of the border.

The BNICM model network was started from portions of the existing regional travel demand model and an older TransModeler-based mesoscopic simulation model. The network was then expanded by adding key roadways and diversion routes in the region. The Aimsun model is hybrid in nature with vast majority of the network areas simulated at mesoscopic level and pockets of microscopic simulation opened at areas of interest. The two major areas for microsimulation include I-190 from I-90 in the south to I-190 and the South Parkway interchange on Grand Island in the north, and I-90 from Route 219 in the south to I-290 in the north.

Figure 2.1 BNICM Model Extents



Background Image Source: Google Maps

More roadway and traffic control details were added into the network to ensure that the model properly represents the field conditions to be able to produce performance measures at operational level. Given the scale and size of the network, some synthetic signal controls were introduced at signalized intersections where no data on the field implemented signal control plans were available. The synthetic signal configurations were based on the actual intersection geometry and adjusted as needed based on the corresponding traffic volumes of the related approaches.

The model then underwent rounds of updates, reviews, and checks by both the GBNRTC staff and Cambridge Systematics to ensure the accuracy of the model network.

2.2 Demand Development

Following the network coding of the BNICM model, an iterative procedure was undertaken to adjust the trip tables as produced by the validated regional demand model to match the field counts. This procedure is generally known as Origin Destination Matrix Estimation (ODME) and is a mathematical process that iteratively makes adjustments to the origin-destination (OD) tables, assigns flows to the network using a static traffic assignment process, and compares them with the observed traffic counts. The differences between the assigned flows and counts from one iteration are then used to further adjust the OD tables before moving to the next iteration. The process is repeated until the errors between the assigned flows and the traffic counts are smaller than the predefined threshold or the ODME process reaches the maximum number of iterations. The end result is a trip table that is based on the overall OD travel patterns as estimated in the GBNRTC travel demand model but better matches the observed traffic counts.

An exhaustive effort was undertaken to collect observed traffic counts for as much of the region as possible. GBNRTC maintains an ongoing traffic count database with various traffic counts collected across its jurisdiction to support various ongoing projects and studies. Count data was further compiled from the New York State Department of Transportation (NYSDOT), the New York State Thruway Authority (NYSTA), the Ministry of Transportation of Ontario (MTO), the Buffalo and Fort Erie Public Bridge Authority, and the Niagara Falls Bridge Commission. Both short term turning movement counts (TMC) and link (automatic traffic recorder) (ATR) for several years (to capture as much count data as possible) and permanent count station data for the 2015 calendar year were collected. The count data was reviewed and compared to each other for compatibility given the various different time periods and years of data. Figure 2.2, Figure 2.3, Figure 2.4, and Figure 2.5 present the locations of various observed traffic counts that were collected and utilized in the refinement of traffic demands for the BNICM.

Figure 2.2 Short Term Automatic Traffic Recorder (ATR) Link Counts

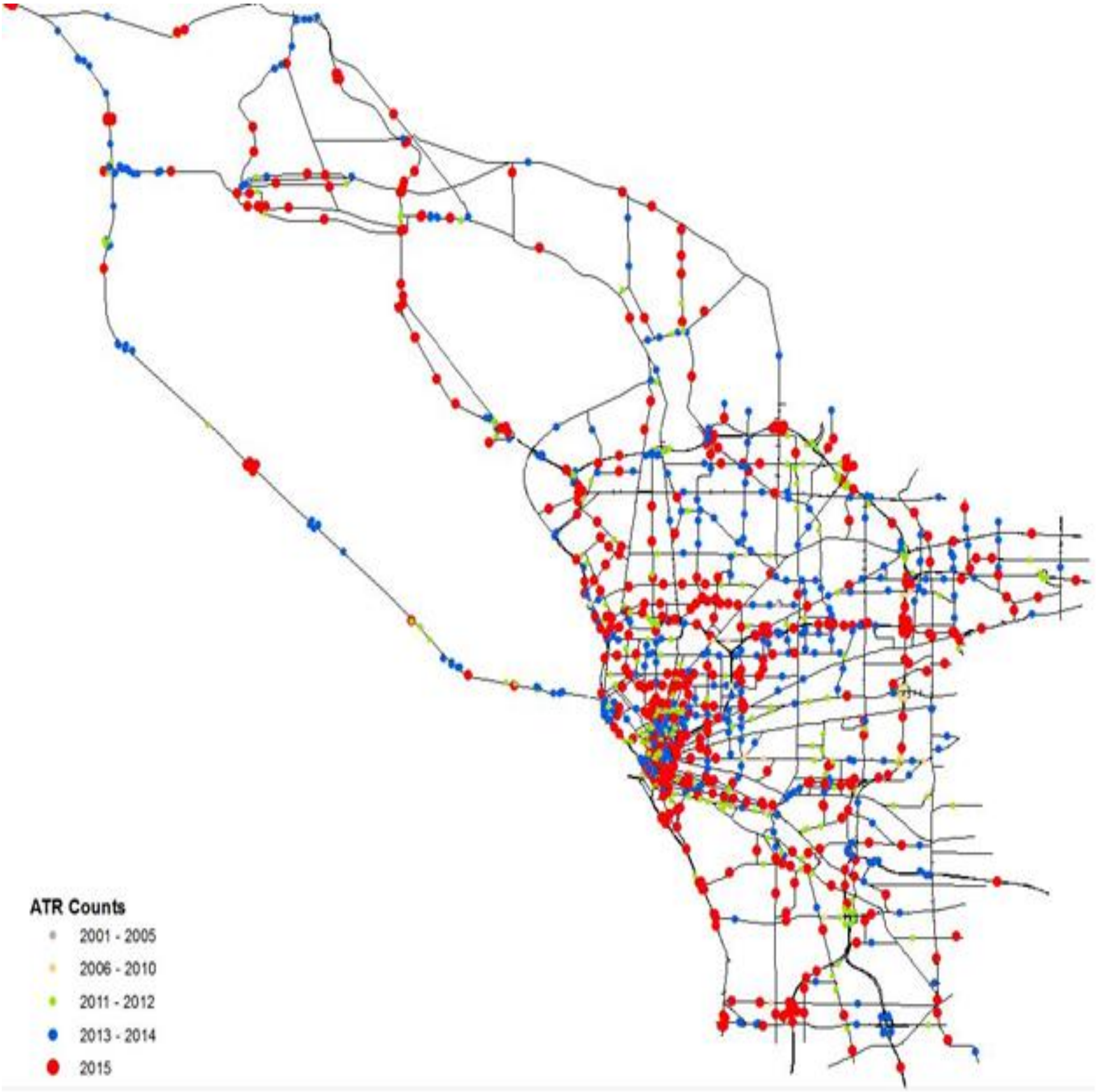


Figure 2.3 Short Term Intersection Turning Movement Counts

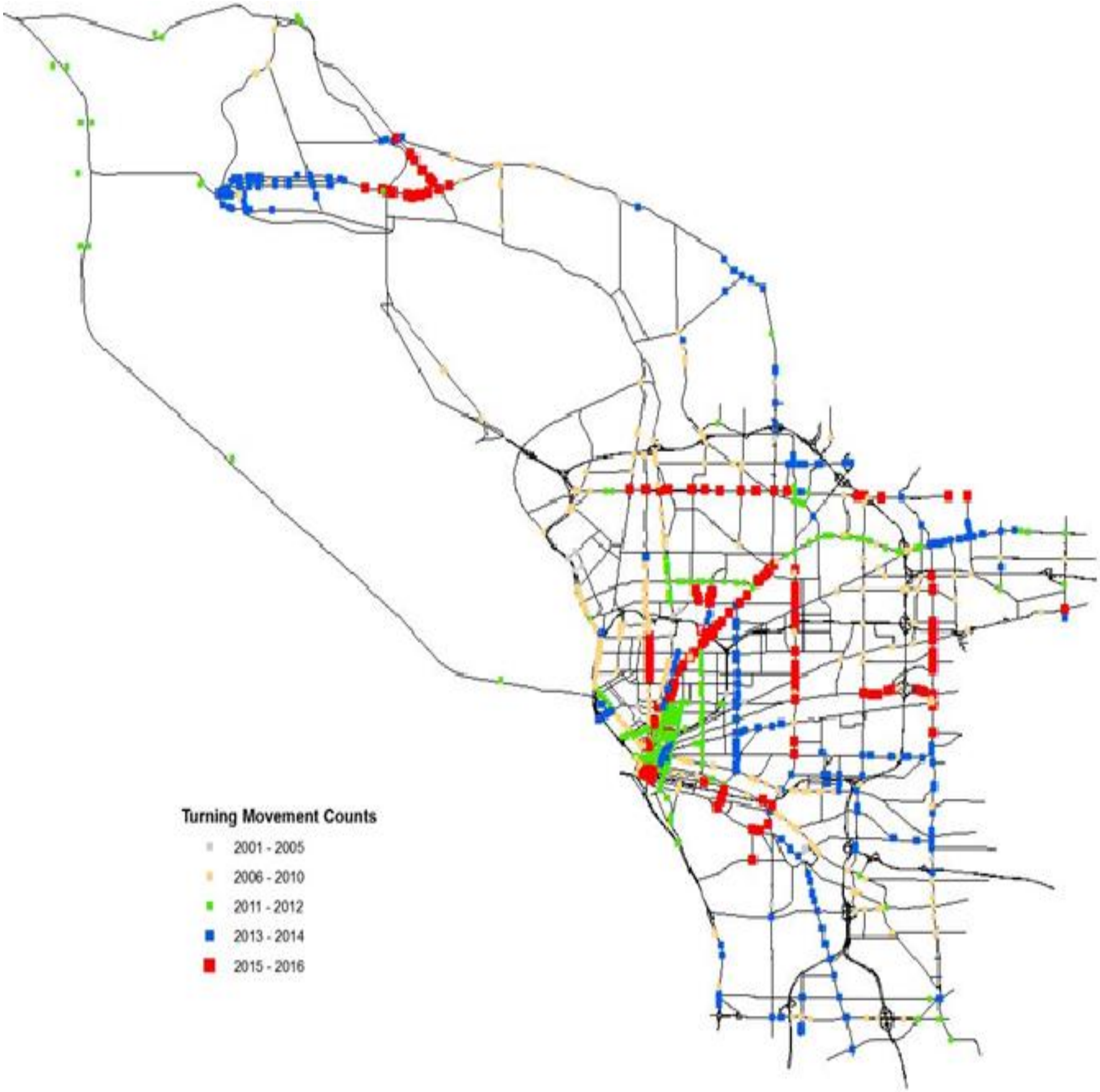


Figure 2.4 NYSTA Permanent Count Stations

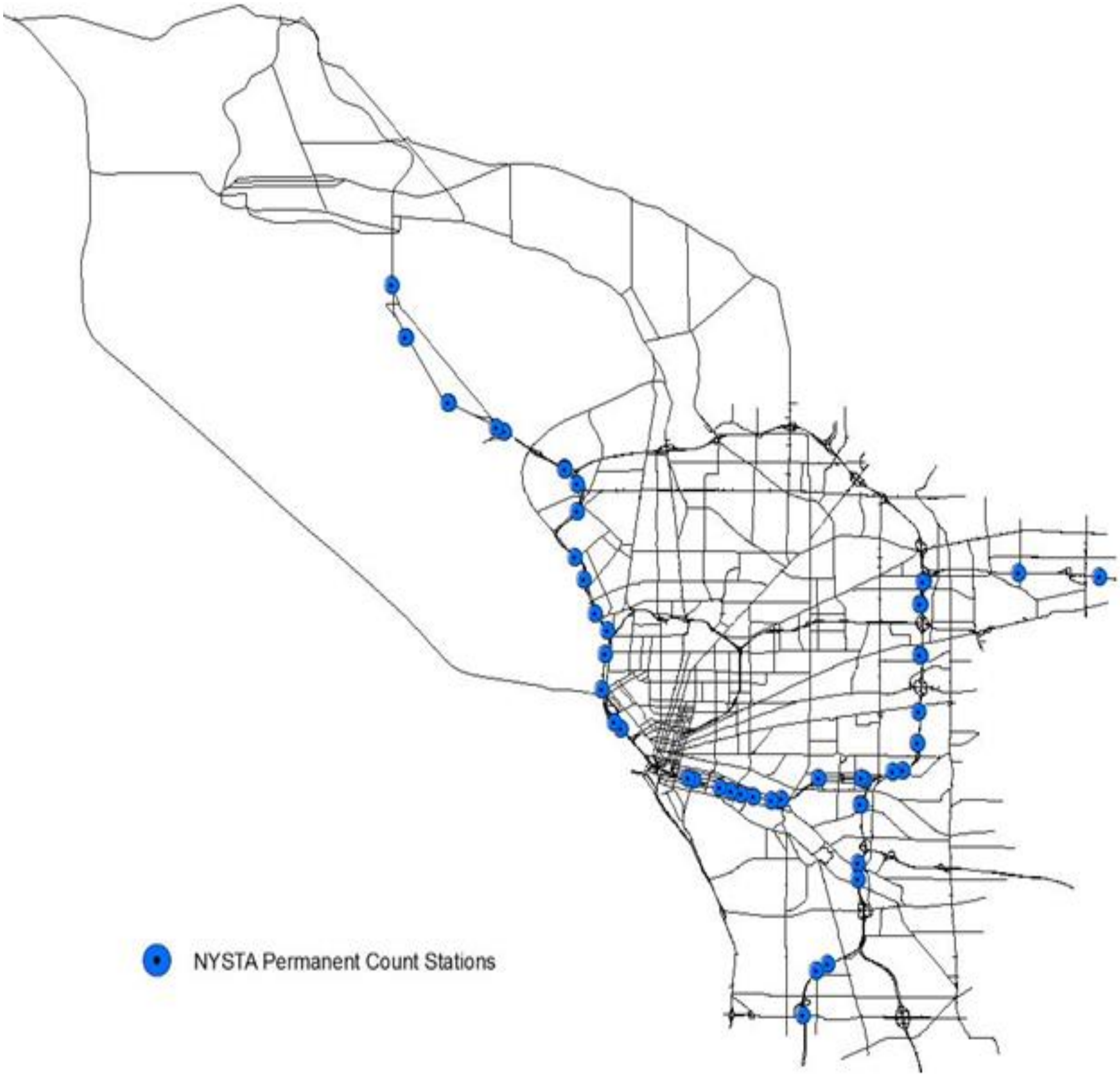
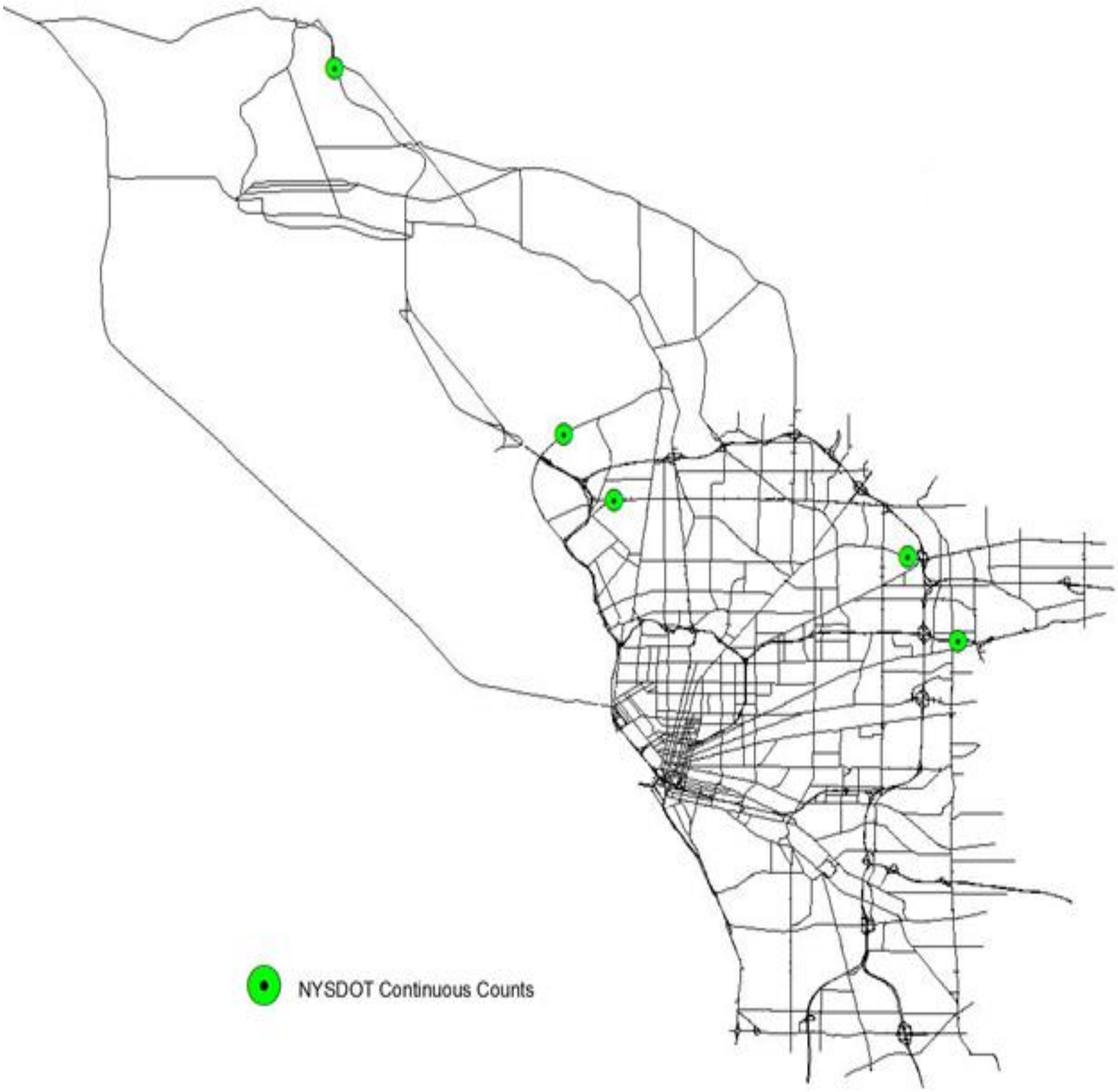


Figure 2.5 NYSDOT Permanent Count Stations



To start the demand refinement for the BNICM model, the travel demands as estimated by the GBNRTC regional travel demand model were extracted using a subarea OD extraction process for a region matching the geographic limits of the BNICM model. As the recently updated GBNTRC travel demand model already had relatively small and refined zone definitions suitable for use in a simulation model, the internal zone structure of the BNICM adopted the same zone system of the regional demand model. New zones were added to represent the external zones for the BNICM based on the link structure of the regional travel demand model.

For the BNICM demand development, the ODME procedures within Aimsun were utilized. Available TMC and ATR counts from various sources were compiled into Real Data Set (RDS) in Aimsun model for flow comparison. Network-wide flow balancing was not conducted given the size of the model and the different sources and time horizons of the observed count data. However, as part of the Aimsun ODME process, a tiered count weight system was assigned to the network links based on the roadway types. Border crossing locations were deemed as the highest importance and therefore given the highest weight of 50, the freeway links were assigned a weight of ten and the rest of the network were given a weight of five. Using the weights as part of the ODME process ensures that more importance was given to the higher-class roadways in the ODME error estimation process in the case of imbalanced or conflicting field counts.

The ODME procedures in Aimsun were single vehicle class based and combined counts for all vehicle class were used as inputs, as limited region-wide classified counts were available. Using what truck share data was available, especially on the freeway corridors, the relative shares of different vehicle classes in the seed matrix were developed and then applied to the estimated OD matrices from the ODME process to create disaggregated individual OD matrices for each vehicle class.

The hourly ODME process was conducted for each hour of the 3-hour AM (7-10 AM) and PM (3-6 PM) peak periods. The resulting ODME assignment link volumes were compared with the hourly peak period counts and refined until the results were reasonable as compared to the observed counts. Care was taken not to over-refine the ODs given the relative differences in counts attributed to the varying time of year and year of counts.

2.3 Model Calibration Process

Before the model could be used to evaluate the impact of ICM strategies on traffic operations, it first needed to be adjusted to ensure that it properly represents the traffic conditions in the study area. The overall goal of model calibration is for the simulated conditions to match the observed route choice patterns and traffic operations as evident from the observed volume and speed conditions from archived data sets. The calibration process was iterative in nature and often required that parameters be adjusted and the steps be repeated considering the size and complex nature of the roadway network within the BNICM model.

One of Aimsun's advantages is its ability to utilize one network model for both mesoscopic and microscopic simulation. This feature provided the option for the BNICM model calibration to be completed for the area-wide mesoscopic model and the corridor-level microscopic model in a single hybrid model scenario simulation.

A two-step approach was adopted to better serve the BNICM hybrid model calibration needs for typical recurring congestion conditions seen within the Typical AM and PM peak periods. In the first step, Macro assignments using the ODME demand were conducted to create the initial vehicle paths. These macro assignment paths served as inputs to inform the hybrid Dynamic User Equilibrium (DUE) simulation runs in the second step. While the macro assignment using static traffic assignment procedures, the DUE process utilized a more robust dynamic traffic assignment (DTA) procedure for route choice, combined with a full regional traffic simulation within each iteration of the DUE. The hybrid DUE runs were utilized to produce performance measures for validation statistics. This two-step DUE-based process enables the hybrid BNICM model to produce better route choice results with the numerous paths available in the large network and converge to a solution within a more reasonable time.

Throughout the calibration process, the initial network and configurations, the related route choice parameters and ODME-produced demand underwent alterations and refinements to allow the DUE simulation results to better match observed real-world condition counts, speeds, and travel times.

2.3.1 Network Refinement

The BNICM model was further refined based on the performance measures and simulation observation of the preliminary hybrid mesoscopic and microscopic DUE runs. Network connectivity issues including missing geometric components, incorrect section directionality and inaccurate connectivity were identified and fixed during this process. Additional turns were introduced at various nodes to improve traffic flow based on the field conditions.

The intersection-specific synthetic signal controls proved to be an efficient and effective way to implement more than 900 signalized intersections in the model, many of which did not have field timing data available. However, from bottleneck locations identified from the test simulation runs, more realistic signal configurations were implemented at selected locations to improve traffic flows within the model so that modeled flows better aligned with the observed flows and congestion patterns. The synthetic signals were manually modified and tested in terms of the signal phasing and timing to produce reasonable traffic conditions.

Driving behavior settings are another major area that underwent iterative tests and adjustments throughout the calibration process. At mesoscopic level, the two primary global variables that could be adjusted to influence capacity and saturation flow include reaction time and jam density. Reaction time is a global parameter which defines the time a driver takes to react to the speed changes of the preceding vehicle. Different mesoscopic reaction times were implemented for vehicle classes through a series of test simulation runs. Jam density is used to define section capacity. Local adjustments were also required after the model settled down on the global calibration parameters. These included the fine tuning of reaction time factors and look-ahead distances on various sections within the model. Reaction time factor is a local parameter that can be used to adjust the global reaction time at individual sections. It serves as a local calibration tool to provide flexibility at locations where reaction times might be different from the overall network (e.g. complex intersections, weaving areas, etc.). Look-ahead distance specifies a set of locations upstream of a decision point (e.g., turn lane or an exit ramp) where vehicles start maneuvers in response of the decision point. The long sections as carried over from the previous models were edited into shorter sections to better model the vehicle behaviors influenced by look-ahead distance settings. This avoided the speed change and bottleneck shifts caused by the lane changes at upstream links of long sections according to the lane changing methodology used within mesoscopic Aimsun.

Microsimulation models simulate individual vehicle behavior and provide a wider range of driving behavior parameters as compared to the mesoscopic models. Global parameters including simulation step and reaction times were defined for the entire microsimulation area within the model. More detailed local driving parameters such as look ahead distance, brake intensity, queue discharge rate, aggressiveness and lane change cooperation rate were updated as needed to better calibrate speeds and bottlenecks to the observed throughput counts. Default values were used as a starting point for the adjustments and field conditions and physical constraints were taken into consideration to avoid extreme values being used.

2.3.2 Demand Calibration

The 3-hour AM and PM period trip tables resulting from the ODME process were assigned to the BNICM network. Based on the initial simulated network performances and the comparison of the simulated and field counts, additional refinements were undertaken to develop better base year demands.

A warmup period is necessary to fill the network with traffic at the start of the simulation. Considering the large geographic coverage of the BNICM network and test simulation results, a 1-hour warmup period was utilized for both the AM and PM base scenarios.

Temporal distribution of traffic demands provides an option for the hourly trip tables to be loaded onto the network based on the field observed peaking patterns. The temporal profiles used in the model were based on the overall field counts but were further adjusted to produce the simulated traffic conditions that better mimic the field demand needed to create the observed bottlenecks and speed contours across the freeway corridors. Temporal shifts were also calibrated in an effort to properly represent the time difference between the departure times where the temporal profiles were applied and actual times when traffic arrive at locations where initial simulation results showed inconsistent results as compared to field counts.

During the volume calibration, a handful of locations on key corridors (e.g., I-190 and I-90) were noticed to have inconsistent simulated volumes as compared to the field counts. While global traffic demand and route choice models were adjusted to provide a match on the overall network, specific techniques targeting these individual sections were adopted. The Link Analysis function within Aimsun was utilized at the sections in question to produce the OD matrices that contain trips passing these sections. The trip tables were then factored up or down to match the field counts and at the same time preserved the OD patterns. This method can be viewed as a manual addition to the ODME process that better calibrate the section volumes to the counts.

2.3.3 Route Choice Calibration

The path costs used in the minimum path calculation in Aimsun are based on a generalized cost function that includes travel time, roadway attractiveness (a bias towards choosing higher capacity facilities) and user costs (tolls).

Given the large size of the network and significant number of path choices, the default cost functions were modified to incorporate a distance component and the toll as part of the cost functions along with the refinement of the attractiveness and user cost coefficients. Unrealistically long detour paths were observed to avoid congested sections in the initial simulation calibration runs. By incorporating distance as a component of the generalized cost functions, drivers would also consider the cost of the detour distance rather than just the travel time as in the default cost function. The toll was included as multiply tolled facilities exist within the network and the user cost coefficients were calibrated to model the local drivers’ sensitivity in terms of paying tolls in the route choice process. The cost functions developed are vehicle class specific and use different parameters for the value of time and vehicle operation costs coefficients cars and trucks.

2.4 Typical Peak Period Scenario Validation Results

The hybrid DUE runs were conducted to produce performance measures for validation statistics. The BNICM model validation process includes volume comparison to the field counts and traffic operation validation to the National Performance Measurement Research Data Set (NPMRDS) based speed contours during the 3-hour AM and PM simulation periods. The validation process was completed when consensus was achieved that base year model reasonably reflected the field traffic conditions and the validation statistics were sufficiently close the validation targets.

One of the primary validation data sets for the BNICM models was speed data from the NPMRDS. A full year of the dataset (July 2015 to June 2016) was assembled and processed to produce time-space speed contour diagrams for typical weekday conditions for the freeway corridors in the BNICM model study area. A similar speed contour diagram was produced for the same corridors from the simulated speed data from the calibrated BNICM models for typical conditions. The speed contour diagrams present the average speeds on the corridor throughout the peak period along the entire corridor. Bottleneck formations and areas of reduced speed on the freeways over the peak period can be visualized and the freeway operations of the model can be visually compared to the freeway operations observed in the field.

The validation summaries for the typical weekday conditions are presented in the next chapter. Based on the results of the final volume and speed validation comparison, it was concluded that the base model was adequately calibrated to the base year typical conditions and were ready for use in future alternative analysis for different ICM strategies.

3.0 Base Conditions

This chapter presents the validation statistics for the final calibrated base condition models, both for the typical recurring congestion conditions as well as the selected non-typical base conditions that were developed for testing the potential for ICM benefits in the Buffalo-Niagara region.

3.1 Typical Conditions: AM Peak Period

Following the calibration process for the BNICM model, the model validation statistics were compiled from the model and compared to the observed conditions data.

Volume validation statistics for the entire model (all link counts included) are presented for each hour of the AM peak period in Figure 3.1 through Figure 3.3. Figure 3.4 and Figure 3.5 present speed contour diagram comparisons between the NPMRDS field data and the simulated conditions along the I-190 corridor. The color shades indicate a range of speeds with dark green showing high speed of 75 mph and red showing low speed of below 25 mph.

As shown in the figures, the BNICM model produced proper level of congestions at matching times at the majority of the study corridors as compared to the NPMRDS data. The most significant inconsistent patterns were at I-90 eastbound where congestions were observed from the NPMRDS data while no compatible congestions were shown in the simulation model. It was confirmed that freeway widening was completed at this location after the NPMRDS data was recorded. These improvements were incorporated into the Aimsun hybrid model as part of the base year conditions and therefore the model produced improved traffic conditions. Cambridge Systematics and GBNRTC staff reviewed the other locations with minor congestion pattern differences and concluded that the simulated results reasonably represented the breadth of the bottlenecks and in some cases were closer to the field conditions according to local knowledge.

Figure 3.1 Simulated Volumes vs. Field Counts - 7 AM to 8 AM

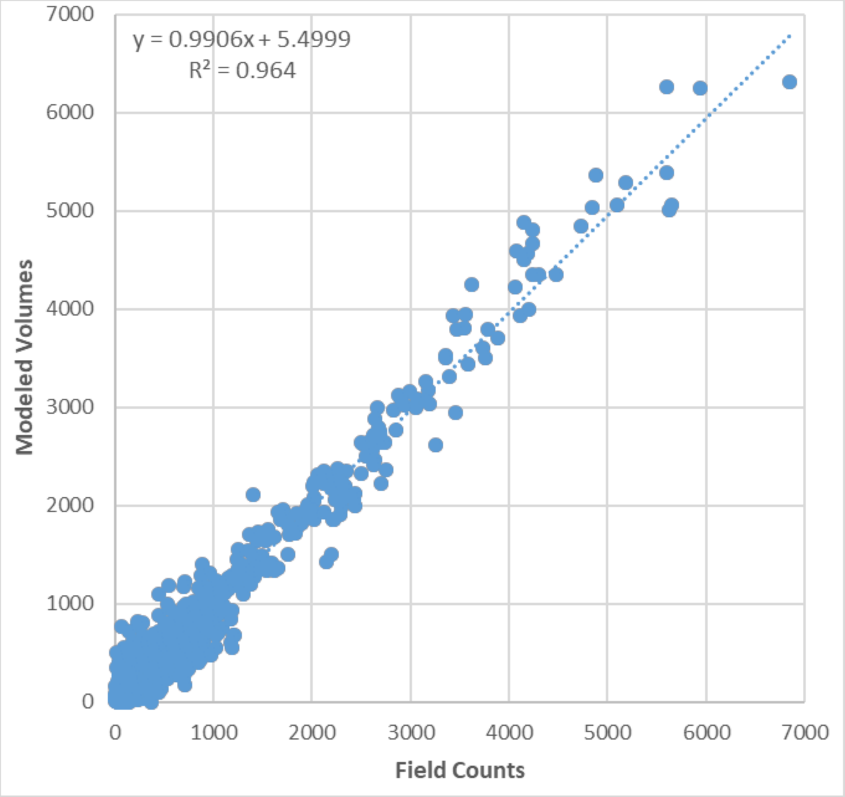


Figure 3.2 Simulated Volumes vs. Field Counts - 8 AM to 9 AM

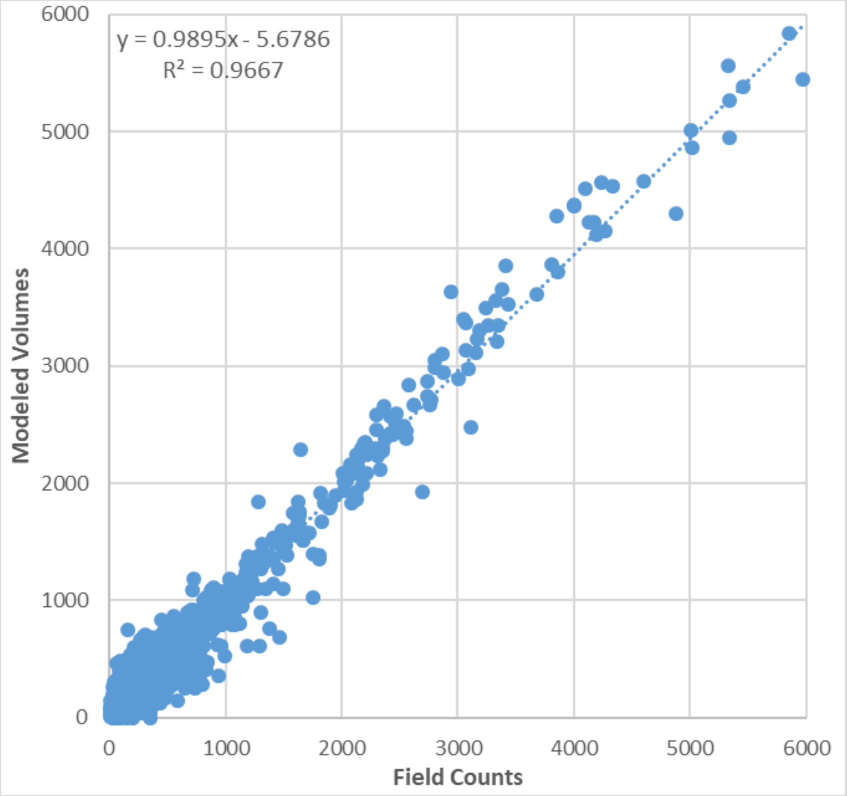


Figure 3.3 Simulated Volumes vs. Field Counts - 9 AM to 10 AM

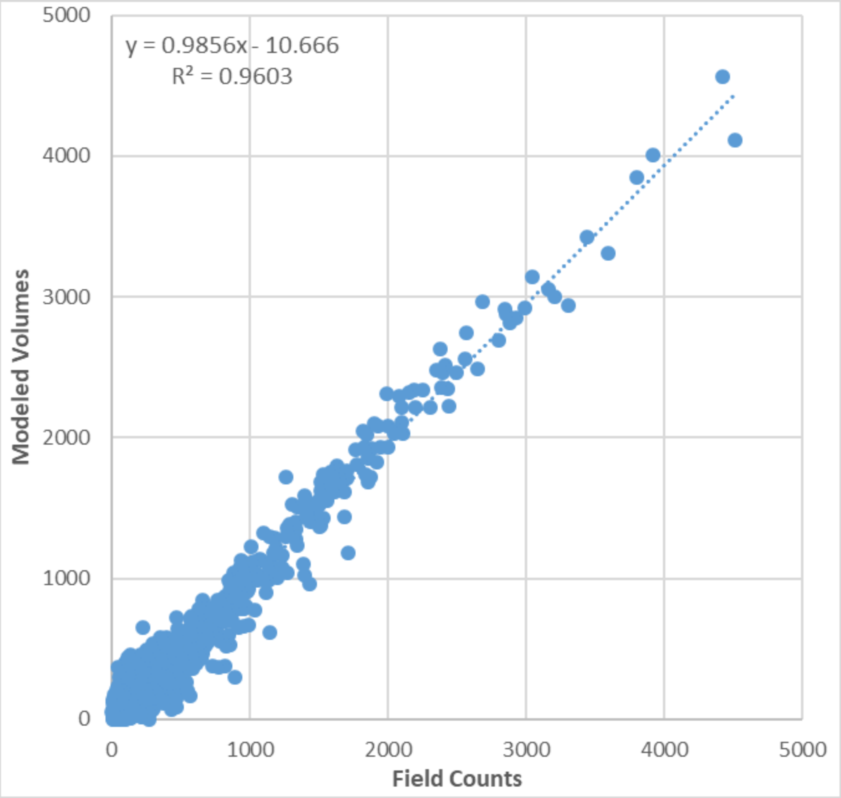


Figure 3.4 Speed Contour - I-190 Northbound AM

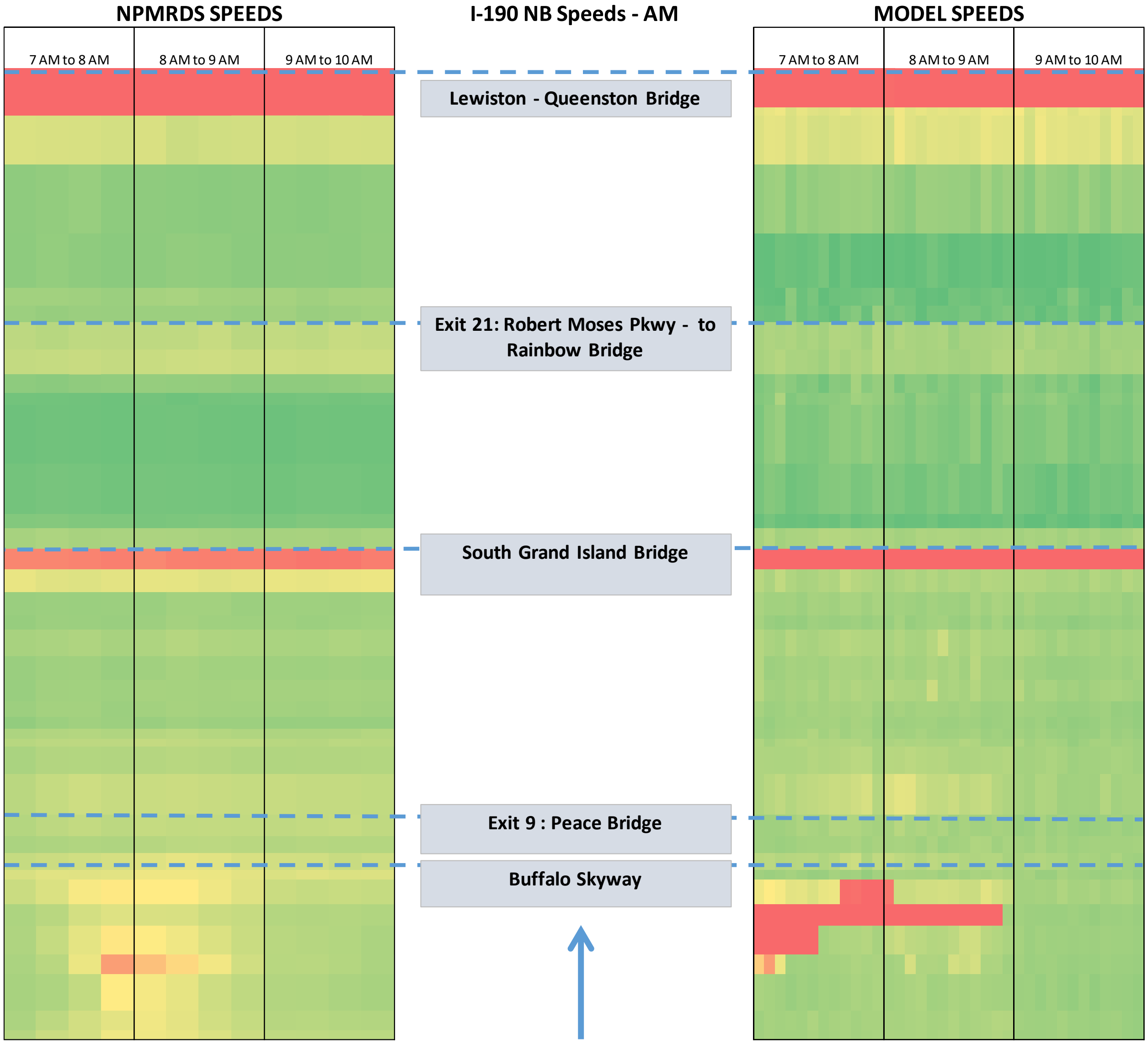
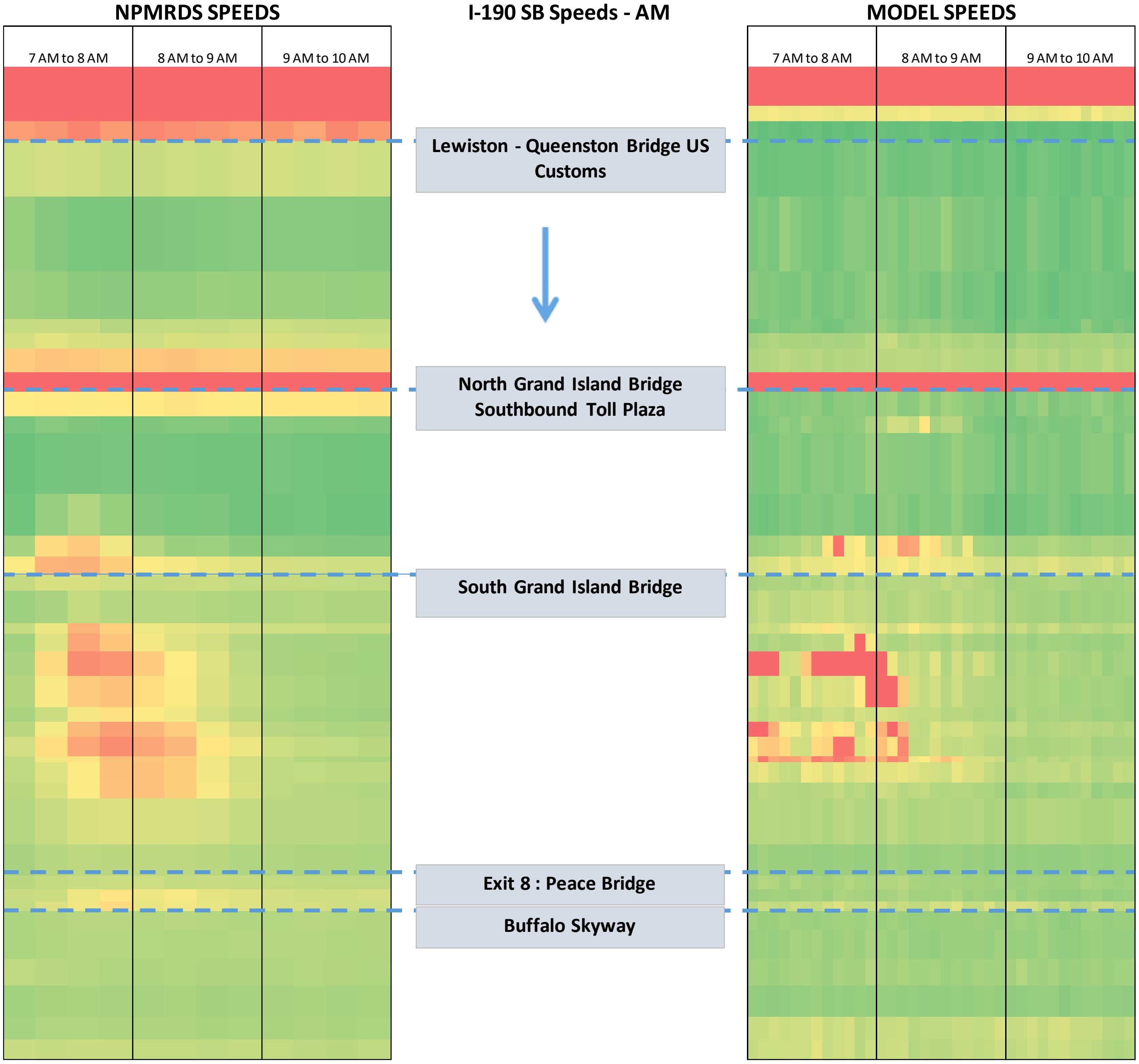


Figure 3.5 Speed Contour - I-190 Southbound AM



3.2 Typical Conditions: PM Peak Period

The volume validation statistics for the entire model (all link counts included) are presented for each hour of the PM peak period in Figure 3.6 through Figure 3.8. Figure 3.9 and Figure 3.10 present speed contour diagram comparisons between the NPMRDS field data and the simulated conditions along the I-190 corridor.

Figure 3.6 Simulated Volumes vs. Field Counts - 3 PM to 4 PM

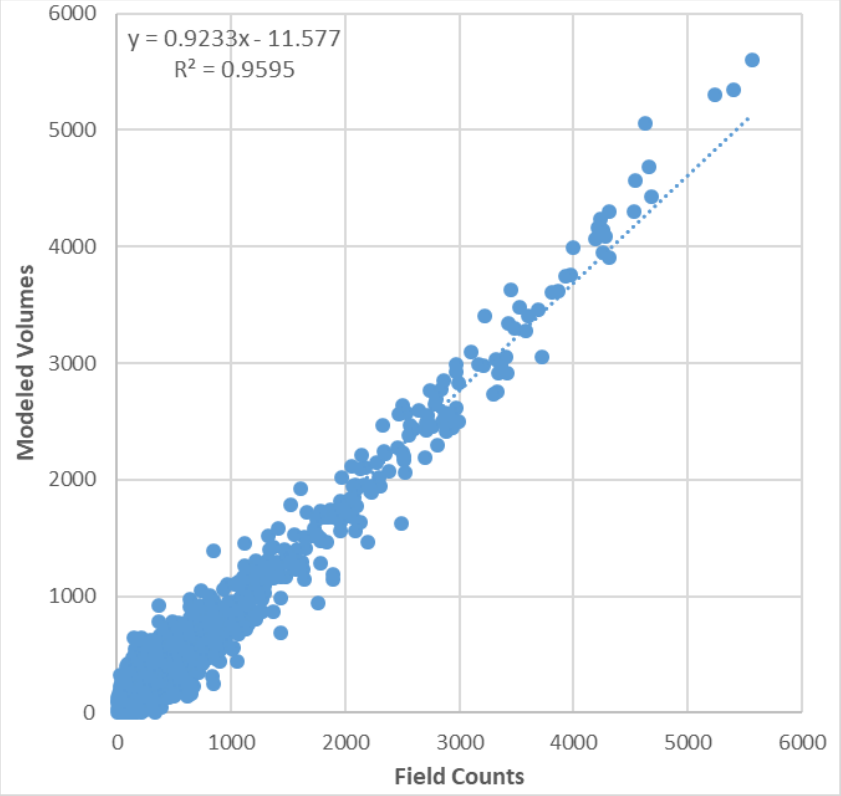


Figure 3.7 Simulated Volumes vs. Field Counts - 4 PM to 5 PM

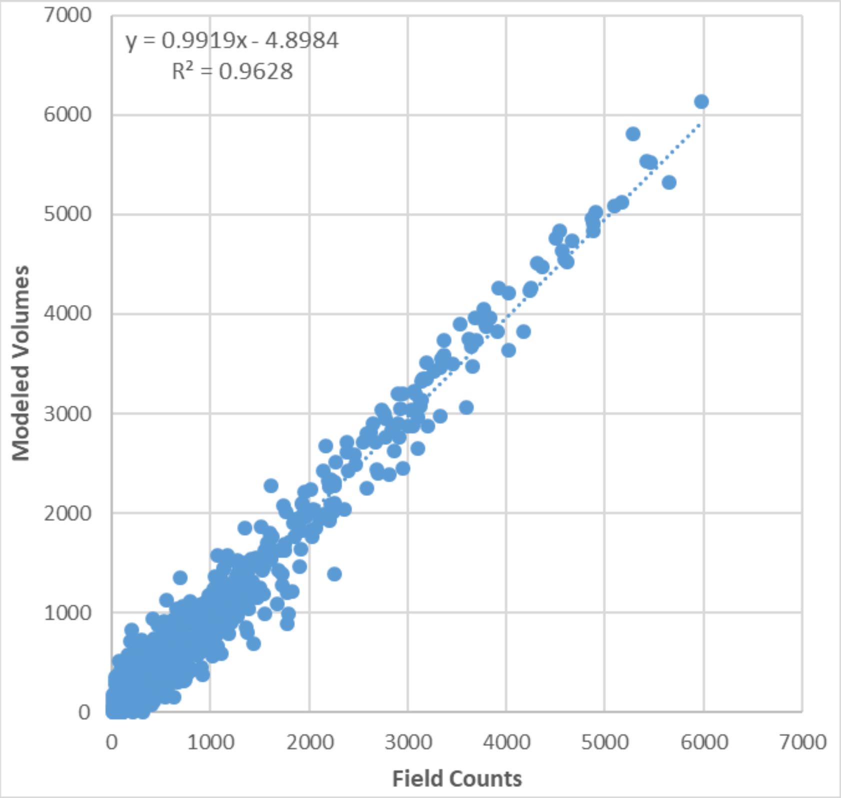


Figure 3.8 Simulated Volumes vs. Field Counts - 5 PM to 6 PM

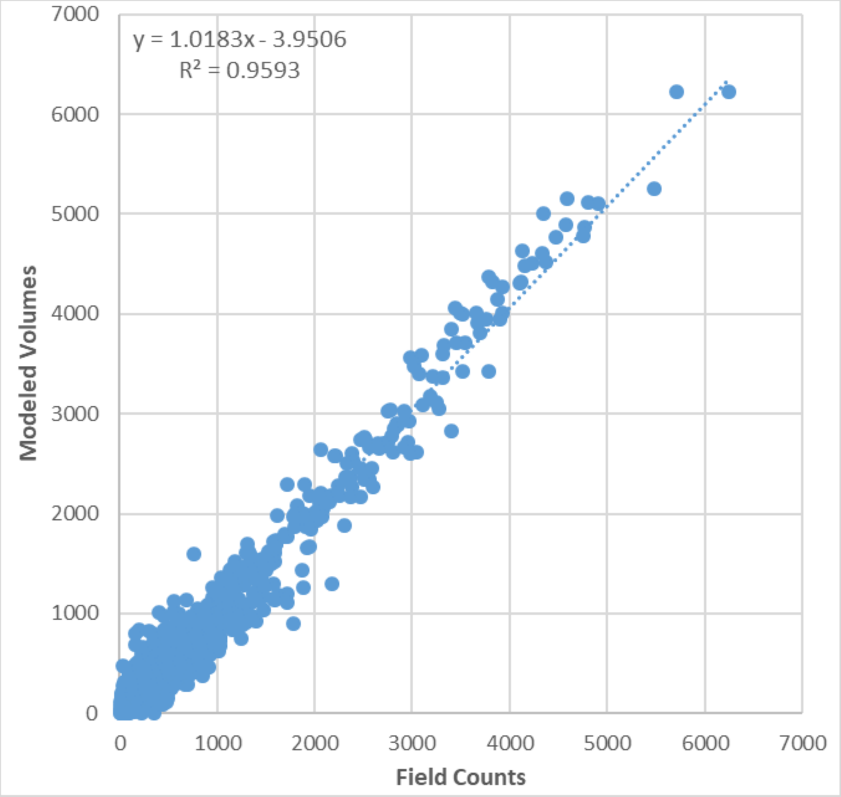


Figure 3.9 Speed Contour - I-190 Northbound PM

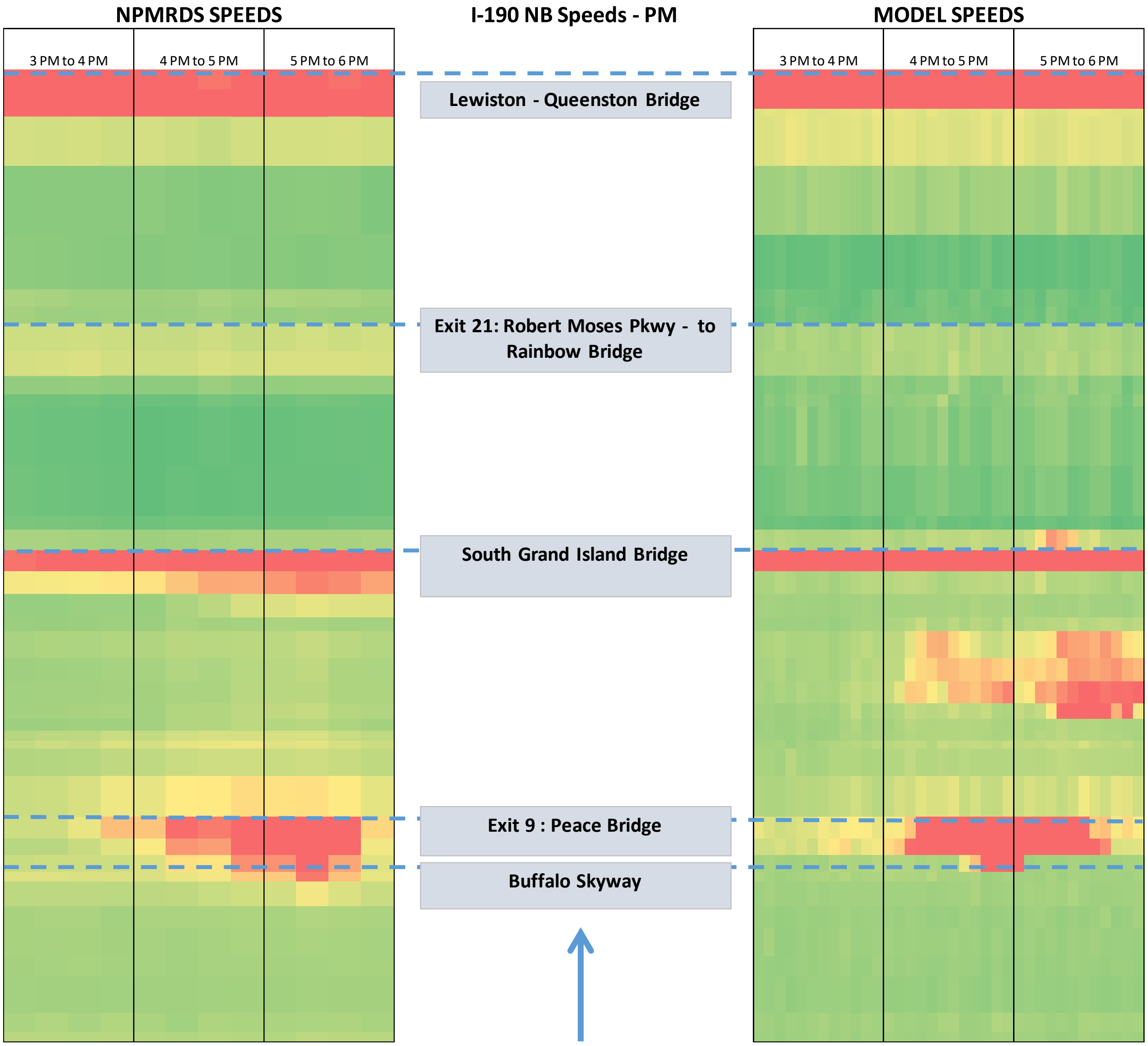
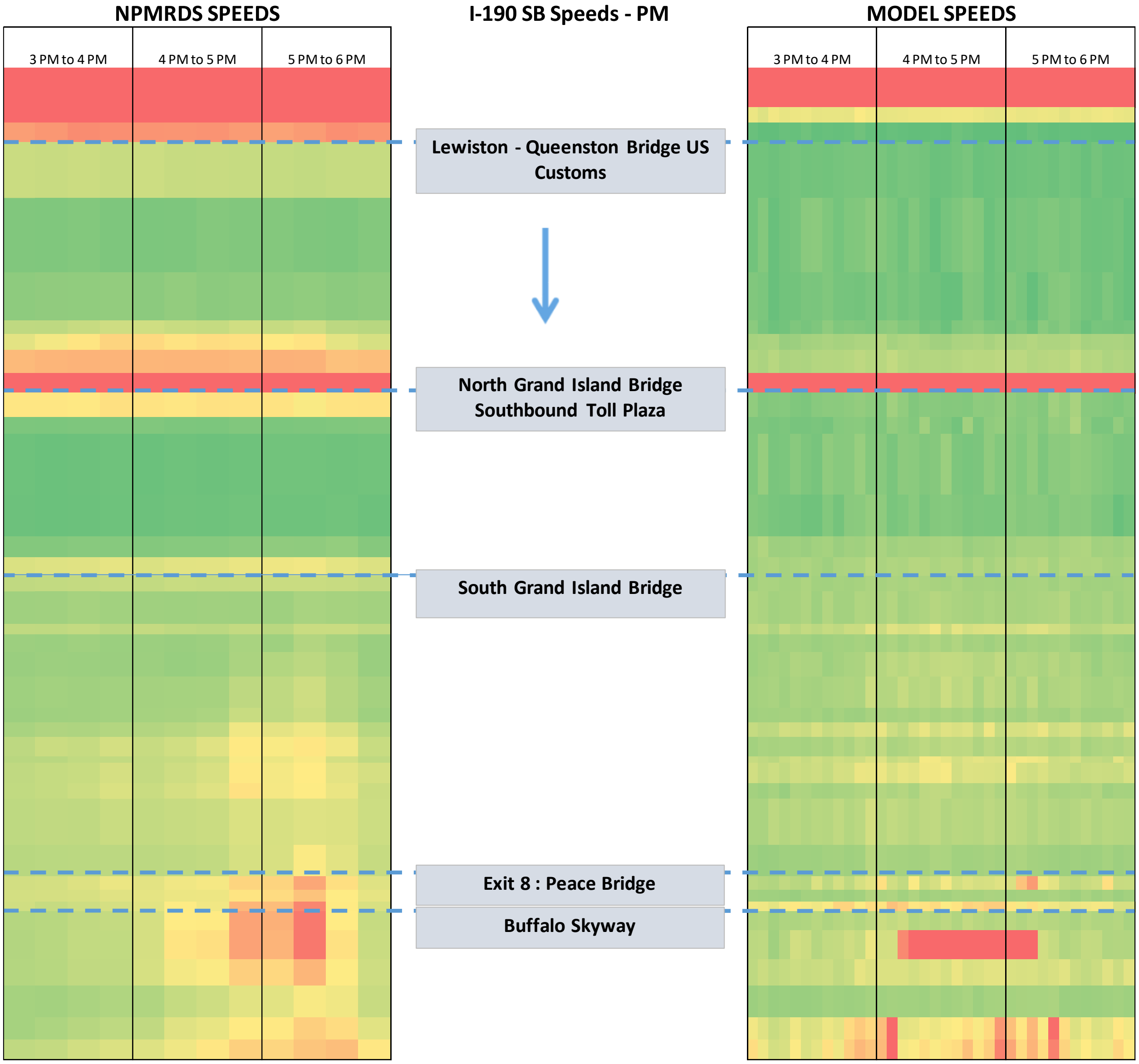


Figure 3.10 Speed Contour - I-190 Southbound PM



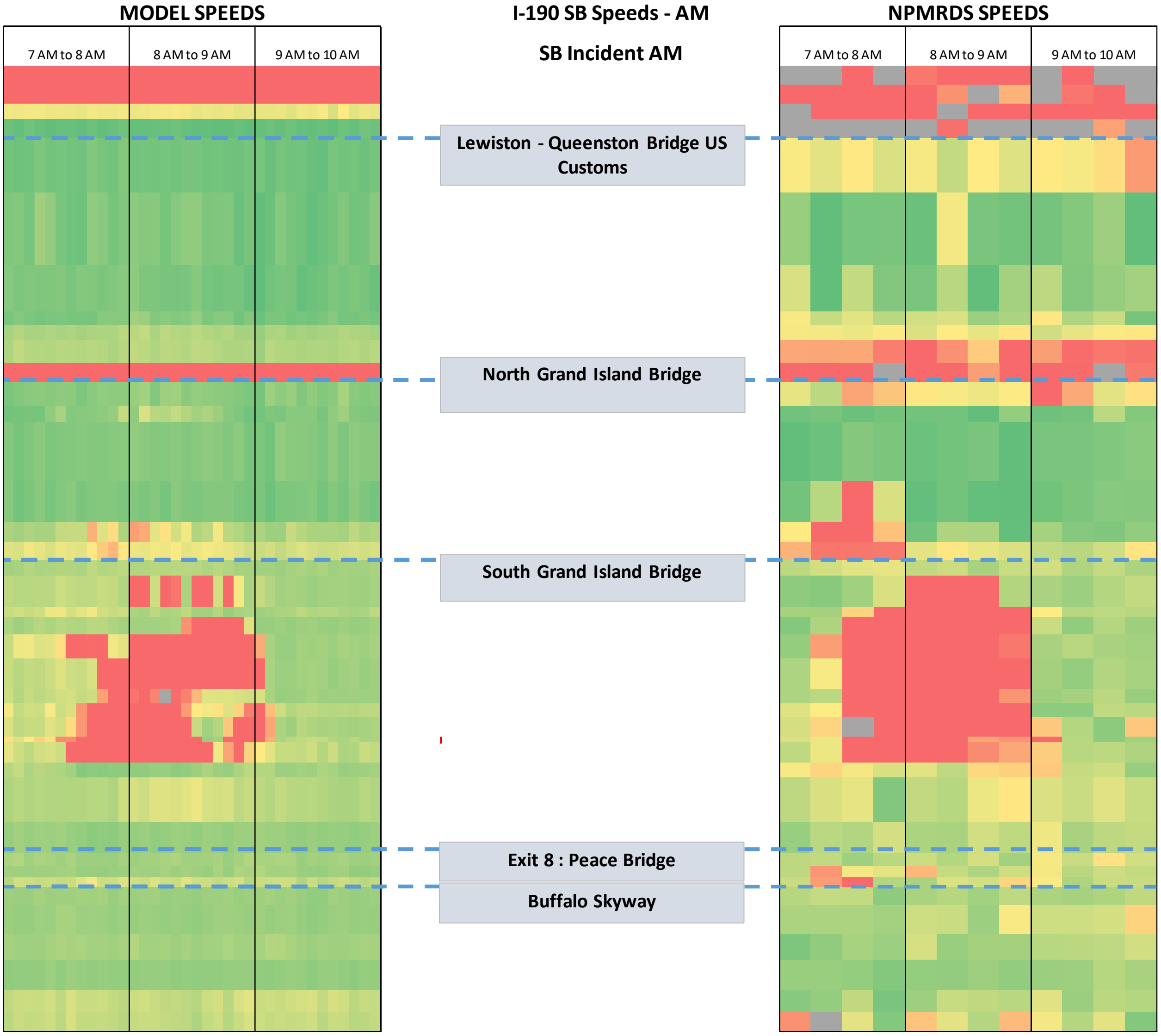
3.3 Crash Condition: AM Peak Period

An incident condition on October 7th, 2015 was selected as the Incident A scenario. The incident happened on I-190 southbound at Exit 11 (Route 198) around 7:34 AM, with one left lane closed (of two lanes). It took approximately 60 minutes to re-open the blocked lane and the total clearance time was about 80 minutes. Upon detection of the incident, Dynamic Message Signs (DMS) were activated to provide advisory about the lane closure as well as updated delay information. Notifications of the incident were also sent via email, text message, and social media.

Multiple incident locations around the I-190 and Route 198 area were tested in the simulation, as no further location information about the exact location of the crash was available. Impact area length and visibility length were adjusted to match the impacted traffic location as depicted in the speed contour maps that were based on the NPMRDS data on the incident day. The left lane was closed in the model and incident pass by speed settings were configured to reflect the severity of the traffic congestion also illustrated by the speed contour maps. To account for the impact of the DMS information, several rerouting percentages were tested as well.

Figure 3.11 illustrates the speed contour comparison between the simulated traffic conditions and the NPMRDS field data from October 7th, 2015. As shown in the figure, the congestion patterns in terms of impacted areas, congested time periods and congestion intensities were similar. Therefore, the base year Incident A scenario was considered calibrated.

Figure 3.11 Incident AM Scenario Speed Contour - I-190 Southbound AM



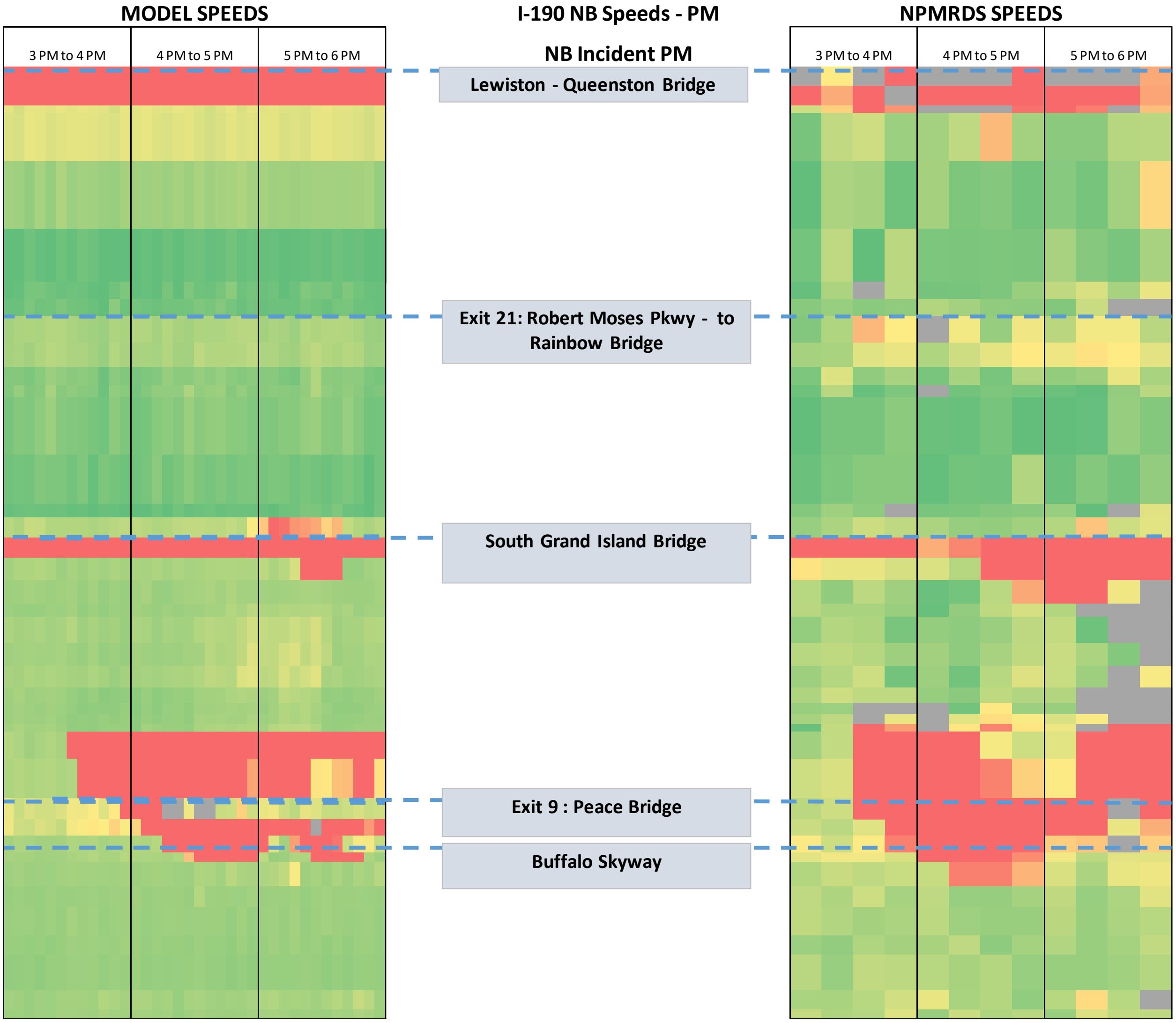
3.4 Crash Condition: PM Peak Period

An incident condition on November 13th, 2015 was selected as the Incident B scenario. The incident happened on I-190 northbound at Exit 11 (Route 198) around 3:31 PM, with one right lane closed. It took approximately 59 minutes to re-open the blocked lane and the total clearance time was about 178 minutes. Upon detection of the incident, DMS were activated to provide advisory about the lane closure as well as updated delay information. Notifications of the incident were also sent via email, text message, and social media.

As with the Incident A scenario, different incident locations around the I-190 and Route 198 area were tested to identify the location that could produce the best simulation results as compared to the field data. Impact area length, visibility length, lane closure, incident pass by speed settings and DMS rerouting percentages were adjusted accordingly.

Figure 3.12 illustrates the speed contour comparison between the simulated traffic conditions and the NPMRDS field data from November 13th, 2015. As shown in the figure, the congestion patterns in terms of impacted areas, congested time periods and congestion intensities were similar. Therefore, the base year Incident B scenario was considered calibrated.

Figure 3.12 Incident PM Scenario Speed Contour - I-190 Northbound PM



3.5 Holiday Demands: PM Peak Period

As holiday traffic demands usually fluctuate and are typically different from normal weekday conditions, the traffic data on selected holiday (July 2nd, 2015) was analyzed to establish a holiday base conditions. Border crossing volumes obtained from the Niagara Falls Bridge Commission showed increased traffic due to holiday. The field log indicated that DMS were activated to notify travelers about the border crossing delays and incident-related information.

The first step to model the Holiday Scenario was to adjust the travel demands at the bridges to match the field crossing volumes. A series of tests were conducted to increase the non-crossing demand to account for the holiday travels. Operation delays at the toll booths and border crossings were considered and a range of delay values were tested. Driving behaviors were also adjusted to mimic the traffic conditions suggested by the speed contours.

Figure 3.13 and Figure 3.14 illustrate the speed contour comparison between the simulated Holiday traffic conditions and the field data recorded from July 2nd, 2015. As shown in the figures, the congestion patterns were reasonably similar.

Figure 3.13 Holiday Scenario Speed Contour - I-190 Northbound PM

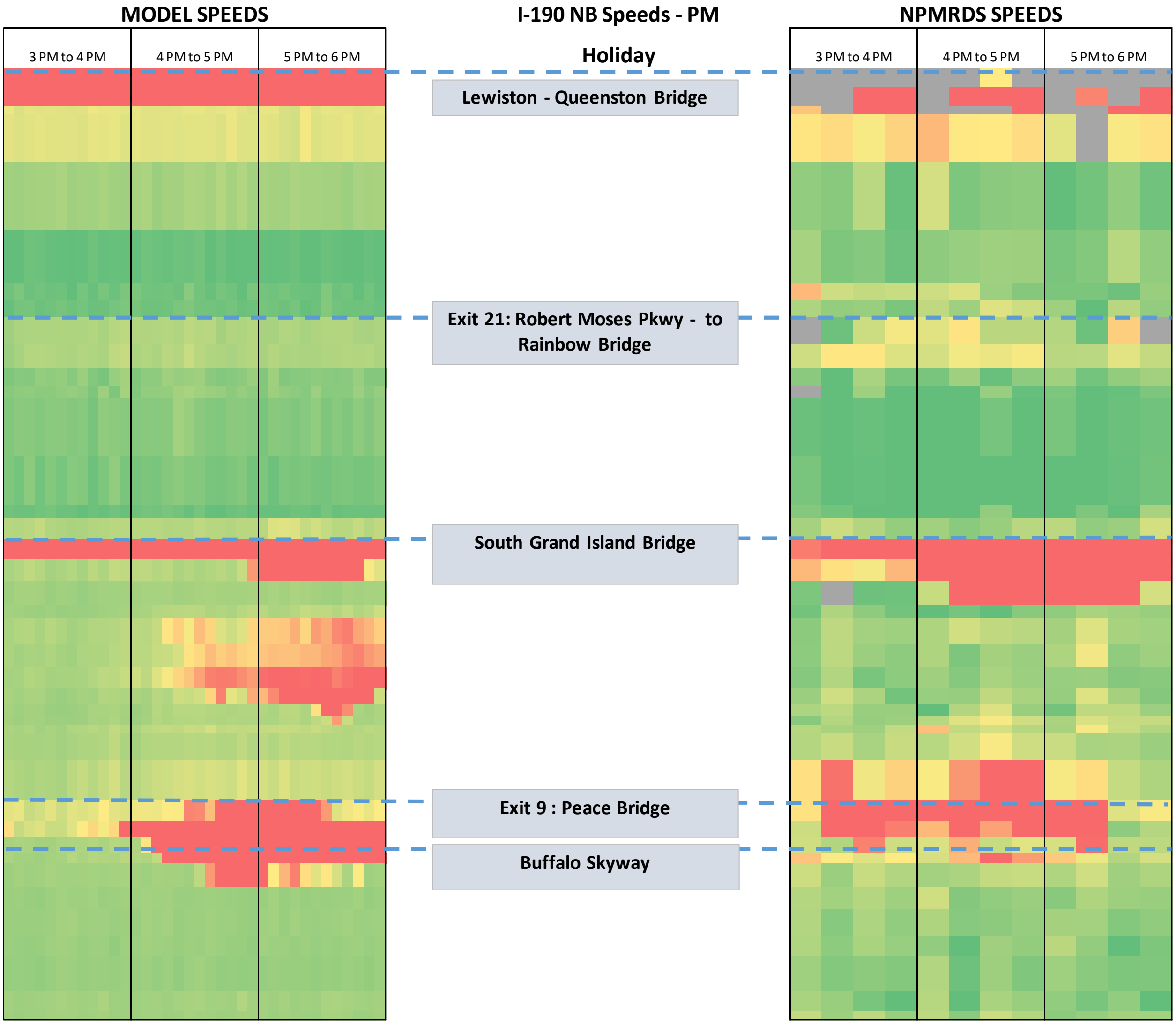
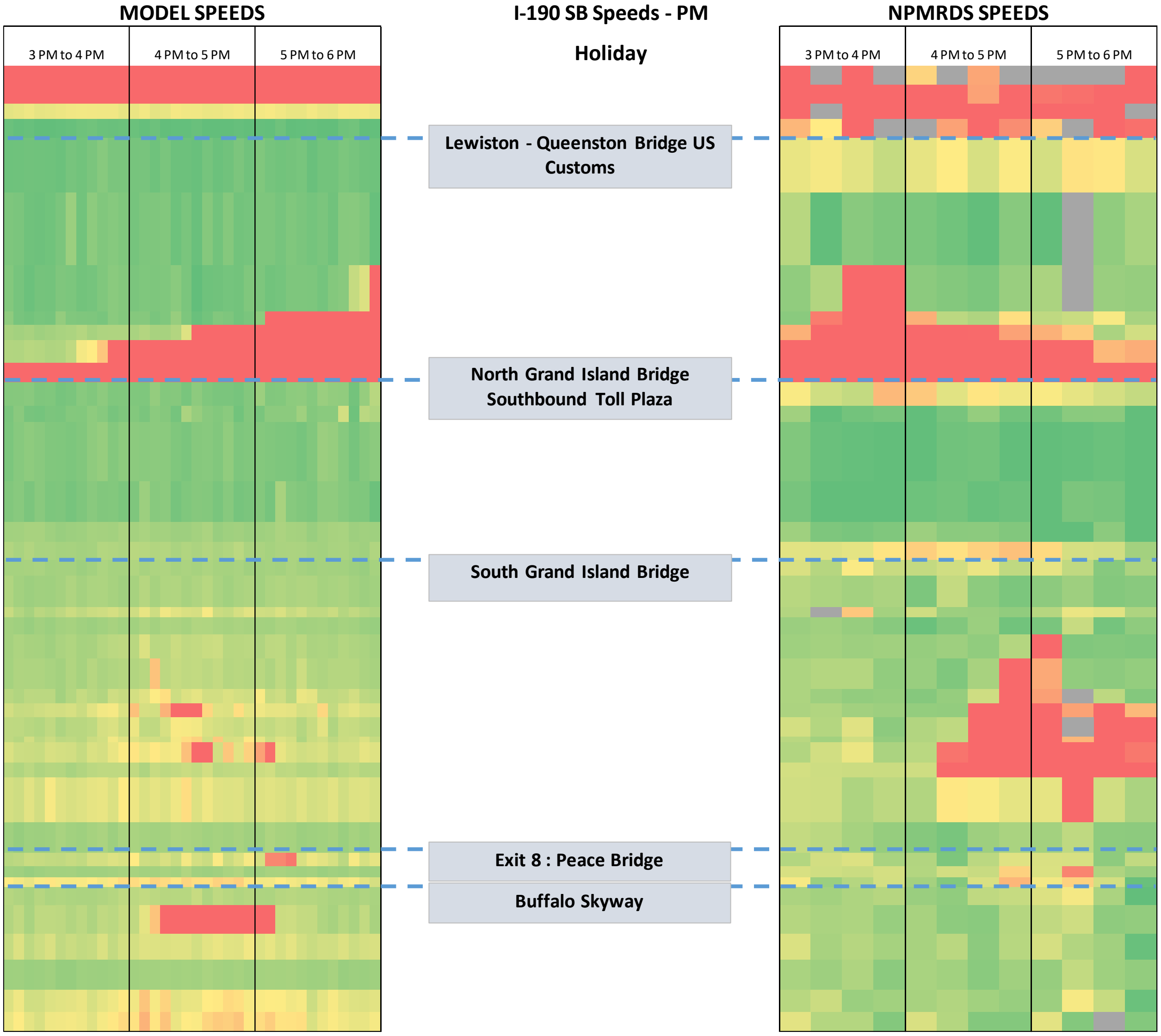


Figure 3.14 Holiday Scenario Speed Contour - I-190 Southbound PM



3.6 Snow Conditions: AM Peak Period

Based on review of historical observed weather data, the morning of January 7th, 2015 was selected to represent the Snow Scenario. Heavy snow was seen in the area during the morning peak and light snow then continued for the entire day. Multiple notes in NITTEC logs regarding crashes and congestions were recorded.

Research papers related to traffic under incremental weather were reviewed. Consistent with the finding of the literature review, parameters including model resolution, microscopic/mesoscopic reaction times and vehicle acceleration and deceleration rates were adjusted to reflect the weather impacts on the driving behaviors. Freeway speeds were lowered based on the roadway conditions indicated by the speed contours. A more cautious driver group with higher reaction times was created and assigned to the network in the first hour (7-8 AM) to account for the heavy snow conditions. An incident recorded at I-190 southbound Exit 5 was also simulated.

Figure 3.15 and Figure 3.16 illustrate the speed contour comparison between the simulated Snow Scenario and the NPMRDS field data from January 7th, 2015. As shown in the figures, the congestion patterns were reasonably similar.

Figure 3.15 Snow Scenario Speed Contour - I-190 Northbound AM

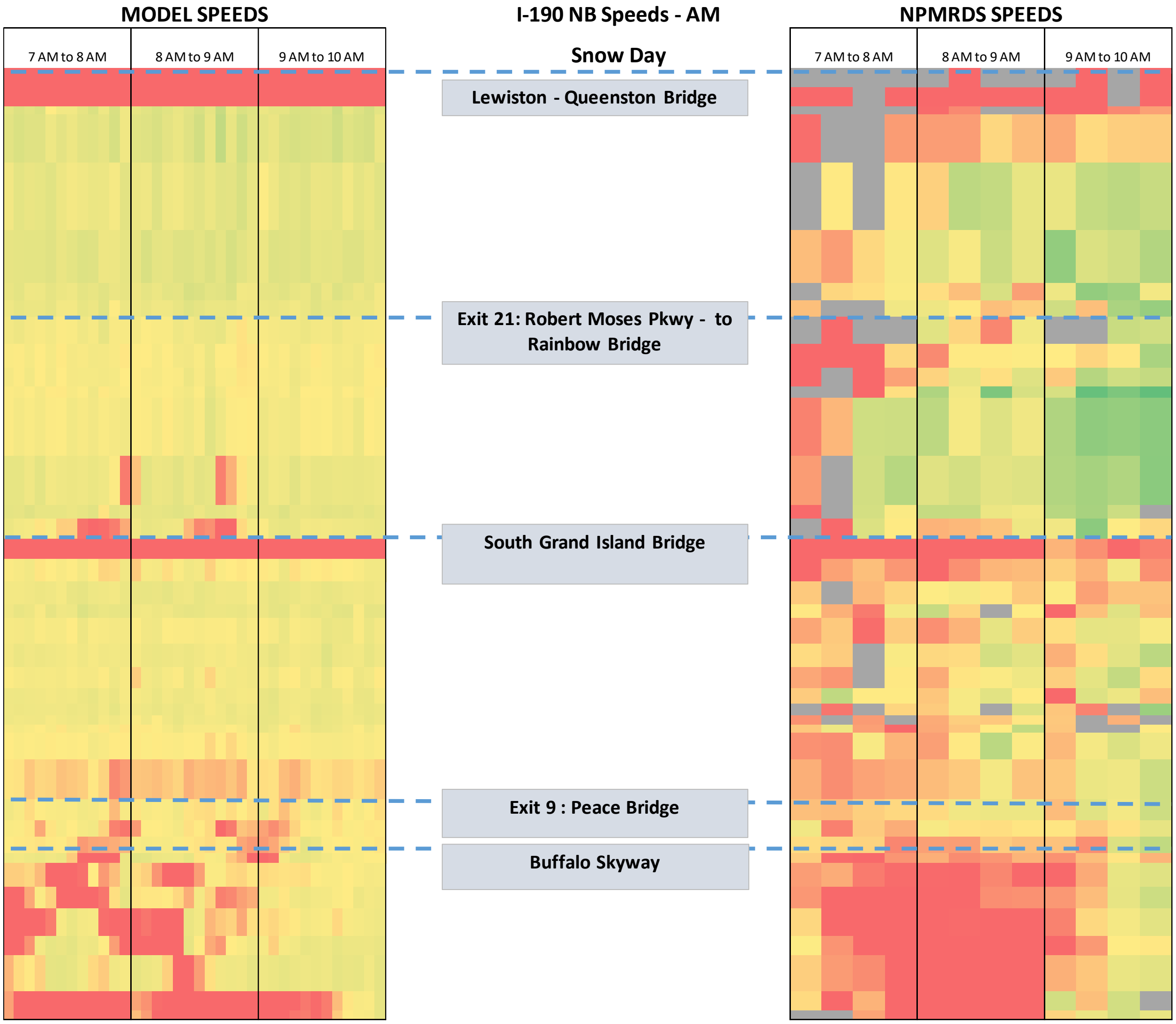
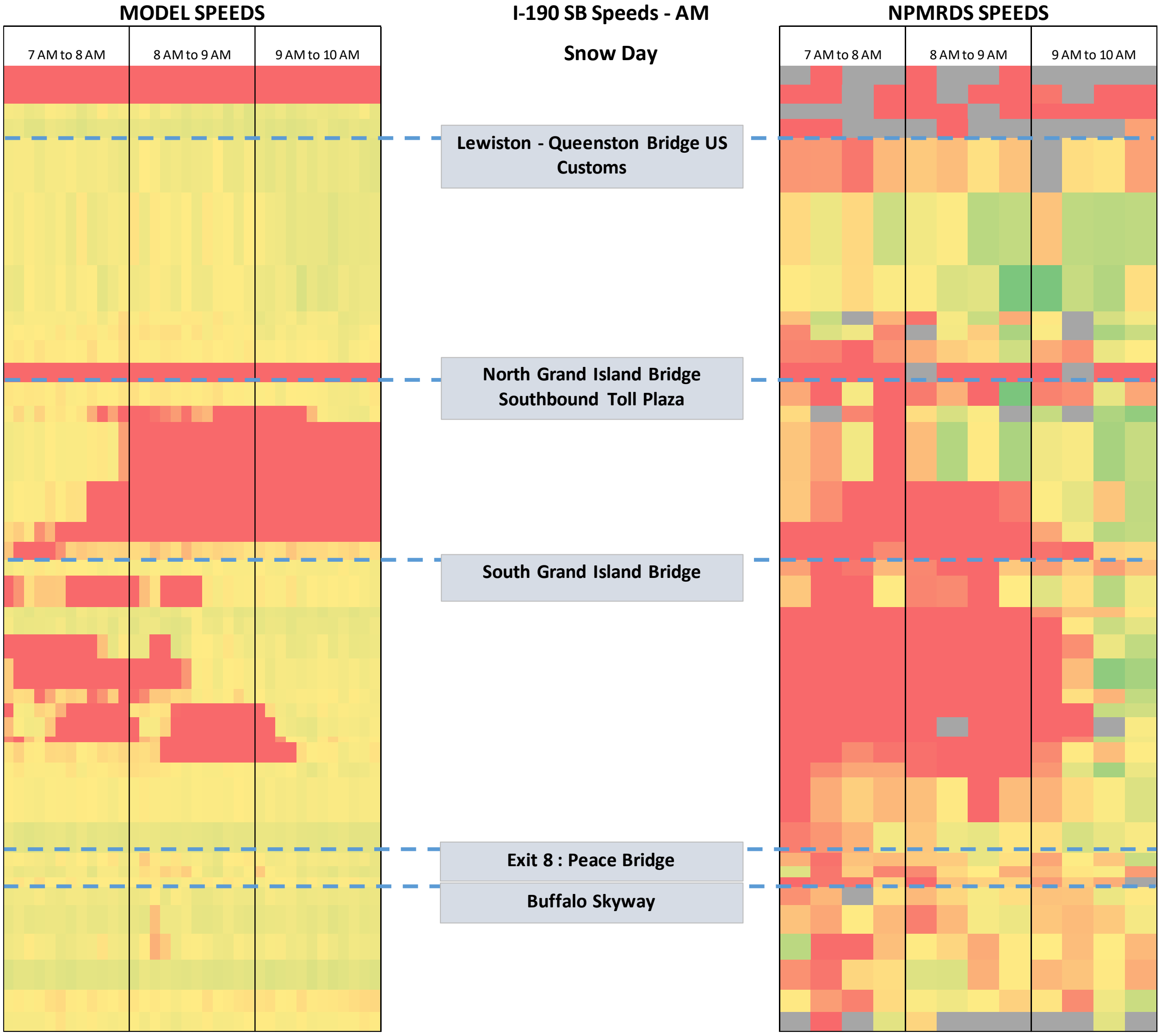


Figure 3.16 Snow Scenario Speed Contour - I-190 Southbound AM



3.7 Game Day Conditions: PM Peak Period

A Buffalo Sabres home game at the KeyBank Center on November 3rd, 2016 was selected to represent the typical Game Day traffic conditions. This game was selected as the Sabres were playing against the Toronto Maple Leafs, which will often bring in large crowds to the game, many of which will drive to Buffalo from the nearby Toronto area. The *Calibration, Proposed Utilization, and Traffic Analysis Comparison for Downtown Buffalo Waterfront Development Simulation Modeling* study was provided by the GBNRTC staff and was utilized in developing the Game event trip generation and distribution. A TransModeler simulation model that was used to study the event scenario in the study was also provided to Cambridge Systematics and was leveraged in preparing the game day traffic condition patterns.

Additional traffic count data collection was also conducted the week of the game. Several ATR traffic counts were conducted in the vicinity of the arena and on key roadways leading to and from the arena. These counts were then used to compare the game day to the other days of that same week to estimate the changes on vehicle flows in the vicinity of the arena on a game day.

The game event demand was developed based on the assumption that around 18,000 people went to the game. Among the total number of attendees, 2,000 boarded public transit and the rest utilized automobile. FHWA-USDOT documents a national average for event destined travelers of 2.5 occupants per vehicle. This ultimately leads to 6,200 additional vehicles entering the network. 70% of the trips were assumed to enter the network during the simulation period of 3-6 PM given the 7 PM game start time.

The additional eastbound bridge crossing volumes (from Canada to the U.S.) were assumed to entirely go to the Sabre game. This additional demand was assigned from a handful of zones on the Canadian side to the parking lots around KeyBank Center. The rest of the game demand that was within the U.S. side was developed under the assumption that the AM trips reflect a similar travel pattern with vehicles entering downtown from external zones and concluding at event zone destinations. The AM trip matrices that contain the AM travel patterns were adjusted to calculate the game demand.

Figure 3.17 and Figure 3.18 illustrate the speed contour comparison between the simulated Game traffic conditions and the field data. As shown in the figures, the congestion patterns were reasonably similar.

Figure 3.17 Game Scenario Speed Contour - I-190 Northbound PM

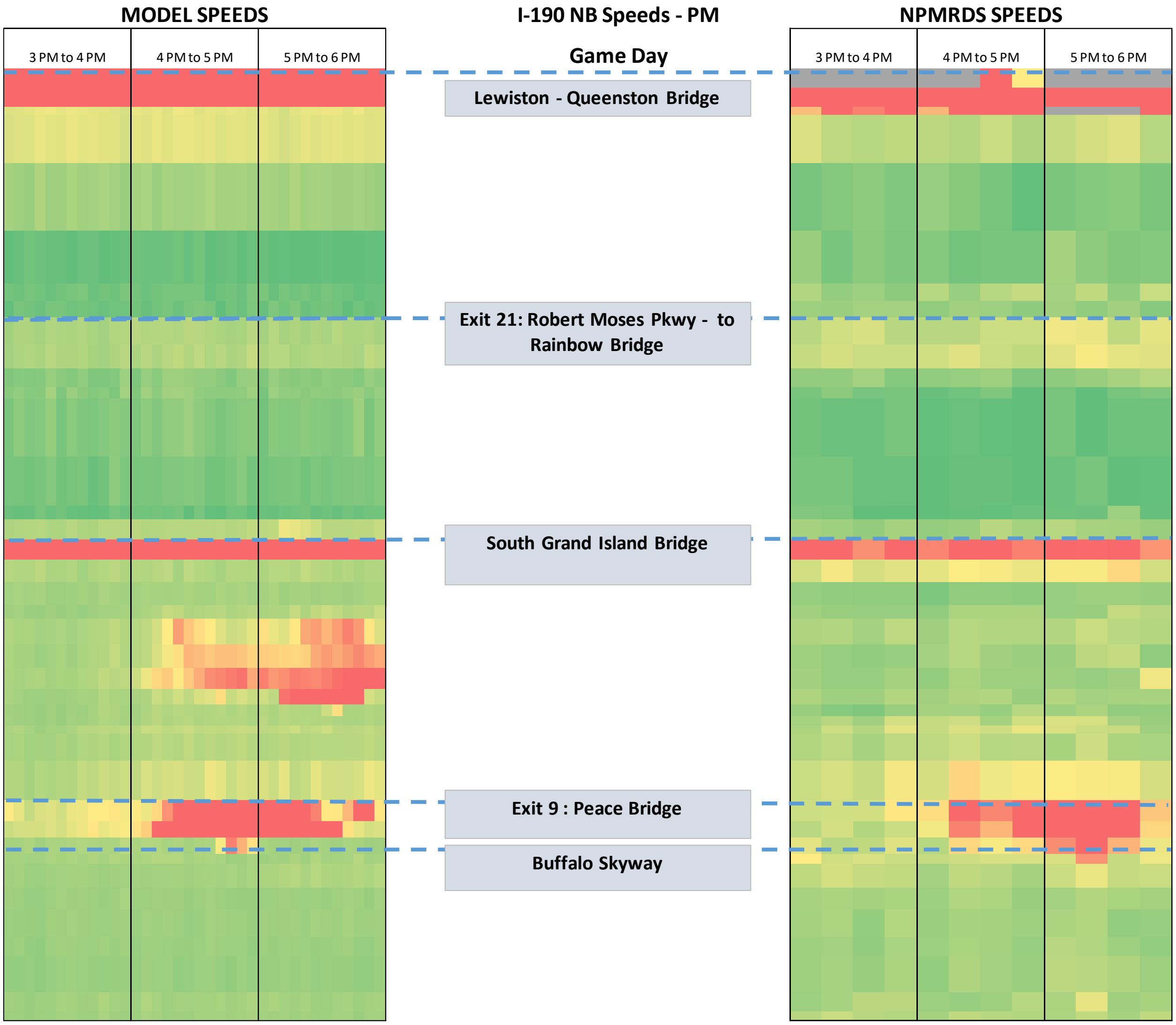
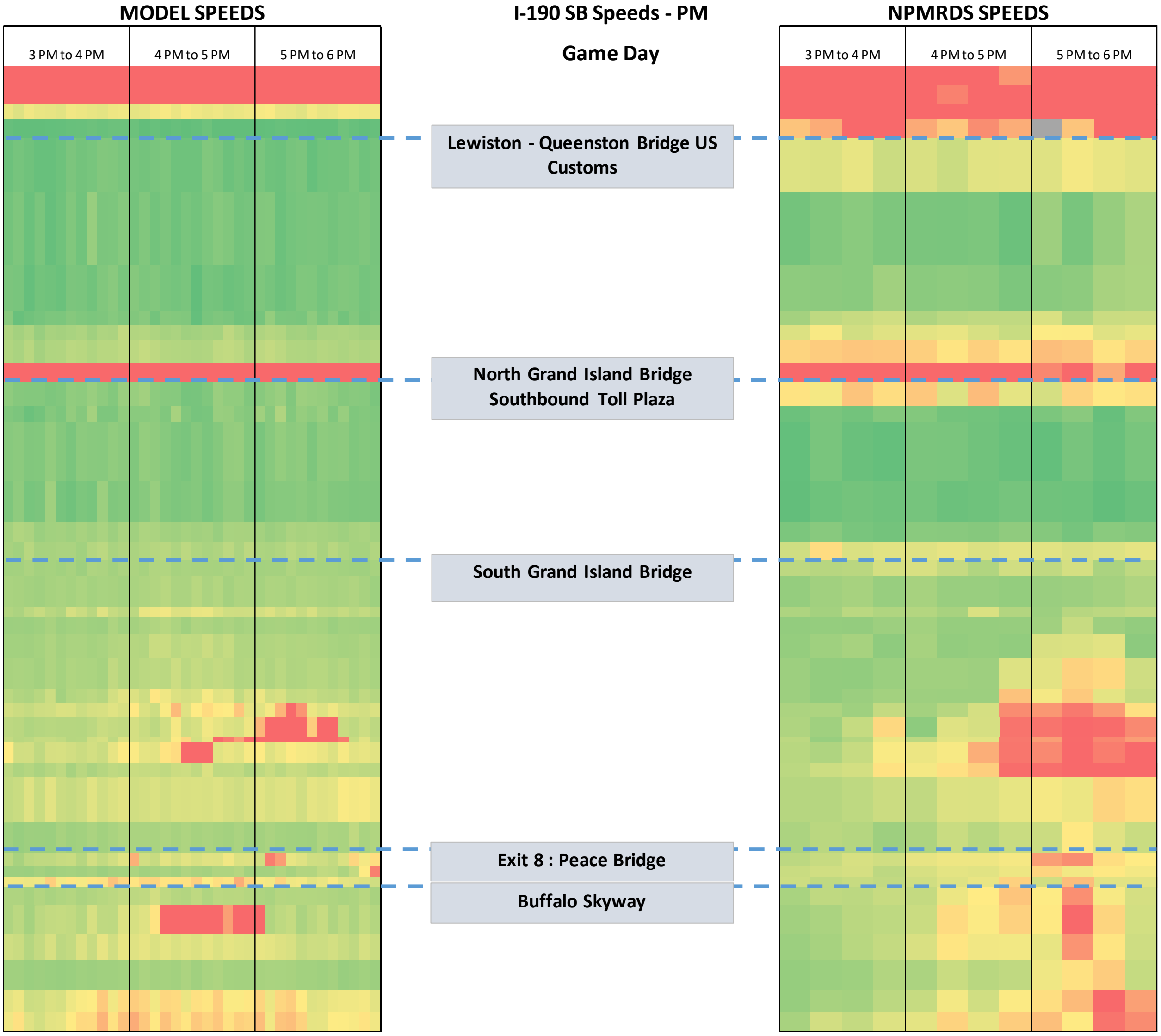


Figure 3.18 Game Scenario Speed Contour - I-190 Southbound PM



4.0 ICM Strategies

Numerous different ICM strategies were considered for inclusion in the BNICM study. A detailing of the larger universe of strategies that were initially considered can be found in the separate document "*Buffalo-Niagara Integrated Corridor Management: ICM Strategies Primer*". The following section presents the specific ICM strategies that were selected for consideration and inclusion in ICM response plans to the various base condition scenarios that were discussed in the previous section. This chapter also includes details on how the various strategies were implemented and incorporated into the simulation modeling efforts to evaluate the effectiveness of the ICM strategies and to estimate the potential strategies benefits to the operations of the Buffalo-Niagara region that could be expected. The following different ICM strategies were selected for consideration in the ICM planning study as part of the response strategies:

- Improved Dynamic Traveler Information
- Freeway Incident Detection and Service Patrol
- Ramp Metering
- Variable Speed Limits and Queue Warnings
- Variable Toll Pricing
- Signal Coordination
- Parking Intelligent Transportation Systems (ITS)
- Dynamic Lane Controls
- Road Weather Information System (RWIS) and Plow Management

Additionally, this section presented details of initial cost estimates for the strategies as deployed in the BNICM evaluations with the simulation model. As detailed cost estimates for each component were not developed at this stage of the analysis, estimated costs to implement and operate the equipment needed to implement many of these strategies were leveraged from FHWA's *Tools for Operations Benefit Cost Analysis (TOPS-BC)* tool. Version 4.0 of the TOPS-BC tool was used for this analysis. This spreadsheet-based toolbox summarizes the typical benefits and costs that have been seen when deploying various ITS and Transportation Systems Management and Operations (TSMO) strategies across the country. Costs are estimated as a mixture of the initial capital installation costs as well as the annual operating and maintenance costs associated with deploying various ITS and TSMO technologies. From these costs, an overall annualized life-cycle cost can be estimated to allow a direct comparison to the annual monetized estimated benefits that can be expected from the deployment of such technologies. While the TOPS-BC tool includes a spreadsheet-based tool to estimate benefits as well, only the cost components of the TOPS-BC tool were used for this study, as the benefit estimate was completed using a more robust simulation-based methodology using the BNICM simulation model.

While this level of cost analysis is appropriate for this level of planning for the a potential ICM deployment, it is recommended that more detailed costs estimates would be developed as part of follow up design and implementation efforts that would be needed to actually deploy these technologies within the Buffalo-Niagara region.

4.1 Dynamic Traveler Information

4.1.1 Background

Improved information about the various current roadway travel conditions across the regional network allows users to better make informed decisions about the travel options that they have in response to the specifics of the network operations at the time of their trip. Such information can help travelers not only better select which route to take to complete their trip with a minimal travel time, but also potentially help identify which mode to take or if changing the departure time of the trip in response to unexpected conditions such as a crash or weather impacts. Overall, the goal of improved Dynamic Traveler Information is to better inform the traveling public of current travel conditions, especially when those conditions are not the normal routine congestion that would commonly be expected during regular commuting peak periods, such as during crashes events, unexpected construction conditions, during high or special demand events, or other non-typical conditions that change the roadway's normal operating conditions.

Dynamic Traveler Information can be communicated via a variety of methods, and the region has already deployed many of them including via New York State's 511 system, the New York State Thruway's smartphone app, NITTEC's traveler information smartphone app, and via messaging on the existing DMS across the region. In recent years, more information is also being passed to the general traveling public through private means, such as via connected in-vehicle navigation systems or smartphone-based applications (e.g. Waze, Google Maps, HERE, Apple Maps, etc.).

4.1.2 BNICM Implementation

With the existing services already provided by NITTEC and its member agencies, combined with the recent growth of the use of private smartphone and in-vehicle navigation systems, there are limited expectations that NITTEC could dramatically increase the transmission of information to in-vehicle devices to better transmit near-real time information to the traveling public than it already is. It is noted that the potential for future connected vehicle technology will provide more options in the future, but the market penetration of vehicles with connected capabilities of receiving transmissions from roadside units deployed by NITTEC is currently minimal and a larger market share is needed to reach a larger share of vehicles operating on the roadways. However, the deployment of additional DMS equipment would allow for an expanded dissemination of real-time dynamic traveler information to a wider proportion of the traveling public in a near real-time manner along the equipped roadways.

For the purposes of this study, the assumption was made that six additional DMS signs would be added to the existing system of DMS signs in the region. While exact locations were not determined in the analysis, the assumption is that they would be added along the northern sections of I-190 (on Grand Island and further points to the north) to expand DMS coverage across the entire I-190 freeway with DMS coverage in the region.

To account for the increased amount of Dynamic Traveler Information in the region in the evaluation of the ICM strategies, the percentage of simulated travelers with current knowledge of the simulated roadway conditions in the BNICM model was conservatively assumed to increase by 10 percent in the ICM analysis scenarios versus the non-ICM analysis scenarios. Within the model, this allows a larger percentage of the simulated drivers to see the real-time simulated traffic congestion conditions and allows them to adjust their travel route dynamically in response to those conditions versus the normal conditions that they were expecting (typical commute travel conditions). This increased awareness of the dynamic roadway conditions was applied to both pre-trip departure route choice changes and to en-route changes within the simulated ICM scenarios.

It is important to note that no prescribed alternative routes were provided to the simulated drivers to follow in place of their normal or habitual travel paths. Instead the additional 10 percent of drivers ‘knew’ of the current roadway conditions across the network and considered making adjustments to their travel paths on their own given their current location, their destination, and the estimated travel times along both their current or habitual route and various different alternative routes under the current network conditions.

4.1.3 Estimated Costs

Costs for the new DMS deployments were estimated using FHWA’s TOPS-BC tool. As NITTEC already operates numerous DMS signs across the region and already has the centralized capabilities and systems in place, only the incremental costs to deploy additional DMS sites were included in the estimated costs. Using the default costs estimates within the TOPS-BC tool, a total levelized annual life cycle cost of $144,978 was estimated for the six additional DMS deployments. Details of the cost estimates are presented in Table 4.1.

Table 4.1 Cost Estimates for Added Dynamic Message Signs

Description of Equipment	Useful Life (years)	Capital / Replacement Costs ($)	Annual O&M Costs ($)	Annualized Costs ($)
Incremental Deployment Cost Components				
Communication Line	5	770	930	1,084
Variable Message Sign	10	89,000	4,200	13,100
Variable Message Sign Tower	25	100,000	220	4,220
Total Incremental Costs (per unit)		189,770	5,350	18,404
Total Incremental Costs (6 signs)				110,424
Total Deployment Levelized Costs (6 signs)				**144,978**

Source: Useful life and unit costs from TOPS-BC v4.0.

4.2 Freeway Incident Detection and Service Patrol

4.2.1 Background

Freeway incident detection allows for a faster detection of crashes or other incidents occurring on the roadways which in turn allows for faster response by the needed emergency responders, faster clearance of the crash or incident from the roadway, and faster restoration of the normal capacity of the roadway. All this equates to less overall user delays created by the crash or incident. While freeway incident detection has traditionally been completed by observations and confirmation via field cameras, freeway patrol vehicles, police or other responders, or even by public travelers, methods have improved in recent years with more wide-spread near real time probe based speed information provided by ‘big data’ sources. Through the implementation of computer algorithms acting as ‘virtual TMC operators’ who can monitor all roadway speeds in real-time, when any roadway section sees speeds drop from the normal or expected speeds for the given time of day and day of the week, alarms can be set to notify TMC operator of the speed drop long before building queues would be normally be noticed. The causation of the disruption can then be determined via field cameras, and the appropriate responders can be dispatched to attend to the crash or incident as appropriate.

While detecting the incident faster is one element that would improve corridor operations, Freeway Service Patrols would further improve on the incident clearance time and the corridor's time to return to normal operations. By having resources ready in the corridor to respond to the incident and help clear the incidents in less time. NYSDOT currently operates their Highway Emergency Local Patrol (HELP) program on many roadways across the state, including along I-290 and SR-33 in the Buffalo-Niagara region, they currently do not operate patrol vehicles along the I-190 corridor. Adding resources to this program to add HELP vehicles to patrol the I-190 corridor during weekday peak periods would help provide assistance and resources to the crashes and incidents along the I-190 corridor.

4.2.2 BNICM Implementation

To include the impacts of a freeway incident detection system deployment and added freeway service patrols in evaluation of the ICM strategies within the BNICM simulation tool, some estimates of the impacts of reduced incident response and lane clearance times needed to be assumed. It was assumed that such a deployment would reduce the time to detect a crash by three minutes and that the time to clear a major crash would reduce by five minutes. When added together, the overall duration of the lane blockage(s) from the moment of the crash to the moment of restoration of the full roadway capacity would be a total of eight minutes faster under the ICM scenarios versus the similar non-ICM scenarios. The shorter incident clearance time was the only change to the inputs of the simulation models; other benefits in terms of reduced system user delays associated with the shortened clearance time would be estimated by the simulation model.

4.2.3 Estimated Costs

Adding Freeway Incident Detection using real-time speed data feeds would require the acquirement of an existing incident detection software and the integration of that system into NITTEC's existing TMC. No additional field cameras were assumed to be added as part of this system deployment, as NITTEC already has good camera coverage of most of the I-190 corridor. Additionally, since NYSDOT already has a robust HELP program across the state and even within the Buffalo-Niagara region, no additional system costs were assumed to be needed and only the incremental costs of addition patrol vehicles to the I-190 corridor were accounted for. Costs to deploy an incident detection system and an expanded freeway service patrol along the I-190 corridor were taken from the TOPS-BC tool for selected components of traffic incident management systems and are summarized in Table 4.2. Based on these unit cost estimates, a total levelized life cycle costs for the detection system and expanded freeway patrol is estimated to cost $296,998 on average per year.

Table 4.2 Cost Estimates for Freeway Incident Detection and Service Patrol

Description of Equipment	Useful Life (years)	Capital / Replacement Costs ($)	Annual O&M Costs ($)	Annualized Costs ($)
System Deployment Cost Components				
TMC System Integration	20	205,000	0	10,250
TMC Incident Response Software	2	15,300	770	8,420
Total System Costs		220,300	770	18,670
Incremental Deployment Cost Components				
Incident Response Vehicle	7	87,000	15,500	27,929
Incident Response Labor	1	0	96,000	96,000
Communication Line	5	770	260	414
Total Incremental Costs (per vehicle)		87,770	111,760	124,343
Total Incremental Costs (2 vehicles)				248,685
Total Deployment Levelized Costs (Incident Detection & 2 patrol vehicles)				**296,998**

Source: Useful life and unit costs from TOPS-BC v4.0.

4.3 Ramp Metering

4.3.1 Background

Ramp metering involves the placement of a system similar to a traffic signal on the on-ramps to a freeway to meter the flow of traffic on the on-ramp, therefore reducing the impacts of many closely spaced or platooned vehicles on the on-ramp trying to enter the freeway in succession. The goal of the ramp meter is not to reduce the total number of vehicles using the ramp over a given peak hour or peak period, but instead to smooth the flow of the on-ramp traffic across that time period. The ramp meter alternates between red and green signal states, with a vehicle being allowed to proceed on the green lights, thus spacing out or metering the flow of traffic on the on-ramp that may arrive together at the on-ramp in a platooned state (say from a nearby arterial traffic signal). By spacing out the on-ramp vehicles, the disruptions to the mainline flows will be minimized and the overall impacts of the ramp junction on the freeway operations are improved by allowing more choice in gaps between mainline vehicles for the on-ramp vehicle to choose from which allows a more controlled merge of the on-ramp vehicle. While this can increase the delays of vehicles on the ramps themselves, in theory the freeway mainline lanes should operate at higher speeds with ramp metering in place and overall mobility of the system should improve. In addition to the mobility benefits, previous deployments of ramp metering have shown to have safety benefits by reducing the number of crashes occurring in the vicinity of the on-ramp.

When ramp meters see short term surges in demands and the available queue space on a given ramp behind the meter fills up, the queue spillback could start to affect nearby arterial operations and can increase the traffic delays on the arterial system. To prevent the impacts to the arterial system, queue detection is often added to the on-ramps near the acceptable end of the ramp meter queue to notify the meter controller when a queue has grown to a point where spillback to the connecting arterial streets is possible. When the queue detector is triggered, the ramp meter controller will reduce the timing between green lights, allowing an increased flow rate of vehicles past the ramp meter to shorten the queue for the ramp meter to a point where arterial operations will not be impacted. While this could degrade the improvements to the on-ramp junction freeway operations, it also prevents queues from the ramp meter spilling back into and affecting the operations of the arterials system, a condition which can potentially negate the delay and safety benefits at the on-ramp junction with the freeway that are provided by the implementation of the ramp meter.

In its most basic form, a simplistic time of day fixed-time metering algorithm can be used to meter traffic given pre-determined typical ramp volumes and freeway mainline conditions. This is akin to a fixed time of day traffic signal control plan at an intersection. While it is easy to implement and has limited sensors to build and maintain, this type of metering cannot easily adapt to varying conditions in the field, such as changing ramp or mainline demands or speeds as seen during high demand conditions or with nearby crash conditions on the roadways.

A more intermediate method of a locally responsive ramp metering system can also be implemented, which is similar to an actuated traffic signal controller. Here, traffic detection sensors are placed on the mainline freeway lanes to inform the ramp meter controller of the speed and flow of mainline operations. Given this information, the metering algorithm can decide how to vary the spacing of the green lights to allow the meter to respond to the mainline conditions present at that particular time. This system also allows the ramp meter to deactivate when mainline conditions are operating well enough that the metering of the on-ramp traffic is not needed since freeway operations are working well enough that plenty of gaps in the mainline flows should exist for on-ramp traffic to merge effectively and safely without metering in place. This prevents the additional delay that could be seen at a ramp meter at times when the metering does not provide benefits to the freeway operations.

A third type ramp meter system treats the overall freeway system as a network of on-ramps and, is more in common with an adaptive traffic signal controller or a series of networked controllers where phase timings are influenced by the operations at multiple different signalized locations. Such ramp metering systems are the costliest to install and operate and given the integrated nature of the traffic detection, localized algorithms that would need to be developed to operate them effectively.

4.3.2 BNICM Implementation

For the BNICM implementation, the intermediate or locally responsive ramp metering systems were assumed to be deployed. Such meters would have traffic detection placed on the ramps themselves to detect the presence of traffic at the meter location (to call a green phase on the meter), queue detection sensors placed towards the start of the on-ramp to determine if a queue flush mode was needed to clear more vehicles off the ramp and maintain arterial operations, and mainline sensors to measure the freeway mainline operational conditions to determine if the ramp meter should operate or if it could be deactivated to reduce ramp delays while still maintaining good level of service operations on the freeway mainline.

Ramp meters were assumed to be placed on 28 on-ramps in the I-190 corridor between the I-90 and I-290 interchanges; no ramp meters were implemented on high speed and high volume freeway to freeway connector ramps from I-90 or I-290, or on the ramp from the Skyway (NY Route 5) to northbound I-190. Given the typical directional nature of congestion along I-190 by peak period, the ramp meters were assumed to be activated by corridor and peak period, with ramp metering active in the peak periods by direction as listed in Table 4.3 and illustrated in Figure 4.1. Ramp meters were allowed set to operate during all three AM peak period and all three PM peak period hours, given that the mainline conditions were such that the ramp meters should be activated.

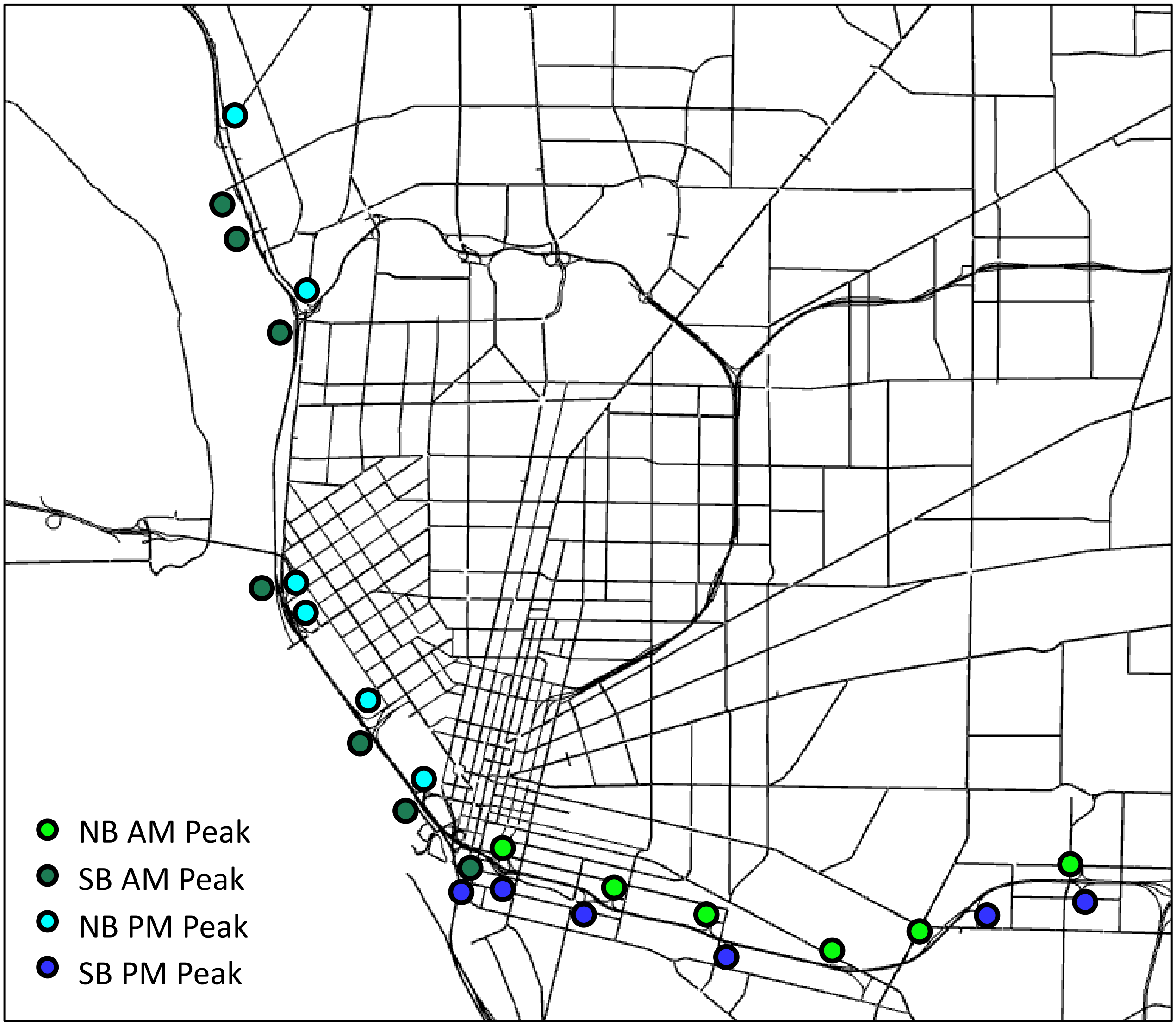
All ramp meters were coded into the BNICM simulation model using the Aimsun built-in flow metering logic. This is a simple logic that adjusts the timing of the metering to release vehicles at flow rate (vehicles per hour) input by the modeler. The input flow rates for the meters for each of the ICM scenarios were based on the simulated hourly flow rates from the corresponding non-ICM scenario. As is the case in real-world where the metering rates are not purely a function of the mainline conditions but must consider the overall demand for each individual ramp, using a flow meter-based approach was a simplified method to include local ramp metering rate calibrations for the individual ramps. Again, the goal of the ramp meters is not to limit or cap the hourly throughput on the ramps, but instead to smooth the flow and headways between individual vehicles as they approach the freeway merge.

All ramp meters were coded to include both queue flush and mainline condition detectors. All detector measurements were reevaluated every minute of the BNICM simulation and the appropriate metering state (normal rates, queue flush rates, or deactivated) for each meter was set using Aimsun's Traffic Management operation tools to change the control parameters of each meter. Meters were coded to enter queue flush rates when the average density of the simulated queue detector exceeded 75 vehicles per mile per lane. The queue flush rates were set to double the normal metering rate, and the queue flush mode continued until the density on the queue detectors was reduced below the activation threshold. All freeway mainline detectors were placed roughly equally as far upstream on the mainline from the ramp merge point as the ramp meter was located on the ramp. All ramp meters were set to activate when the average mainline detector density increased above 35 vehicles per mile per lane (per HCM definitions, the threshold between LOS D and LOS E operations for a basic freeway segment), and deactivate (a constant green provided) when the mainline densities were below that threshold value.

Table 4.3 Proposed Ramp Meter Activations by Time Period

Direction	AM Peak Period	PM Peak Period
I-190 Northbound	• Exit 1 Ogden St • Exit 2 Clinton St • Exit 3 Seneca St • Exit 4 Smith St • Exit 5 Hamburg/Louisiana St • Exit 6 Elm/Oak St	• Exit 7 Church St • Exit 8 Niagara St • Exit 9 Porter Ave • Exit 9 Peace Bridge • Exit 11 NY-198 • Exit 14 Ontario St
I-190 Southbound	• Exit 17 River Rd (NB loop) • Exit 17 River Rd (SB slip) • Exit 13 Hertel Ave / Austin St • Exit 12 Hamilton / Amherst St • Exit 11 NY-198 • Exit 9 Peace Bridge • Exit 9 Busti Ave • Exit 8 Niagara St	• Exit 8 Niagara St • Exit 7 Church St • Exit 7 NY-5 (Skyway) • Exit 6 Elm/Oak St • Exit 6 Washington St • Exit 5 Hamburg St / Louisiana St • Exit 4 Smith St • Exit 2 Clinton St • Exit 1 Odgen St

Figure 4.1 Proposed Ramp Meter Locations



4.3.1 Estimated Costs

Different types of ramp metering systems and timing algorithms exist and have been used across the country. While they have different benefits to be expected, they also have varying costs associated with them. Costs to deploy a locally responsive ramp metering system were taken from the TOPS-BC tool for traffic actuated ramp meters and are summarized in Table 4.4. Based on these unit cost estimates, a total levelized life cycle cost to deploy and operate the 28 ramp meters is estimated to be $356,791 on average per year.

Table 4.4 Cost Estimates for Ramp Metering Deployment

Description of Equipment	Useful Life (years)	Capital / Replacement Costs ($)	Annual O&M Costs ($)	Annualized Costs ($)
System Deployment Cost Components				
TMC Hardware	5	18,000	1,600	6,500
TMC Software / Integration	5	77,000	0	15,400
Labor		0	56,000	56,000
Total System Costs		95,000	57,600	77,900
Incremental Deployment Cost Components				
Ramp Meter (Signal, Controller)	10	30,000	1,900	4,900
Loop Detectors	10	20,000	480	2,480
Communication Line	5	770	260	414
Total Incremental Costs (per meter)		50,770	2,640	7,794
Total Incremental Costs (28 meters)				218,232
Total Deployment Levelized Costs (28 meters)				**356,791**

Source: *Useful life and unit costs from TOPS-BC v4.0.*

4.4 Variable Speed Limits and Queue Warning

4.4.1 Background

A variable speed limit (VSL) system works by lowering the speed limits from the normal posted speed limits on selected portions of roadways given the operating conditions at hand, usually with the aim of preventing crashes or lowering the severity of crashes. This could be in response to weather conditions, work zone or road work conditions, or due to slow or queued downstream congested conditions. While implementing a VSL system could provide benefits in the first two conditions, the latter condition of using a VSL system to warn drivers of downstream congestion conditions was the primary reasoning for deploying a VSL system within the Buffalo-Niagara region. In a modern VSL systems, speed limits are generally presented to the drivers either on gantries above the roadway, with one variable speed limit sign per lane, or on roadside signs. Overhead signs are preferred due to the increased visibility with drivers, although roadside units are much less expensive to deploy. Ideally, the variable speed limit changes are not simply advisory in nature but instead are regulatory and enforceable by police; this can increase the adherence of the driving populations to the reduced speed limits.

While some metering effects from a VLS system could in theory increase throughput at bottlenecks and improve travel times (similar to a ramp metering system) by limiting the size and severity of that bottleneck, here a VSL system is considered for deployment here to instead improve safety by warning approaching traffic to slow their speeds based on the downstream speed conditions and by minimizing the speed differentials of vehicles of vehicles as they approach a bottleneck or queued conditions along a roadway.

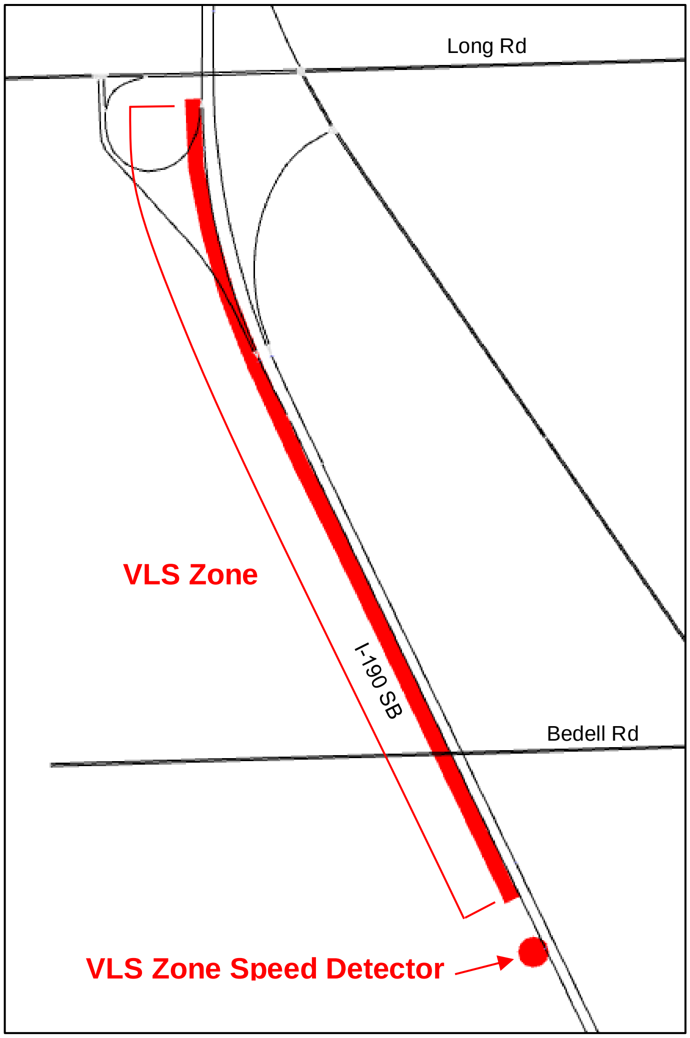
The resulting expectation from such a deployment is that the number of crashes associated with vehicles arriving at high speeds to the back of a queue on the freeway are reduced. This warning is especially important when the congested conditions are not expected by the drivers. Given the recurring nature of many bottlenecks during the typical commute periods, many drivers expect congestion at these locations and may alter their driving to be more cautious as they approach these locations. But, when drivers are unfamiliar with the normal roadway conditions (non-commuters) or when the bottlenecks and congestion existing in an unexpected way, such as from a crash, unusually high demands, or other atypical conditions, the VSL systems can prove to be more helpful. While the primary benefit is safety, there are associated mobility and reliability benefits from the prevented crashes as well. While this is not the primary intended effect of a VSL and queue warning system, there is the potential for substantial benefits from this aspect of the VSL implementation as well.

While variable speed limits and queue warning systems have been used in a few locations in the U.S. for many years (e.g. New Jersey Turnpike), their use has more traditionally been based on static conditions, such as construction activities, congestion warnings, or adverse weather. These older systems would lower the regulatory speed limits, often by a fixed amount such as lowering speed limits on a bridge during high wind conditions, or purely warn drivers of congested or construction activities downstream of the driver's current locations. These changes would often result from an operator issuing the change command to field equipment, and the modified speed limits or warnings would generally not change until the condition was cleared. More modern variable speed limit and queue warning systems, such as those recently deployed in Europe and other locations around the world, are much more dynamic in nature and can be used to adjust the speed limits based on the downstream congestion and conditions throughout a peak period. This more modern system is what is proposed for deployment in the I-190 corridor, with upstream speed limits being set in response to the prevailing downstream operating speeds to warn of the downstream queued conditions.

4.4.2 BNICM Implementation

The VSL system was assumed to be in place and operate along the entirety of the I-190 corridor in both directions, from the approaches to the Lewiston-Queenston Bridge in the north to the interchange with I-90 in the south. To evaluate the impacts of the VSL system on travel time and speed operations within the BNICM model, protocols using traffic management tools within Aimsun were developed to simulate the dynamic speed sensing and speed limit changes as they would happen in the field. To simulate the VSL system, the entire I-190 corridor was divided into VSL zones approximately 1 mile in length in each direction. All Aimsun sections along I-190 within each of these zones were then identified. Traffic detectors were placed on the I-190 mainline lanes just downstream of the end of each VSL zone, with the average simulated speed of that detector reported every 60 seconds. Based on the average speed of that detector for the previous 60 seconds, the VSL signs for the VSL zone were set in 5 mile per hour increments such that the VSL sign presented a speed that was slightly higher than that downstream detected speed. For example, if the detector reported an average speed of 47.2 miles per hour, the VSL zone speed was set to 50 miles per hour, and all sections within that VSL zone were set to a speed limit to 50 miles per hour. The VSL speeds were adjusted up or down every 60 seconds in the simulation based on the detected downstream speed. If the downstream speeds increase, VSL speeds were increased; if speeds fell, then the VSL speeds were lowered. All VSL zones operated with the same maximum speed limit as currently exists in the field, and the minimum speed present on any VSL was 35 miles per hour. Figure 4.2 present an illustration of one of these VSL zones and its detection point long I-190 in the southbound direction on Grand Island.

Figure 4.2 Example of VSL Zone and Speed Detection Point



4.4.3 Estimated Costs

The projected deployment of a VSL and queue warning system can have significant costs associated with the amount of infrastructure to be built to properly display the dynamic speed limit signs. While a more detailed engineering design would need to be undertaken to refine the projected costs, the estimated costs to deploy a VSL and queue warning system across the length of the I-190 corridor are presented in the following Table 4.5.

Table 4.5 Cost Estimates for Variable Speed Limits and Queue Warning

Description of Equipment	Useful Life (years)	Capital / Replacement Costs ($)	Annual O&M Costs ($)	Annualized Costs ($)
System Deployment Cost Components				
Engineering Design	25	154,000	0	6,160
Software Module	20	300,000	3,000	18,000
ATM TOC Hardware	25	50,000	1,250	3,250
Total System Costs		504,000	4,250	27,410
Incremental Deployment Cost Components				
Gantries with large DMS and CCTV	25	920,000	18,400	55,200
Controller	10	25,000	1,250	3,750
Speed Limit / Lane Control Signs	10	10,000	500	1,500
Detectors	10	10,000	500	1,500
Mast Arm Assembly with Dynamic Speed Limit Signs	10	150,000	7,500	22,500
Roadside Dynamic Speed Limit Signs	25	20,000	1,000	1,800
Camera Assembly	10	65,000	3,250	9,750
Telecom / Power Duct Bank	25	250,000	6,250	16,250
Telecommunications	25	40,000	800	2,400
Power	25	40,000	400	2,000
On Site Backup Generator / UPS	10	10,000	250	1,250
Total Incremental Costs (per mile)		1,540,000	40,100	117,900
Total Incremental Costs (28 miles)				3,301,200
Total Deployment Levelized Costs (28 miles)				**4,137,343**

Source: Useful life and unit costs from TOPS-BC v4.0.

4.5 Variable Toll Pricing

4.5.1 Background

Variable toll pricing involves modifying the toll rates paid by the traveling public to use a tolled facility based on the time that the facility is used, often by charging a higher toll rate during hours of peak usage and congestion versus the typical non-peak period conditions. By varying the toll rates by time, the pricing can be used as a demand management tool to provide economic incentives to the drivers to alter their normal behavior to use a congested toll facility during less congested times by paying a lower toll rate or by using an alternative route during the times of peak congestion. Also sometimes referred to as congestion pricing, the differential between off-peak and peak toll rates be set to encourage less peak period usage, which in turn would improve peak period mobility and reliability.

While a more robust method of variable toll pricing, dynamic toll pricing, could be implemented to adjust the toll rates in smaller increments (e.g. every 5 minutes), such systems are more commonly used in managed lane systems where the driver is presented with the toll rates and can immediately decide whether or not to pay that rate to use the toll facility, or whether they opt for the non-tolled option. Given that the alternative non-tolled options to the Grand Island Bridges are not immediately available to the drivers, dynamic tolling was not considered and instead a fixed time of day schedule based on recurring congestion to set higher peak period tolls based on normal recurring congestion was selected as the basis for a variable toll rate ICM strategy.

4.5.2 BNICM Implementation

Based on a review of the normal typical weekday congestion patterns on Grand Island, a two-hour morning peak period (7-9am) was selected for an increased southbound toll rate and a two-hour afternoon peak period (4-6pm) was selected for an increased northbound toll rate. For both peak periods and directions, it was assumed a one-dollar increased toll rate would be charged during the peak periods as compared to the off-peak period. This could be implemented as a pure increase of the peak period toll rate, or as a combination of a slight reduction of the current toll rate for off-peak hours and a less than one dollar increase for the peak period by direction. Details on the rate change would need to be completed in a more in-depth revenue assessment to be completed in consultation with the NYS Thruway Authority.

Drivers’ responses to a toll change are best estimated through an examination of the traveling population’s value of travel time and willingness to pay parameters. Since surveys or other estimates of such parameters from the Buffalo-Niagara region were not available, values were borrowed from another recently completed study of potential reintroduction of tolling in Connecticut.

Drivers can react to the toll increases in one of three ways; they may be incentivized to shift their travel schedule by departing slightly earlier or later than they currently do and choose to pay the off-peak toll rate, they may seek a new alternative route to avoid paying the toll rate at all, or they may see the increased toll rates as not significant enough to adjust their travel schedule or routes and will continue pay the increased toll rate. Each of these driver reactions were considered and incorporated into the BNICM modeling of the implementation of a variable toll ICM strategy; with the results illustrated in Figure 4.3 for the southbound direction in the AM peak and Figure 4.4 for the northbound direction in the PM peak.

The first reaction of drivers, those that would shift their travel times from the peak two-hour increased toll window into the off-peak, was estimated by looking at the volumes and travel times for the simulation period and some presumed time shift sensitivities based on the above-mentioned Connecticut studies. These values ranged as high as 15% for the immediate start or end of the peak period windows to 0% for the core middle time intervals of the peak period. A select link analysis to extract the O-D pairs was undertaken for the non-ICM simulations and OD demand matrices were manually adjusted to shift these demands into the off-peak time intervals. These demands are illustrated in the figures in both grey (volumes shifted from the peak period) and in yellow (volumes shifted into the off-peak periods).

The second driver reaction was assumed that a portion of the traffic would consider changing the travel route away from the Grand Island toll bridges all together. This portion of the population was considered to be 25% of the drivers that remained in the peak period and did not shift trip departure times to the off-peak.

This portion of the remaining peak period drivers were segmented out of the normal O-D demand pairs and a new vehicle class was created for these potential route shift drivers. For this new vehicle class in the simulation, the assumed habitual routes choice models developed for the standard vehicle classes were removed, and these new vehicles classes were allowed to select new routes to complete their trip based on the new increased toll rates and the resulting changes in the peak period congestion levels and travel times. These trips are represented in the figures as the orange trips. It is important to note that these vehicles were only permitted to consider a new route during the simulation; they were not forced onto a new route. If the alternative travel routes without tolls were significantly larger in time than the equivalent value of time of the added one-dollar toll surcharge during the peak periods, then those trips would continue to use the Grand Island Bridges and pay the increased toll rate for the peak period.

For vehicles not considering a time shift or route shift, those vehicles remained and traveled at the same time along the same route. Those vehicles are represented it the figures in blue.

Figure 4.3 Variable Toll Impacts for Southbound AM Peak Period Traffic

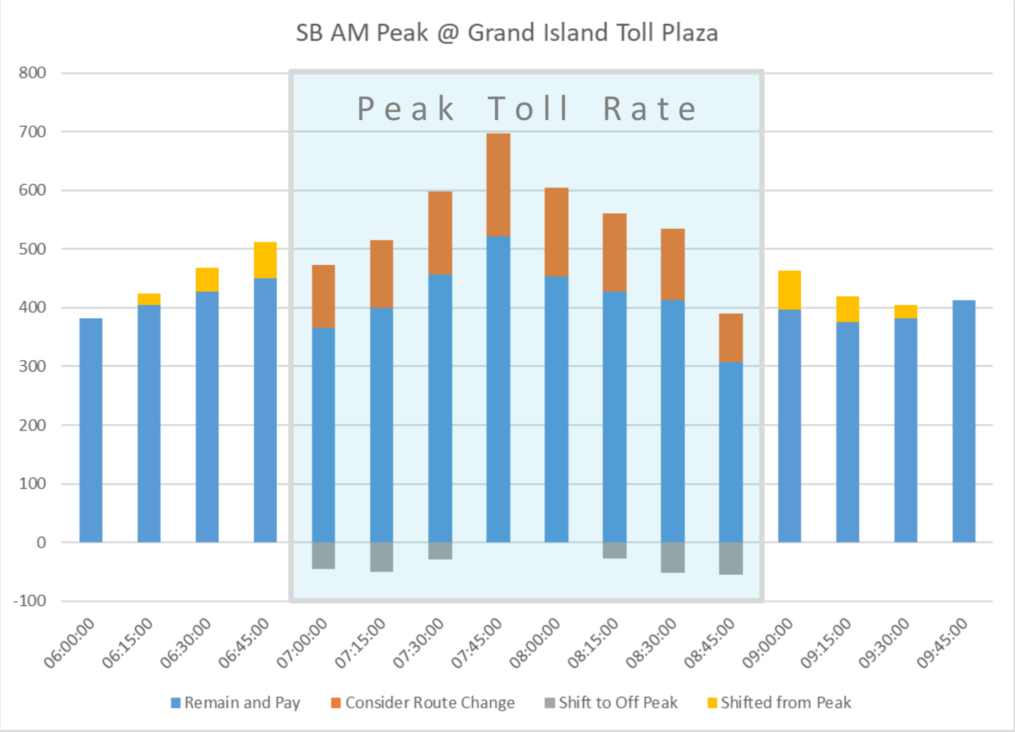
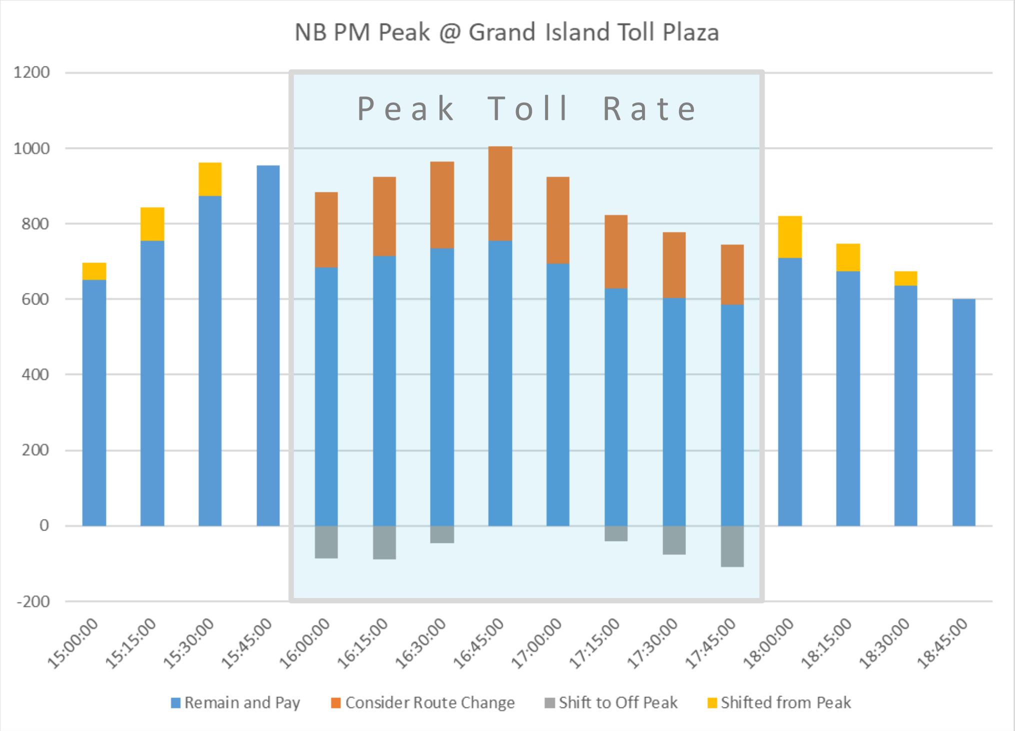


Figure 4.4 Variable Toll Impacts for Northbound PM Peak Period Traffic



4.5.3 Estimated Costs

As both of the Grand Island Toll Plazas were recently demolished and replaced with cashless tolling methods using either electronic (E-ZPass) transponders or a camera-based pay by license plate method, the costs to implement adjust the peak period toll rates from the off peak rates should be minimal and negligible over the life of the deployment as it relates to the costs of toll collection.

It is recognized that the existing signage would need to be adjusted to reflect the new toll rates. Existing static signs could be modified if a purely weekday peak period time of day toll rates system were to be implemented. If adjustable pricing were to be put into effect, the existing signs could be modified to add a small dynamic sign to report the variable toll rates currently in effect. For either option, the costs associated with such a change should be minimal over the life of the ICM deployment.

Finally, while some additional revenue might be expected from a peak period toll increase, no added revenues were assumed to be received as part of this deployment. Instead, it was assumed that the variations between the off-peak and peak toll rates would be set such that the implementation of variable toll rates would be revenue neutral or any new revenues would be used to offset any forecasted costs associated with implementing a variable toll system.

4.6 Signal Coordination

4.6.1 Background

As the previous ICM strategies have more predominantly targeted freeway facilities, it should also be noted that the arterial system has room to improve. Proper signal timings maintenance and coordination has always been an effort that should be undertaken to optimize efficiencies on the arterial system by reducing the delays at the intersections. Collecting routine traffic counts in peak periods and retiming of signals is nothing new. Based on these reviews, signal timings can be updated and retimed throughout the years as normal travel patterns change, either from land use changes and growth or changes in nearby roadway capacities that alter the normal, regular flow of traffic.

However, as an ICM strategy, signal retiming and coordination go beyond the normal travel patterns and focus on adapting signal timings and coordination on key arterials that are pressed to play a role in relieving congestions from freeway based system disruptions or non-typical conditions (e.g. high demand days, crashes, weather impacts, and other conditions). The primary focus of signal coordination as an ICM strategy is to bring the signal timing and coordination on key arterials into alignment with the strategies being implemented to better manage the freeways, so that collectively the overall roadway network is improved, especially under atypical conditions. Under these conditions, drivers may seek alternative paths on the arterial roadway in attempts to avoid congestion on the freeways; this behavior is only reinforced through some of the other ICM strategies mentioned above, including better dissemination of travel information to the drivers. Signal coordination as an ICM strategy aims to implement modified signal timings and coordination parameters on arterials that can serve as key alternative routes for the freeways as a direct response to the ongoing event that is being managed. For example, if a crash on a freeway imposes a dramatic reduction in the capacity of the freeway, a signal coordination response plan could be selected in the TMC and be pushed to signal controllers in the field to improve green times and coordination in the direction of flow on the arterial that we can expect to see increased traffic flows and congestion as drivers divert away from the freeway during the crash blockage. Such response plans, often referred to as signal flush plans, aim to move or flush that increased or unexpected traffic through the arterials as much as possible without adversely affecting the overall operations of the arterial system. After the crash is removed and any potential increased traffic flows on the arterial are returned to normal, the signal response plans can be removed, and signal timings can return to their normal time-of-day operations.

It is important to remember when developing ICM signal coordination of flush plans that the overall safe operations of the arterial system must remain intact. This includes maintaining acceptable minimum green times on all needed phases to provide safe pedestrian crossing times, and not minimizing green times provided to phases not serving the increased detour traffic flows to the point where delays become unreasonable. In these conditions, the increases in delays on the side streets may offset any potential travel time savings to the diverted drives, or even worse delayed drivers may become increasingly impatient and start to drive in more unsafe manners, such as aggressively using clearance times at signals or accepting smaller and less safe gaps in vehicle flows. The important element is that the signal response plans are tailored to the problem at hand and look at the overall network, not just the diversion flows that are added to the arterial system. This is especially true on already heavily traveled and congested arterials.

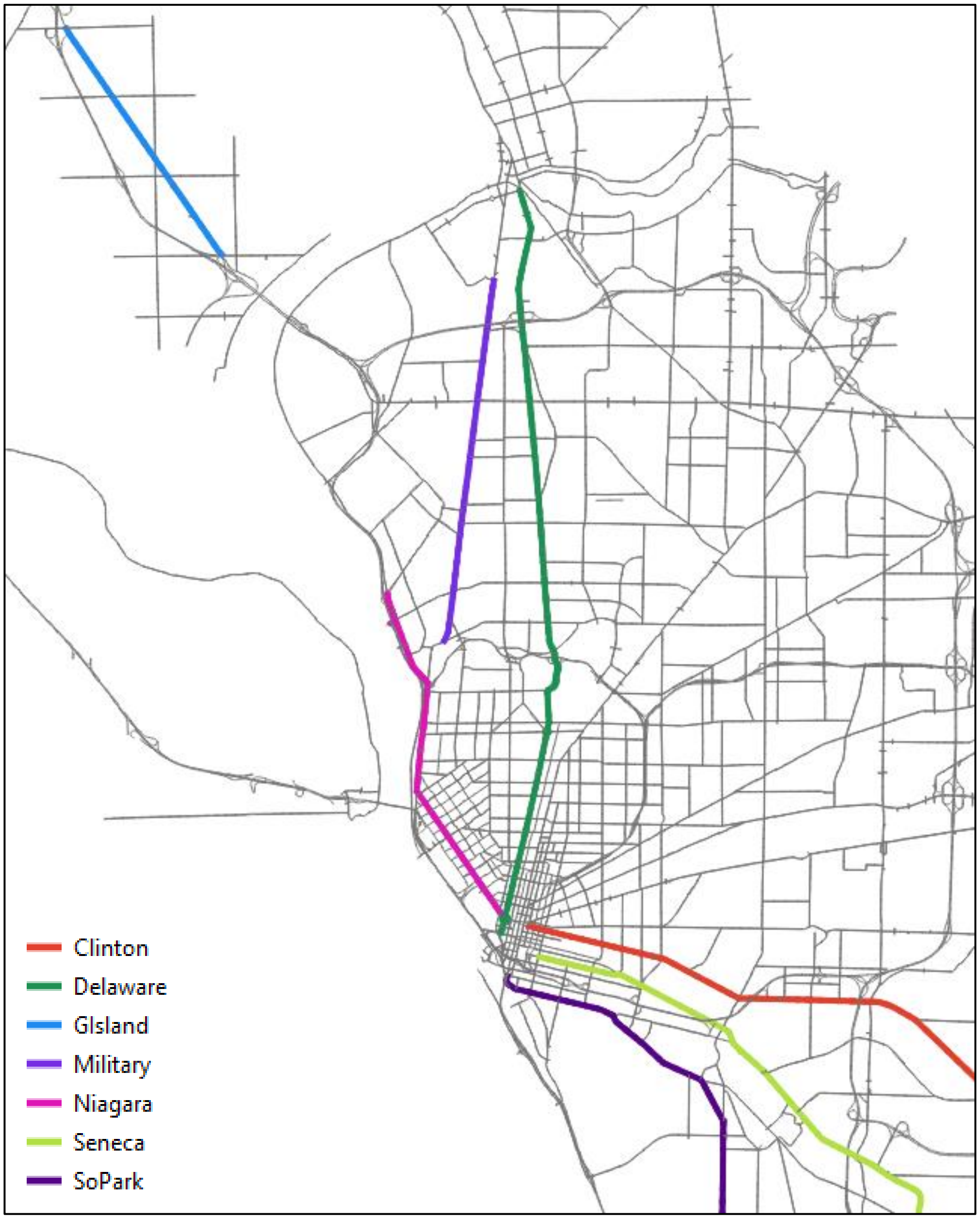
For these reasons, potential response plans should be developed and evaluated well ahead of any actual event occurring in the field and the implementation of the response plans in the field. While the exact timing and nature of the crash or disruption in the field cannot be known, a variety of response plans can be developed in advance knowing when and where disruptions usually occur through reviewing historical crash records. Then, when a crash or other event occurs in the field, a response plan that was developed for a similar type of crash could be implemented to adjust the signal timings in the field to help the overall roadway network respond to the event. Testing of the developed response plans through planning exercises such as simulating the response plans and assessing the impacts of the signal timing changes and refining the response plans is highly suggested prior to implementation of a response plan in the field.

Finally, it is also important to know the state of the arterial system and roadways on which signal timing changes will be made, so adding detection of traffic speeds and flows on the arterial to be adjusted should also be implemented in addition to upgrading the signal controller and communications needed to push signal timing response plans to the field in near-real-time. This detection of arterial conditions can be used to determine if the arterial is actually functioning in a normal condition manner similar to what was assumed in the development of the response plans. If the arterial is also experiencing unusual conditions, either from a separate crash, construction, demand-attracting event, or signal hardware malfunction, the developed response plans may not function as intended, and subsequent changes could make overall delays and travel times on the arterial worse.

4.6.2 BNICM Implementation

To determine the possible corridors to consider developing response plan retiming strategies for, major arterial corridors in the region were first reviewed by GBNTRC and NITTEC staff to select potential corridors for response plan signal retiming. These corridors included the major arterial corridors of Niagara Street, Delaware Avenue, South Park Avenue, Seneca Street, Clinton Street, Military Road, and Grand Island Boulevard. Figure 4.5 presents these corridors and their limits within the overall BNICM network.

Figure 4.5 Corridors Considered for Signal Coordination



Following the identification of the potential corridors to be updated, the base condition models that were developed to evaluate the ICM strategies were reviewed with the potential of each of these corridors to assist in the management of traffic in response to conditions going beyond the normal typical commute periods. For both the AM Crash and the PM Crash BNICM base condition models, it was determined that the Niagara Street corridor could have signal timings adjusted to assist in the management of the simulated crash conditions. As both simulated crash conditions occurred on I-190 near the SR-198 interchange, the proximity and the ramp connections to Niagara Street made it a clear choice to serve detour traffic during the crash events. For each of the AM and PM Crash conditions, a separate response plan was developed that retimed all twenty-six signals between and including Elmwood Avenue in the south to Ontario Street in the north. These sections of Niagara were selected to be adjusted considering the severity of the crash, the duration of the lane blockages.

For each of the Crash conditions periods, the response plans were initially based on the existing typical AM or PM peak period signal timings but adjusted in two different ways. First, the signal controllers were revised to run a common cycle length of 120 seconds for most of the signals; however, given that some cycles were running much shorter cycle lengths, some minor intersections instead were retimed to operate with a 60 second cycle length. This maintained operations at minor intersections similar to the existing conditions, including allowing permitted left turns on clearance intervals and more frequent pedestrian crossing opportunities, while still allowing some better progression to be established along the corridor. Second, the signals were retimed to add additional green time to the direction of travel that we would expect to see increased flows in as part of the driver responses to the crash conditions; southbound in the AM Crash base condition, and northbound the PM Crash base condition. The added green time resulted in the direction of increased flows receiving up to an approximate maximum of 10 percent more green per cycle as compared to the original signal timings. Changes were not made uniformly to all signals, but instead changes were made signal by signal considering how much green time per cycle the peak direction already received before the timing adjustments, as well as the level of the volumes that the side streets process under normal operating conditions at intersections with other major arterials.

The overall goal in the response plans was to allow a larger green wave of progression through the corridor along Niagara Street in the peak direction to allow improved throughput of that direction of Niagara Street during the Crash event without unreasonably disrupting the operations of the corridor. It should be noted that response plan signal timings were tested several times, and the final selected response plans for the AM Crash and PM Crash base conditions were developed by reviewing the initial simulations and revising and improving upon the previous response plans, but the retimings fell short of an optimization of the signals timings to the simulated flows. This optimization was purposefully not done to maintain a more realistic set of retimings considering that the true field conditions signal by signal would not truly be available and the response plans are still pre-set timing plans planned for a Crash similar to the simulated condition, and optimization of the retimings is not able to be truly determined unless a more robust (and expensive) adaptive signal system is implemented.

Some latency was also assumed in the timing of the implemented response plans being implemented in the field as well. With operations in the field, it will take a several minutes to detect the crash, decide on a response plan to implement, push that response plan to the field, and allows for the signal controller to transition from the existing timings to the new response plan timings. Accordingly, the timing of the implementation of the response plans taking effect in the simulation model lag the actual time of the simulated crash by an assumed ten minutes latency. Similarly, the response plans continued in the simulation model after the crash itself has been cleared, as the response plans in the field would ideally continue until the congestion impacts from the crash are resolved and the volumes on the arterials return to normal conditions.

4.6.1 Estimated Costs

In order to implement a signal coordination system that is capable of changing timing plans at key signal controllers in near real-time as part of an ICM incident response plans, several components would need to be updated in the field. First, the signal controllers would need to be updated to modern signal controllers capable of remote communication with the capacity to store and implement numerous different pre-set timing plans associated with different types of ICM events. Next, a real-time communication link to the signal would need to be established and maintained. Finally, adding sufficient detection at the signalized intersection would be advisable to provide greater real-time feedback on operations of the arterial and the signalized intersections, both before and during a response plan implementation.

The estimated costs to implement all needed changes are presented in Table 4.6, and were estimated by reviewing recent cost data provided by NITTEC associated with upgrading signal controllers in the region. The costs listed are only for the Niagara Street Corridor as evaluated in this project. While other arterial corridors would also expect to be upgraded and response plans developed to allow a deployed ICM system to use those other arterial corridors in a similar manner to the proposed ICM strategy discussed here, only costs associated with upgrading the Niagara Street corridor are included since that is the only corridor where signal coordination in response to an ICM event was tested (and therefore only those benefits are estimated to date).

Table 4.6 Cost Estimates for Signal Coordination

Description of Equipment	Useful Life (years)	Capital / Replacement Costs ($)	Annual O&M Costs ($)	Annualized Costs ($)
System Deployment Cost Components				
TMC Software for Signal Control	5	32,000	3,200	9,600
Total System Costs		32,000	3,200	9,600
Incremental Deployment Cost Components				
Signal Controller Upgrades	10	7,500	340	1,090
Communications	1	0	1,200	1,200
On Site Backup Generator / UPS	5	12,000	1,000	3,400
Total Incremental Costs (per signal)		19,500	2,540	5,690
Total Incremental Costs (26 Signals along Niagara St)				147,940
Total Deployment Levelized Costs (26 Signals)				**173,306**

Source: *Estimates based recent signal controller upgrade costs completed in the region (NITTEC)*

4.7 Other Strategies Considered

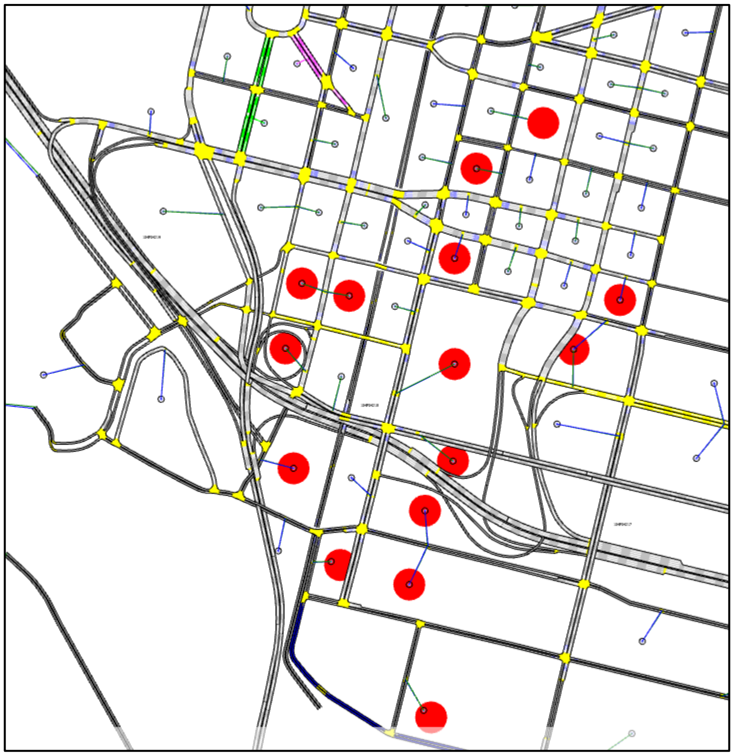
In addition to the above selected ICM strategies, a handful of other potential ICM strategies were selected for consideration under certain base conditions. However, at this stage of the BNICM analysis, these strategies were not directly tested or evaluated for effectiveness or benefit to cost efficiencies which are presented later in this report. The following sections describe the strategies generally and how they could potentially improve on conditions within the Buffalo-Niagara Region. It is suggested that these strategies be revisited and analyzed in the future before any future ICM design or deployment activities occur under future efforts.

4.7.1 Parking ITS

In order to help improve congestion seen downtown during events like those modeled in the Game Day Base Condition, a Parking ITS system could be deployed to help guide and better distribute event attendees arriving in private vehicles towards appropriate and available parking lots. The goal of such a system would be to minimized travel delays and congestion on the arterials in the vicinity of the Keybank Center. While a parking ITS system would expected to be most beneficial during Game Day conditions or similar special events which attract a large numbers of attendees, there could potentially be additional benefits seen during normal peak hours to help general, non-event generated traffic find available parking more quickly and with less delays and less circulating on the roadways looking for available parking.

Most Parking ITS deployments utilize small roadside dynamic message signs on arterials which could act as both a dynamic trailblazer sign to help direct drivers unfamiliar with the roadways and facilities given current operations conditions and levels of congestion in the area and act as a real-time parking information system to display the number of currently available parking spots at various parking lots in the area. Figure 4.6 presents the blocks with significant parking facilities in the vicinity of the Keybank Center. By leveraging the information provided at selected locations, drivers can be directed along more optimum routes to avoid congestion hot spots and direct them to nearby logical parking facilities with spaces rather than having the driver circulate the area looking for parking spots.

Figure 4.6 Game Day Parking Facilities



In addition to the roadside signs, a Parking ITS system would also require the installation of sensing equipment at parking facilities (surface lots or parking ramps) to determine and provide back to a central control center the current number of available parking spaces in that particular facility. Knowing the capacity of the facilities, gate controls and counters can be used measure number of entering and exiting vehicles over time to determine the number of available spaces at the given time. While not nearly as commonplace, curbside parking sensors are also now becoming more widely used to help measure and report curbside parking space occupancy and availability as well.

4.7.2 Dynamic Lane Controls

Dynamic Lane Controls could be implemented to help improve safety and operations in a variety of conditions. Usually used on freeways, a deployed system places small dynamic signs above each lane to dynamically open and close lanes, usually in advance of unusual downstream conditions, such as a crash, construction, or other lane blockages. Drivers can be told which lanes to use to help better move vehicles around closed lanes, and to help make for safer conditions for emergency responders or construction workers working on the roadways. Within the Buffalo-Niagara Region, such a system could be leveraged during crash events, or potentially during snow events when roadways when plows are actively working on the roadways, when snow is only partially removed from the roadway, or potentially when ramps may be closed due to snow conditions.

The primary benefits of dynamic lane control systems are expected to be improved safety and prevention of either primary or more often secondary crashes, in unexpected conditions. However, it is noted that mobility and reliability benefits could also be seen as a secondary benefit of those prevented crashes. The system could potentially be integrated with the proposed variable speed limit system to minimize hardware installation costs, but further investigations into the potential system integrations would be needed.

4.7.3 Road Weather Information Systems & Plow Management

Directly applicable to snow impacted conditions, an improved Road Weather Information System (RWIS) and a Plow Management system could be leveraged to help provide information to the traveling public during adverse weather conditions. RWIS sensors can be placed in the field to assess the environmental conditions, potentially including sensors to measure roadway surface temperatures to advise of conditions in which roadway surface freezing is likely or localized limitations in visibility. While general environmental weather monitoring can help provide these estimates, more detailed and localized information from RWIS sensors can help with more accurate forecasts and reporting of roadway surface conditions and limited visibility during inclement weather. Advisories of potential freeze conditions could be shared with drivers on DMS directly in advance of the area of concern, or more broadly distributed to the traveling public in an attempt to change trip making and route choice decisions either en-route or even before a traveler leaves their current location.

A plow management system usually operates by placing automated vehicle location (AVL) devices on the plows and further knows the current state of the snowplow and/or salt/sand spreading devices. Such systems are often used by agencies as part of Maintenance Decision Support Systems (MDSS) to help manage plow assets during a snow removal event and to help make snow removal operations more efficient. However, by transmitting the GPS and snow removal status of plows back to the TMC, roadway managers can monitor which roadways have been recently plowed or treated and advise the traveling public of such information, either on DMS signs around the region, via 511, or via website or mobile phone applications so that drivers can make more informed decisions about which roadways they choose to complete their trips, or even to modify the departure of a trip given the status of the roadway conditions and how recently their preferred travel route has been cleared of snow or treated.

Both systems aim to better inform the public of road conditions during a snow evert to allow them to make more informed and better decisions about their travel during snow events, and to ultimately reduce weather-related crashes from occurring during snow events.

4.8 Strategy Packages for Base Conditions

The previous sections outline the ICM strategies that were considered to be included in a response plan to better manage the roadway network during an ICM event seen it the field. However, certain strategies by their nature are more applicable during certain operational conditions. Table 4.7 presents the matrix of the ICM strategies against the Base conditions for which BNICM Models were developed. Within this matrix, cells are marked with dots where specific ICM strategies are expected to provide benefits under each of the operational base conditions. Filled dots indicate that those strategies were evaluated within the BNICM simulation models, with those results discussed in the next chapter. Hollow dots are combinations of strategies and base conditions that expect to see benefits but estimates of those benefits have not been completed with the BNICM model simulations or included in the overall benefit cost analyses.

Since the permutations of various ICM strategies and base conditions to be evaluated within the BNICM Model presented an immense number of scenarios to simulate and analyze, packages of ICM strategy deployments were developed to streamline the simulation and evaluation of the effectiveness of the ICM strategies during the different base conditions. The first package is targeted at deploying freeway focused ICM strategies and includes all of the first five strategies listed in the table. The second package retained those freeway-focused ICM strategies but also added the signal coordination strategy to the response plans to present more of a network-wide response plan.

Table 4.7 Candidate ICM Strategies by Base Condition

ICM Strategies	AM / PM Typical Commute	Vehicle Crash Conditions	Holiday Demands	Snow Conditions	Game Day Conditions	Evaluation Package
Dynamic Traveler Information	●	●	●	●	●	A+B
Freeway Incident Detection and Service Patrol	●	●				A+B
Ramp Metering	●	●				A+B
Variable Speed Limits and Queue Warning	●	●		●		A+B
Variable Toll Pricing	●		●			A+B
Signal Coordination	●	●	●		●	B
Parking ITS					○	
Dynamic Lane Controls		○		○		
Road Weather Information Systems and Plow Management System				○		

Further details regarding the simulation-based evaluations of the ICM strategies are presented in the next chapter.

5.0 Strategy Simulations and Results

Following the selection of various potential ICM strategies to be evaluated, the simulation models developed and described in Chapter 3 for all base conditions where update to reflect the No Build, or pre-ICM conditions. Following the development and simulation of those No Build scenarios, a series of simulations were completed to evaluate the effectiveness of the potential ICM strategies. This chapter describes those processes and presents the performance metrics for the final set of ICM Scenarios and the resulting benefit-cost analyses of the proposed ICM deployment packages.

5.1 ICM Scenario Simulations

5.1.1 No Build Modifications

During the time that was needed to develop and calibrate the various base conditions models, there were two significant changes made to the regional roadway network. As these changes were already in place by the time the ICM scenario simulations were to be undertaken, the two changes were added to each of the base condition models and a series of No Build or ‘without ICM’ models were created.

The first significant change was the completion of construction and opening of the new on-ramp from the Peace Bridge to allow traffic entering the U.S. from Canada to directly access northbound I-190. The new ramp was added to all the base condition simulation models to match the recent aerial photos of the completed construction, and simulated traffic then had the option of using the ramp.

The second change was the implementation of fully electronic toll collection at the two Grand Island Bridges and associated removal of the toll collection barriers and related geometric changes made to I-190. For both toll plazas, the parameters used to model the speed and throughput characteristics of the toll barriers were removed and the post-construction conditions and lane configurations were coded into each of the No Build base conditions models. Toll charges to the simulated drivers using the bridges remained in the model unchanged.

The BNICM base condition models were only changed to reflect the updated roadway conditions from the above two network changes during the creation of the No Build models. The underlying demands for travel were unchanged and no growth traffic was assumed or implemented give the short time frame for between the observed conditions to which the base conditions were calibrated and those implemented changes in the field. All calibrated parameters (both network and driver response parameters) remained in place as well, with the exception of parameters included in the calibrated models related to the operations of the now removed toll barriers.

5.1.2 ICM Scenario Simulation Procedures

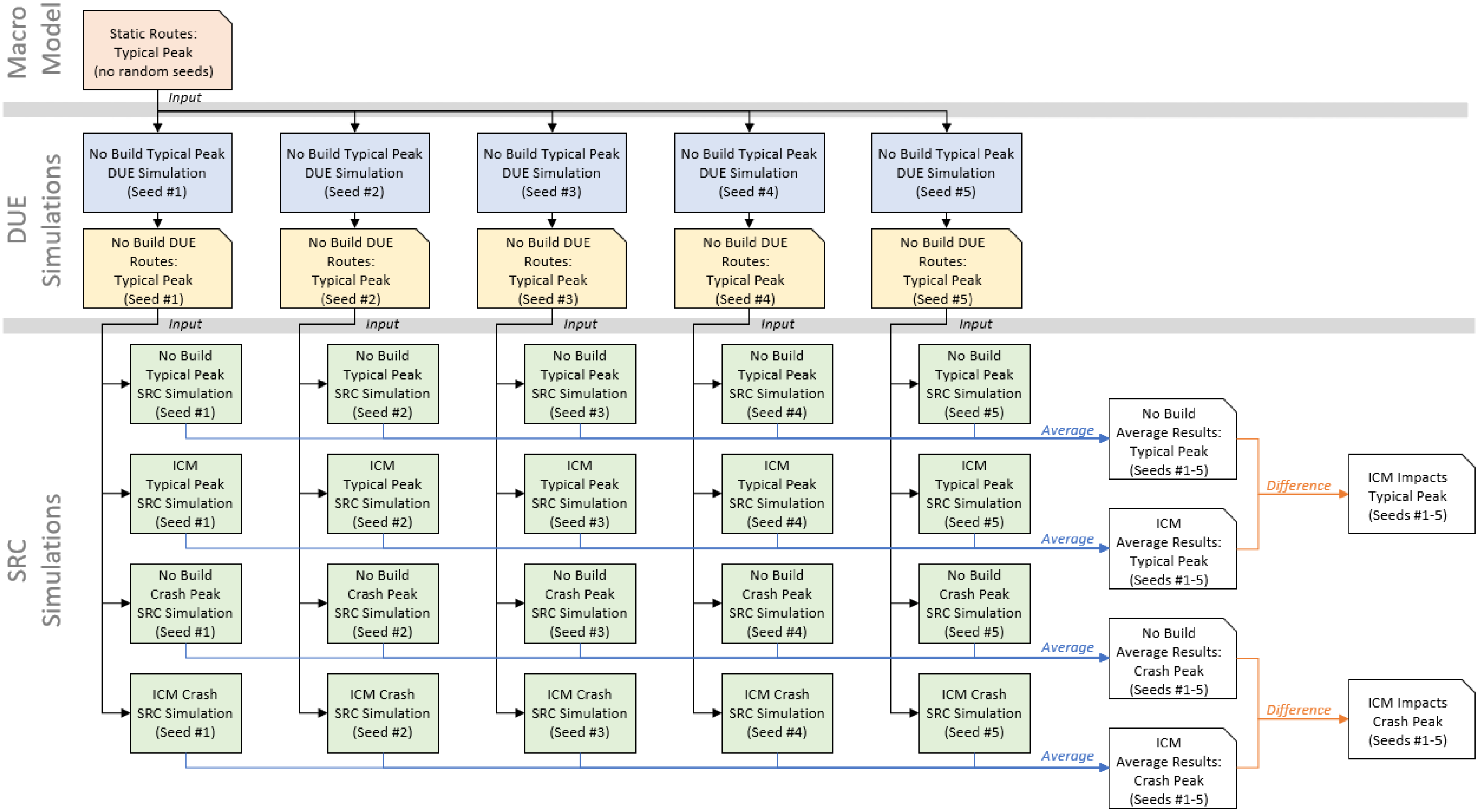
While the assumption of no demand changes was made, there remained the possibility that drivers would adjust their travel routes given these two changes to the roadway network. To reassess these potential changes in route choices, the No Build models for the typical AM and PM peak period congestion were simulated using a full Dynamic User Equilibrium (DUE) process as was done for the initial base condition typical peak periods calibrations so that simulated drivers could learn of the typical congestion patterns and choose a route to complete their trip accordingly.

As was done with the base condition models, these typical peak period route choices were used as the habitual paths that drivers use in each of the non-typical peak period base conditions, which were all simulated with an Aimsun Stochastic Route Choice (SRC) simulation. The SRC method, sometimes referred to as a one-shot simulation, is standard for simulating traffic conditions during atypical events and allows a better representation of the route choices and driver responses during specific events that are not expected. Since drivers do not know of the actual roadway operational conditions created by the atypical event (e.g. a crash) before the event occurs, most drivers are instead traveling on their typical or habitual route choices as they would during a typical peak period. The SRC simulation then allows a subset of the drivers who are attentive to the real time conditions to modify their habitual paths in response to the event at hand. These are the same methods that were used to simulation the non-typical peak period base condition models.

While the SRC simulation methods better model driver behaviors and reactions during non-recurring conditions and events, the downside is the introduction of more stochastic noise into the simulation results. The DUE approach to simulate typical peak period conditions accounts for this noise by establishing route choices based on numerous iterative assignments to minimize the impacts of noise in path choice. However, in an SRC simulation, the drivers do not have this opportunity to learn from prior iterations, and instead react to the conditions at hand which inherently results in noisier results. Within standard simulation practice, this is usually accounted for by simulating a scenario numerous times with an SRC approach while changing only the input random seed value to re-randomize the driver decisions, and then taking the average of those different random seed simulation results as the final performance metrics for that scenario. When this approach was undertaken during initial simulation testing of the ICM scenarios, there was more noise in the results between the random seed simulations than was desired, making it harder to isolate the smaller degree of impacts on network performance from the implemented ICM strategies between No Build and Build simulations.

To minimize this noise, a modified base condition simulation procedure was implemented for both the No Build and Build simulations. As part of either the DUE or SRC simulations, the input fractional O-D demands for each O-D pair by time interval are probabilistically converted into actual vehicle trips with specific departure times. This is an internal process in Aimsun which is affected by the random seed provided. Given the large scale of the BNICM model and the large number of zones within the model, many O-D pairs with a small likelihood of generating a trip within a given time interval may have a trip generated within one simulation but may not with another simulation using a different random seed. This created an inconsistency between which O-D pairs had DUE established route choices and which O-D trips were simulated in the SRC simulation using another random seed. To correct for this, instead of using a singular set of route choices from one DUE simulation as inputs to multiple SRC simulations with different random seeds as was initially done, the typical AM and PM peak period base conditions models were simulated five times through the DUE process with different random seeds, which created one set of experienced or habitual route choices for each of the random seeds used. These random seed specific route choices were then then used as inputs to five different SRC simulations each using the same random seed as was used in the DUE which produced the route choices. This minimized the impacts of changes in the O-D demands and the route choice paths for each of the five different random seeds used for the SRC simulations. After developing this modified procedure, the route choices created from the No Build typical conditions model simulations were then used as the baseline habitual route choices for all No Build (without ICM) and Build (with ICM) scenario analyses occurring within that peak period, including the typical simulations as well as the crash, snow, game day, or holiday demand base conditions. The final scenario results are still taken as the average of the results of the five different SRC simulations completed for each scenario. Figure 5.1 illustrates the ICM scenario simulation procedures for the No Build and ICM strategy simulations, and the determination of the changes in the performance metrics associated with the ICM strategies.

Figure 5.1 Example of ICM Scenario Simulation Procedures



5.2 Performance Metrics for ICM Evaluation

In order to determine the effectiveness of the simulated ICM strategies, a set of key performance metrics were extracted from both the No Build and ICM strategy simulations and compared; the difference between the two sets of performance metrics were taken as the impact of the deployed strategies on those performance metrics. The selected metrics were targeted to represent key performance indicators relating to the goals of the ICM effort while also being metrics that could be used as inputs into a benefit cost analysis to evaluate the overall effectiveness of the proposed ICM deployments. In addition to performance measures extracted from the BNICM model, additional safety performance metrics which could not be estimated using the model were assumed based on the experiences in previous deployments of similar strategies deployed in other regions. The following describes the performance metrics used to evaluate the potential benefits of the proposed ICM deployment, as well as the methods for converting them into monetary values for use in the benefit cost analysis completed for the two analyzed packages of ICM deployments.

5.2.1 Travel Time Benefits

One of the goals of the ICM deployment is to improve the overall mobility of the region and to reduce the levels of congestion and traveler delays seen on the region’s roadways. Measuring the total user travel time is a good metric to determine the overall impacts on mobility. While difficult to measure in the field, within the BNICM models the total vehicle hours of travel (VHT) for all vehicles can be tallied from all simulated vehicles and those times can readily be compared between scenarios of the same base conditions with and without ICM strategies modeled.

While delay is often used as a metric to evaluate the performance of a particular corridor, total VHT was selected in lieu of travel delay since many of the ICM strategies may result in some vehicles shifting between freeways to arterials. Since delay in Aimsun is defined as the time a vehicle spends traveling at any speed less than the vehicle’s desired free flow speed, which in turn is a function of a roadway’s speed limit, total travel time can be a better metric of the total impact on the overall time it takes users to complete their trips if vehicles change routes to roadways with different speed limits. Total travel time is also a metric that can be more directly relatable to the user’s defined experience and objective, as the route choice and travel speed may be less important to the user than the actual travel time to complete their trip from origin to destination is.

It is also important to remember that within an ICM framework for transportation management, the goal is not to improve the operations of one facility at the detriment to another; instead the goal is to improve the overall mobility and reduce travel times for all users. While not all roadway operations should be expected to improve as strategies will change the routes that users choose to travel and will result in some roadways seeing increased demands and potentially increased delays and lowered speeds, the goal is to have a net improvement to operations for the network. Therefore, the total travel time performance metric must consider travel times for vehicles on all roadway types, be it a freeway, ramp, arterial, collector or local roadway. Similarly, since some ICM strategies aim to shift travelers to less congested time periods, the travel times from all time intervals needs to be tallied as well. As a result, the total travel time for all vehicles on all roadways in all simulated time intervals was used as the total travel time metric for the simulated scenarios.

One change was made to this concept; given the large size of the model, the travel times were tallied only in the areas where the implemented ICM strategies could conceivably have impacts. As discussed above, the stochastic nature of any simulation model can add noise into the results. By not including the areas of the model that were far removed from corridors with the tested ICM strategies, the noise inherent in the simulation results could be further reduced and the impacts of the ICM strategies themselves could be better isolated between simulations. Considering this, the travel times from all roadways of any class in the vicinity of the I-190 and cross-border corridors and all other reasonable detours to those corridors were included. This includes the I-290, SR33, SR198 corridors on the U.S. side of the border, as well as all freeways and arterials in Canada connecting the international bridges. All roadways in the downtown Buffalo and downtown Niagara Falls regions were also included in the total travel time tallies to account for arterial diversions away from the I-190 corridor.

While the travel time metric can be directly compared between simulations of the same base condition, to provide a comparison of the travel time benefits to other benefits in non-time units and ultimately to the costs of the proposed ICM deployments, the travel time metric needed to be translated into a dollar value. This monetization of the travel time metrics was completed by using a presumed average value of travel time of $14.92 per vehicle per hour.

Finally, while computing the travel time benefits from the ICM deployment can be estimated on a case by case basis for the different base conditions simulated, in order to compute the annual benefits for use in the benefit cost analysis, the benefits computed per scenario needed to be prorated by the number of times those conditions can be expected to be seen on an annual basis to arrive at the total annual benefits in reduced user travel time from the ICM deployment. To complete this conversion, the number of times per year that each base condition is expected to be seen per year needed to be estimated. Table 5.1 presents the presumed numbers of day per year that the simulated base conditions will occur. While these numbers can be expected to change somewhat year by year, the annualization of the travel time benefits using a set per annum assumption for the base condition frequencies provides a consistent conversion for the analysis.

Table 5.1 Frequency of Base Conditions per Year

Base Condition	Weekdays per Year AM Peak Period	Weekdays per Year PM Peak Period
Typical Commute	190	154
Crash	45	63
Snow Conditions	15	n/a
Game Day	n/a	25
Holiday Demand	n/a	8
Total Weekday	250	250

These conditions of course do not represent all possible conditions that would be seen over the course of a year. For example, snow conditions can be certainly be expected in the PM peak period, or increased holiday demands could be seen during an AM peak period. However, since not all possible combinations of base conditions by peak period could be examined under the resources of this study, those base conditions that were simulated per peak period were used to split up the number of non-holiday weekdays per year (approximately 250 days per year) that can be expected.

Based on this assumed frequency of the base conditions occurring on an annual basis, the per period reduced travel time benefits estimated from the scenario models where multiplied through by the respective number of days per year, and the total annual benefits is the summation of those products.

5.2.2 Travel Mileage Savings Benefits

Vehicle-miles of travel (VMT) is a standard measure of the aggregate distance driven by all individual drivers. VMT imposes costs on motorists for a variety of reasons.

The impacts of VMT reductions (or increases) are calculated by summing fuel costs ($3.18 and $3.00 for a gallon of gasoline and diesel fuel, respectively) at representative fuel efficiency levels and non-fuel costs of vehicle operation ($0.313 and $0.429 for cars and trucks, respectively).

5.2.1 Carbon Emissions

Emissions are tracked in units of metric tons, and relate in complex ways to VHT, VMT, and operating speed profile (choice of cruising speed and rates of acceleration). In general, smooth flowing traffic at moderate speeds provides the lowest rate of emissions per mile traveled. A metric ton is 1,000 kg, and to establish scale, we note that the quoted average emissions rate for a mid-size sedan (Toyota Camry, 2018 Model Year) is 264 grams per mile driven[5].

For this study, Carbon Dioxide (CO_2) was the emissions species tracked. The production of CO_2 is proportional to fuel consumed, thus is effectively also a proxy for the total level of fuel consumption by all drivers combined.

5.2.2 Safety Benefits

Several of the selected ICM Strategies aimed to provide safer operations of the roadways and to prevent crashes from occurring. While safety metrics are very important to the evaluation of the benefits of the ICM strategies, the impact of the deployed ICM strategies cannot easily be evaluated by a simulation model, especially a simulation model at a regional scale like the BNICM model is. Instead, off-model estimates of the safety benefits needed to be assumed and used in the analysis.

To estimate the safety benefits that could be seen from the select ICM strategies, a review of literature was conducted of the reported improvements in the crash rates that were seen after actual deployments of those strategies in other regions. Table 5.2 present the results of that literature review. Based on this review, a conservative assumption of a collective 20% reduction in the number of crashes occurring during the peak periods would be seen as a result of the ICM deployment of all of the listed ICM strategies.

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[5] https://www.fueleconomy.gov/

Table 5.2 Observed Safety Benefits of Selected ICM Strategies

ICM Strategy	Crash Type	Typical Crash Rate Reduction	Range of Observed Reductions
Queue Warning	Primary	-20%	-4 to -42%
	Secondary	-45%	-40% to -50%
Variable Speed Limits	Primary	-20%	-11% to -37%
	Secondary	-67%	-n/a (one reference)
Ramp Metering	Primary	-26%	-26% to -39%
	Secondary	n/a	n/a

Source: CS Literature Review of ITS Benefits

To better understand the nature of those 20% of crashes that could be prevented and the potential benefits that would be seen to the region with those crashes prevented, a review of the reported crashes along the I-190 corridor was examined. Logs of the NITTEC reported accident data for 2018 were provided and examined to determine the number of crashes under weekday peak period conditions. Only those crashes which were reported and logged as part of the TMC's operations were included; other minor crashes that were not noticed or logged within the TMC were excluded. Within the NITTEC logs, the reported crashes are reported by the level of severity. A severity code of 1 indicates a minor crash, typically involving one or two vehicles with no or minor injuries, which is expected to have a lane closure of less than 30 minutes. A crash of severity code 2 typically involves multiple crashes involving injuries and has an expected duration of between 30 and 120 minutes. Finally, a severity code of 3 indicates a major crash event, typically involved hazardous materials, tractor trailers, or full road closures with detouring of traffic and a duration expected to be more than 120 minutes. While the severity code generalizes the overall impact to the roadways operations, the logs also record the time taken to clear the travel lanes blocked by the reported crash, as well as an estimate of the total time required for traffic operations to recover from the disruption of the crash and return to typical operations given the time of day and day of the week. Table 5.3 presents a summary of the 2018 reported crashes by severity type, including ranges of the lane clearance times and the return to normal times, for crashes reported in the AM and PM peak periods during typical weekdays.

Table 5.3 2018 Crash Summary: I-190 Corridor

		Lane Clearance Time (minutes)					Return to Normal Time (minutes)				
Severity Rating	**Reported Crashes**	**Min**	**25th %ile**	**50th %ile**	**75th %ile**	**Max**	**Min**	**25th %ile**	**50th %ile**	**75th %ile**	**Max**
Weekday AM Peak Period (7-10 am)											
1: Minor	47	2	15	25	43	69	2	20	39	46	99
2: Intermediate	8	51	56	62	78	107	58	73	79	85	107
3: Major	1	301	301	301	301	301	301	301	301	301	301
Total	56	54 Primary Crashes; 2 Secondary Crashes									
Weekday PM Peak Period (3-6 pm)											
1: Minor	63	2	13	23	40	95	4	25	41	66	222
2: Intermediate	16	16	43	58	59	118	36	59	69	90	128

		Lane Clearance Time (minutes)					Return to Normal Time (minutes)				
Severity Rating	**Reported Crashes**	**Min**	**25th %ile**	**50th %ile**	**75th %ile**	**Max**	**Min**	**25th %ile**	**50th %ile**	**75th %ile**	**Max**
Weekday AM Peak Period (7-10 am)											
1: Minor	47	2	15	25	43	69	2	20	39	46	99
2: Intermediate	8	51	56	62	78	107	58	73	79	85	107
3: Major	1	301	301	301	301	301	301	301	301	301	301
3: Major	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Total	79	78 Primary Crashes; 1 Secondary Crashes									

Source: CS Analysis of NITTEC Provided TMC Log Datasets

While the literature review reported reductions in rates of secondary crashes significantly higher than the reduction in rates of primary crashes, due to the limited number of crashes which were identified and reported as a secondary crash event in the NITTEC records, a separate rate for reducing secondary crashes was not estimated for predicting the ICM deployment benefits. Therefore the 20% reduction of crashes was assumed to apply to all crash severities, and a total of 27 annual peak period crashes can be expected to be prevented per year. Under these assumptions, the resulting estimate of annual prevented crashes to be seen from the proposed ICM deployment is shown in Table 5.4.

Table 5.4 Prevented Crash Predictions for ICM Deployment

	NITTEC Reported 2018 Crashes			Predicted Annual Crashes Prevented from ICM Deployment (20% of 2018 Crashes)		
Number of Crashes Per Year	**AM Peak Period**	**PM Peak Period**	**Both Peak Periods**	**AM Peak Period**	**PM Peak Period**	**Both Peak Periods**
Minor Crashes (Severity 1)	47	63	110	9.4	12.6	22.0
Medium & Major Crashes (Severity 2-3)	9	16	25	1.8	3.2	5.0
Total Crashes (Any Severity)	56	79	135	11.2	15.8	27.0

In order to estimate the societal costs of these crashes in dollar values so that the safety benefits can be included the overall cost benefit analysis of the proposed ICM deployment, guidance was taken from the FHWA publication *Crash Costs for Highway Safety Analysis*[6]. This document includes an overview of different cost components that can result from vehicle crashes and includes recommended national comprehensive crash cost units per crash given the maximum severity of the injuries sustained in the crash. The costs are meant to account for the broad range of societal costs that are attributable to a crash, and include medical, property, loss of income, and other quality of life costs that can result from a crash. The recommended costs associated with the 'KABCO' injury classification scale for crash severity ratings were

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[6] Crash Costs for Highway Safety Analysis (FHWA-SA-17-071), Federal Highway Administration, January 2018

used for this study. The recommended national crash costs were adjusted to represent New York State costs based on the state factors also presented in the document.

Since the severity index to which the crash costs are attributed are different than those used by NITTEC to assess crash severity and the two scales are not directly relatable, a different method for developing a per crash cost needed to be developed. While detailed crash frequency data using the KABCO severity scale could not be found for the Buffalo-Niagara Region, New York statewide crash frequencies using this scale were available. A summary report[7] from the New York State Department of Motor Vehicles reported the number and frequency of crashes across the state using the KABCO scale for the 2014 year (the most recent year available at the time of the analysis). This reported frequency of crashes occurring in New York was used to develop a severity-adjusted per crash cost. Two different costs were developed; one which included the costs associated with any crash of any severity, while the second more conservative cost excluded the costs and frequency of fatal crashes. Table 5.5 presents both the national and New York State average comprehensive costs per crash, as well as the New York State reported crash frequencies, and the resulting crash unit costs calculated from this data.

Table 5.5 Crash Costs by Crash Type

Severity Code	Severity Description	National Cost Per Crash	New York Cost per Crash (US x 1.22116)	NYS 2014 Crash Frequency	NY Any Severity Weighted Per Crash Cost	NY Non-Fatal Weighted Per Crash Costs
K	Fatality	$ 11,295,400	$ 13,793,500	0.4%	Include	Exclude
A	Serious Injury	$ 655,000	$ 799,900	3.6%	Include	Include
B	Minor Injury	$ 198,500	$ 242,400	6.3%	Include	Include
C	Possible Injury	$ 125,600	$ 153,400	31.0%	Include	Include
U	Unknown Severity	n/a	n/a	1.8%	Exclude	Exclude
O	No Injury (Property Damage Only)	$ 11,900	$14,500	56.9%	Include	Include
		NY Severity-Weighted Cost Per Crash:			$ 157,888	**$ 102,119**

Source: CS analysis of Table 34 from *Crash Costs for Highway Safety Analysis* and NYS DMV 2014 Summary of Motor Vehicle Crashes

The second more conservative crash unit cost of $102,199 per crash was selected for use in the benefit costs analysis for the ICM deployment due to the lowered likelihood of a fatal crash occurring in the weekday peak periods versus other hours. This calculated cost per crash was then multiplied by 27, the predicted number of crashes to be prevented per year, to arrive at the estimated total prevented crash cost benefits of $2,757,200 per year to be expected from the proposed ICM deployment.

5.2.3 Saved User Time from Prevented Crashes

While the various costs directly associated with a crash are included in the costs presented above, there are additional user benefits from improved reliability and mobility associated with the prevented crashes. If a crash can be prevented, than the time that would have been spent in congestion caused by that crashes is also prevented, and the traveling public sees less vehicle hours traveled on the roadways over a year. To

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[7] New York State Department of Motor Vehicles, Summary of Motor Vehicle Crashes, 2014 Statewide Statistical Summary, https://dmv.ny.gov/statistic/2014-nyccrashsummary.pdf, accessed May 2019

estimate the travel time impacts associated with crashes, the BNICM model was used to simulate different possible crashes. The overall difference in the performance metrics between a simulation of a typical peak period with a crash occurring and a simulation of the same peak period without a crash occurring was then taken as the mobility impacts of that crash.

Two simulation models were already developed for more severe crashes as part of the base conditions; one in each of the AM and PM peak period. However, additional metrics needed to be developed for more minor crashes. Based on an analysis of the NITTEC TMC crash logs to identify the most typical crash locations for typical peak period minor crashes, four more models representing each direction of I-190 in each of the AM and PM peak periods were developed to estimate the mobility impacts of minor crashes. Those models simulated minor crashes under the following conditions:

- I-190 Southbound near Exit 11 (SR198) in the AM Peak Period
- I-190 Northbound near Exit 2 (Clinton Street) in the AM Peak Period
- I-190 Southbound near Exit 4 (Smith Street) in the PM Peak Period
- I-190 Northbound near Exit 9 (Peace Bridge / Busti Avenue) in the PM peak period

The time for the simulated crashes to occur within the each of the above crash scenarios was selected based on average reported crash time in the NITTEC records at each of hot-spot crash locations. The simulated lane clearance time for each crash model was taken as the typical lane clearance times for minor severity 1 crashes across the I-190 corridor, approximately 25 minutes. Based on these assumed parameters of a typical minor crash in each period and for each direction of the I-190 corridor, the minor crash models were each simulated under five random seeds and the average performance metrics were computed for each crash scenario.

Following the simulation of each of the above crash scenarios, the total hours of travel time metrics were extracted and compared between the models with the simulated crashes and the models of the typical peak periods without a simulated crash. The overall difference in the vehicle hours of travel time between the model with the crash and the model without the crash were taken as the overall travel time impacts associated with that simulated crash. This estimate of the time costs (in total vehicle hours) was multiplied by the average value of time to monetize the time costs, and then multiplied through by the predicted number of prevented crashes by severity per year by to arrive at the annual benefits in reduced user travel costs that can be attributed to the crashes prevented by the ICM deployment. This arrived at a total annual benefit of $765,021 in improved mobility from prevented crashes. The components used to calculate this benefit are presented in Table 5.6.

Table 5.6 Travel Time Benefits from Prevented Crashes

	AM			PM			
	Costs Per Crash		# of Prevented Crashes	Costs Per Crash		# of Prevented Crashes	Total Annual Benefits ($)
Simulated Crash	**veh-hrs**	**$**		**veh-hrs**	**$**		
NB Minor Crash	1,148	$ 17,130	9.4	1,709	$ 25,503	12.6	$ 505,023
SB Minor Crash	1,259	$ 18,784		1,868	$ 27,867		
NB Medium/Major Crash	n/a	n/a	1.8	4,259	$ 63,541	3.2	$ 259,998
SB Medium/Major Crash	2,110	$ 31,482		n/a	n/a		
Total							**$ 765,021**

5.3 ICM Performance: Targeted Freeway Implementation (Package A)

In order to assess the direct mobility impacts of the proposed ICM deployments, various combinations of the different ICM packages were assembled and simulated in the BNICM model for the different base conditions. The following section outlines the key measures of effectiveness (MOEs) that were extracted from those simulation results to arrive at the non-safety benefits from the proposed ICM deployment.

Numerous simulations were completed to assess the various impacts of the different ICM strategies. Simulations were conducted to evaluate scenarios including both the isolated deployment of ICM strategies as well as the deployment of various combinations of the ICM strategies for each of the various base condition BNICM models. The set of performance results presented here represent the expected impacts of a package of ICM strategies that target the freeway corridors in the Buffalo Niagara region and included deployments of additional ITS technology on the entirety of the I-190 corridor, from the I-90 interchange, through downtown Buffalo, across Grand Island, and finally to the Lewiston-Queenston Bridge. The ICM strategies included in this first package include the following:

- Improved dynamic traveler information,
- Freeway incident detection and expanded service patrol vehicles,
- Locally responsive ramp metering,
- Variable speed limit queue warning system
- Variable time of day toll pricing at the Grand Island toll bridges.

5.3.1 Performance Summary

The presentation of results for Package A in this section is organized as follows:

- Sections 5.3.1.1, 5.3.1.2, and 5.3.1.3 present results in terms of VHT, VMT, and CO_2 Emissions, respectively

- Section 5.3.2 presents results of project-level benefit-cost ratio calculations

5.3.1.1. Vehicle Hours Traveled

As discussed in previous sections, the mobility performance metrics attributed to the simulated strategies were taken as the difference between the average results of the with ICM simulation models and the No Build (without ICM) simulation models. The benefits presented here represent the cumulative deployment of the entire package of ICM strategies listed above. However, results presented do include the interpreted relative performance of the ICM strategies as they contribute to the overall total benefits of the combined package of ICM strategy deployment. Table 5.7 presents the change in vehicle hours travelled as estimated by the simulation of ICM strategies versus simulations without ICM strategies under the different established base conditions for weekday peak period, as well as the percent reduction in VHT seen as a result of the ICM deployment for the entire Package A deployment. Note that negative values represent an increase in the VHT as a result of the ICM deployment, while positive values indicate benefits from the ICM deployment. While the mobility benefits vary by base condition and do in some cases increase the VHT on the roadways, an overall general trend of the impacts of the different ICM strategies on mobility can still be seen while looking at the results by ICM strategy.

Table 5.7 Daily VHT Benefits from ICM Deployment Package A

Base Condition	Peak Period	Dynamic Traveler Information, Incident Detection & Freeway Service Patrol	Ramp Metering (marginal impact beyond column to left)	Variable Speed Limits and Queue Warning (marginal impact beyond column to left)	Variable Toll Pricing (marginal impact beyond column to left)	Combined Strategies	Combined Percent Reduction for Base Condition
Typical Commute	AM	1,457	-658	235	418	**1,452**	**4.3%**
Crash	AM	-240	106	-64	n/a	**-197**	**-0.6%**
Snow Condition	AM	800	172	53	n/a	**1,024**	**2.3%**
Typical Commute	PM	1,768	-97	-92	331	**1,909**	**4.4%**
Crash	PM	309	-215	-997	n/a	**-903**	**-2.0%**
Holiday Demand	PM	209	-171	143	n/a	**-237**	**-0.6%**
Game Day	PM	312	-464	381	n/a	**-396**	**-0.9%**

The deployment of improved dynamic traveler information systems, a freeway incident detection system, and an expanded freeway patrol program in the region generally yields reductions in vehicle hours traveled in all cases except for the AM crash base condition. That general trend of a reduction of VHT is expected, as with better information about the dynamic nature of conditions, travelers should be able to seek improved routes and improve on the overall travel time. The negative benefits are seen in the AM Crash condition can be attributed to increases in travel times in areas of the region where traffic diverts in attempts unsuccessfully to avoid congestion on the freeway from the crash condition.

Ramp metering impacts can be seen to generally provide disbenefits in terms of vehicle hours travelled, by slightly increasing the vehicle hours traveled. While some of the base conditions do improve, most of the simulated base conditions see increases in total vehicle hours of travel. This too can be expected, as the introduction of meters on the ramps inherently add some additional delay and travel time to vehicles entering the freeway system. The freeway mainline conditions would be expected to operate with improved conditions with the metering of the ramps, however, some of those improvements to the freeway main line should be expected to see moved to the ramps and potentially the arterial system through the introduction of the meters. It is important to remember that aside from mobility impacts of the ramp meters, benefits should also be expected to provide safety benefits through lowered crash rates as well as improvements in reliability over the course of a year with fewer crashes occurring per year, which would offset the increases in travel times on a per peak basis.

The travel time impacts of the deployment of a variable speed limit and queue warning system see varied amounts of travel time benefits and disbenefits, as seen with the ramp meters. This too should be expected as the goal of this deployment specifically aims to reduce the speeds and slow traffic as it approaches congested conditions to improve safety conditions and is not generally reported to improve mobility when deployed. It is noted that for the majority of the conditions where disbenefits in terms of travel times are seen from this strategy, the overall scale of the disbenefits is not large. Again, it is noted that these metrics are isolated to the mobility benefits and any of the safety benefits from the ICM deployment should offset any disbenefits seen in travel times.

The introduction of variable tolls can be seen to have positive impacts on simulated vehicle hours of travel in both the AM and PM typical commute conditions. These benefits are expected as the higher toll rates during the core peak hours would encourage travel in the less congested peak shoulder hours or potentially on alternative routes.

For all of the base conditions analyzed, it is noted that the traffic signal controls on the arterial network are unchanged during the ICM deployment of strategy Package A. As a result, no signal timing plans were adjusted as part of a response plan deployed during the ICM event in an attempt to allow the arterial network to process any additional traffic that may detour from the freeway. Doing so could improve operations on the arterial system during an ICM and includes a more holistic approach of using ICM strategies with regards to the entire roadway network management. Please see the next section presenting the results of the ICM deployment strategy Package B for revised results estimates considering the deployment of additional strategies on the arterial system to help manage the potential impacts of increased traffic flows on those arterial streets resulting from the ICM Package A deployment.

While it is recommend that the arterial systems be upgraded to allow for real-time signal timing plan adjustments to allow more flexibility in using the arterials to help manage an ICM event, the results of Package A are still presented to understand the impact of various ICM strategies that could be deployed without the integration of real-time signal control systems on the arterial network. Freeway control systems are generally controlled by fewer agencies and entities and deployment would be expected to involve less interagency coordination and could be deployed more quickly. While not tested or evaluated under this effort, certain ICM strategies that encourage the use of arterial systems may be more selectively activated or deactivated under certain base conditions until the ability to expand arterial operations to allow real time adjustments and coordination with local agencies operating signals can be incorporated into a real-time ICM deployment strategy.

5.3.1.2. Vehicle Miles Traveled

Table 5.8 contains the impacts on vehicle-miles of travel from ICM Package A, with positive numbers indicating reduced VMT, and negative numbers reflecting increased VMT.

The combined strategies of freeway ICM lead to decreased VMT during the AM and PM typical commute periods. This arises mainly from the addition of Variable Tolling strategies, which encourages some traffic to shift away from the core peak period or other corridors. The combined strategies yield the largest increase in VMT during the Snow condition, which is due to drivers taking alternate routes which are faster (but longer) to their destinations to avoid their normal routes which see increase congestion under the reduced capacity conditions of the Snow event. During the AM Crash condition, the dominant impact is from *Dynamic Traveler Info, Incident Detection, and Freeway Service Patrol* (though the impact on VMT is smaller than the VMT impacts from other ICM strategies during other conditions).

Table 5.8 Daily VMT Benefits from ICM Deployment Package A

Base Condition	Peak Period	Dynamic Traveler Information, Incident Detection & Freeway Service Patrol	Ramp Metering (marginal impact beyond column to left)	Variable Speed Limits and Queue Warning (marginal impact beyond column to left)	Variable Toll Pricing (marginal impact beyond column to left)	Combined Strategies	Combined Percent Reduction for Base Condition
Typical Commute	AM	-11,554	-90	6,300	35,360	30,016	1.3%
Crash	AM	-8,219	-2,570	1,792	n/a	-8,997	-0.4%
Snow Condition	AM	-128,383	-17,707	18,443	n/a	-127,647	-6.1%
Typical Commute	PM	-307	1,938	-422	29,064	30,273	1.1%
Crash	PM	-11,506	-19	-25,513	n/a	-37,038	-1.4%
Holiday Demand	PM	-12,747	1,347	-3,941	n/a	-15,341	-0.5%
Game Day	PM	-2,778	8,668	-2,211	n/a	3,679	0.1%

5.3.1.3. Carbon Emissions

Table 5.9 show the emissions impacts of Package A. As with VMT, there is a decrease in CO_2 emissions during the typical commute period and an increase during the Crash and Snow AM conditions. The single most impactful ICM strategy during the AM and PM Typical Commute periods at reducing CO_2 emissions is Variable Tolling Pricing.

Table 5.9 Daily Emissions Benefits (metric tons CO_2) from ICM Deployment Package A

Base Condition	Peak Period	Dynamic Traveler Information, Incident Detection & Freeway Service Patrol	Ramp Metering (marginal impact beyond column to left)	Variable Speed Limits and Queue Warning (marginal impact beyond column to left)	Variable Toll Pricing (marginal impact beyond column to left)	Combined Strategies	Combined Percent Reduction for Base Condition
Typical Commute	AM	-2.37	-1.52	3.06	11.36	10.53	1.0%
Crash	AM	-2.82	-1.61	1.67	n/a	-2.75	-0.3%
Snow Condition	AM	-46.10	-5.93	4.59	n/a	-47.44	-4.6%
Typical Commute	PM	-0.11	-0.37	1.82	9.30	10.64	0.8%
Crash	PM	-5.48	-0.45	-9.84	n/a	-15.77	-1.3%
Holiday Demand	PM	-5.51	-0.72	0.97	n/a	-5.27	-0.4%
Game Day	PM	-1.44	1.11	2.08	n/a	1.76	0.1%

5.3.2 Benefit-Cost Analysis

The previous section presented the changes in the mobility benefits that could be seen during one weekday peak period under various different base conditions. However, as discussed above the expected benefits of the ICM deployment go beyond improvement of mobility in one peak period under specific conditions but also aimed to provide safety benefits over the course of a year as crashes are prevented through the deployment of such ICM strategies. In order to provide a common basis for the comparison of both the mobility and safety benefits of the ICM deployment as well as a comparison of the expected annual costs to deploy and operate the ICM system, all benefits were converted into monetary values and an annual benefit cost analysis was completed using the same monetization and annualization methods previously discussed in preceding sections. Table 5.10, Table 5.11, and Table 5.12 present the annualized benefits from VHT, VMT, and Emissions Impacts, respectively. Table 5.13 presents the benefit cost ratio for the deployment of the ICM Package A strategies.

Collectively, the impacts of the Package A ICM deployments would reduce over half a million vehicle hours of travel over the course of a year; this equates into over $7.5 million in user benefits. It is important to note that this only accounts for direct mobility impacts of the ICM deployments during the non-holiday weekday peak periods. The VMT reductions impacts are approximately $2.5 million, and the emissions impacts are valued at $65,000.

Table 5.10 Annual VHT Benefits from ICM Deployment Package A

Base Condition	Peak Period	Number of Days per Year	Monetized VHT Benefits per Occurrence (veh-hr)	Annual VHT Benefits (veh-hr)	Monetized Annual VHT Benefits ($)
Typical Commute	AM	190	1,452	275,827	$ 4,115,341
Crash	AM	45	-197	-8,881	- $ 132,509
Snow Condition	AM	15	1,024	15,359	$ 229,150
Annual Weekday AM Peaks		**250**	**n/a**	**282,304**	**$ 4,221,982**
Typical Commute	PM	154	1,909	293,926	$ 4,385,376
Crash	PM	63	-903	-56,864	- $ 844,852
Holiday Demand	PM	8	-237	-1,896	- $ 28,285
Game Day	PM	25	-396	-9,892	- $ 147,594
Annual Weekday PM Peaks		**250**	**n/a**	**225,244**	**$ 3,360,646**
Annual Recurring Mobility Benefits (Weekday Peak Periods)				**507,549**	**$ 7,572,628**

Table 5.11 Annual VMT Benefits from ICM Deployment Package A

Base Condition	Peak Period	Number of Days per Year	VMT Benefits per Occurrence (veh-mi)	Annual VMT Benefits (veh-mi)	Monetized Annual VMT Benefits ($)
Typical Commute	AM	190	30,016	5,702,975	$ 2,604,117
Crash	AM	45	-8,997	-404,865	-$ 184,871
Snow Condition	AM	15	-127,647	-1,914,705	-$ 874,301
Annual Weekday AM Peaks		**250**	**n/a**	**3,383,405**	**$ 1,544,945**
Typical Commute	PM	154	30,273	4,662,042	$ 2,011,927
Crash	PM	63	-37,038	-2,333,394	-$ 1,006,988
Holiday Demand	PM	8	-15,341	-122,728	-$ 52,964
Game Day	PM	25	3,679	91,975	$ 39,692
Annual Weekday PM Peaks		**250**	**n/a**	**2,297,895**	**$ 991,668**
Annual Recurring Mobility Benefits (Weekday Peak Periods)				**5,681,300**	**$ 2,536,613**

Table 5.12 Annual Emissions Benefits (metric tons CO_2) from ICM Deployment Package A

Base Condition	Peak Period	Number of Days per Year	Emissions Benefits per Occurrence (tons CO_2)	Annual Emissions Benefits (tons CO_2)	Monetized Annual Emissions Benefits ($)
Typical Commute	AM	190	10.53	2,000.7	$ 72,025
Crash	AM	45	-2.75	-123.8	-$ 4,455
Snow Condition	AM	15	-47.44	-711.6	-$ 25,618
Annual Weekday AM Peaks		**250**	**n/a**	**1,165.4**	**$ 41,953**
Typical Commute	PM	154	10.64	1,638.6	$ 58,988
Crash	PM	63	-15.77	-993.5	-$ 35,766
Holiday Demand	PM	8	-5.27	-42.2	-$ 1,518
Game Day	PM	25	1.76	44.0	$ 1,584
Annual Weekday PM Peaks		**250**	**n/a**	646.9	$ 23,288
Annual Recurring Emissions Benefits (Weekday Peak Periods)				**1,812.2**	**$ 65,241**

Collectively, Package A of the ICM deployment would provide annual benefits of over $13 million. When compared to the total annualized system deployment costs ($4.9 million) the deployment of Package A ICM strategies to focus on the I-190 and cross border freeway focused corridors is predicted to yield a benefit to cost ratio of 2.77. Details of each component of the Package A ICM deployment benefits and costs are presented in Table 5.13.

Table 5.13 Benefit Cost Ratio for ICM Deployment Package A

Item	Annual Value ($)
Recurring Mobility Benefits (Weekday Peak Periods)	$ 7,572,628
Recurring VMT Benefits (Weekday Peak Periods)	$ 2,536,613
Recurring Emissions Benefits (Weekday Peak Periods)	$ 65,241
Mobility Benefits from Prevented Crashes	$ 765,021
Prevented Crash Costs	$ 2,757,205
Total Benefits	**$ 13,696,708**
Additional DMS	$ 144,978
Ramp Metering	$ 356,791
Variable Speed Limits / Queue Warnings	$ 4,137,343
Freeway Incident Detection & Patrol	$ 296,998
Total Costs	**$ 4,936,110**
Benefit/Cost Ratio for ICM Deployment Package A	**2.77**

5.4 ICM Performance: Added Arterial Improvements (Package B)

As the above Package A ICM deployments primarily included strategies that targeted freeway operations, the simulation results showed increases in hours of travel outside of the freeway roadways and highlighted the need for additional implementations of strategies along on the arterial roadways. This is especially the case for the base condition crash scenarios, where overall system-wide increases in vehicle hours travelled was seen as a result of the ICM Package A scenario deployment.

To improve on the overall mobility performance of the ICM deployment under those crash conditions, additional strategies were developed and implemented within the BNICM simulation models to improve on signal coordination and arterial throughput during an ICM crash event. While no specific detour routes are designated or recommended to the traveling public during the crash event, drivers familiar with the roadways will seek alternative paths. Given the nature of the crash is being simulated in both the AM and PM Crash base conditions (along I-190 near the SR-198 interchange), it is expected that Niagara Street will see the majority traffic attempting to divert from the I-190 corridor. For both of the AM and PM Crash scenarios, separate signal control response plans were developed to help Niagara Street operate more efficiently given increased demands during the crashes. All signal controllers along Niagara Street from Elmwood Avenue in the South to Niagara Street in the north were adjusted as part of the response plans. Separate signal timing response plans were developed for each of the peak periods and targeted the direction of flow affected by the crash; southbound in the AM peak, and northbound in the PM peak. Slight different adjustments were made at each individual signal, but in general the adjustments set a common cycle length to improve coordination between intersections and adjusted the green time for the direction along Niagara Street expected to see increased flows during the crashes.

Within the BNICM simulation models, the signal coordination response plans were coded to start approximately 10 minutes after the time of the simulation crash. This time was designed to reflect the cumulative latency associated with the time it would take for the crash to be detected, an appropriate response plan to be selected within the TMC, and for the signal controllers to implement the selected response plan timings. The response timing plans were also kept in effect past the clearance time of the crash until the I-190 corridor return to normal operations and the overall congestion impacts resulting from the crash were dissipated. After this time, the signals within the Niagara Street corridor in the BNICM models reverted to their normal time of day timing plans.

It is important to note that the only difference between the Package B deployment and the Package A deployment was the addition of the signal coordination response plans. The Package B scenario still includes all strategies included under Package A, and no adjustments or refinement were made to the implementation details of those other strategies.

5.4.1 Performance Summary

The presentation of results for Package B in this section is organized as follows:

- Sections 5.4.1.1, 5.4.1.2, and 5.4.1.3 present results in terms of VHT, VMT, and CO_2 Emissions, respectively
- Section 5.4.2 presents results of project-level benefit-cost ratio calculations

5.4.1.1. Vehicle Hours Traveled

Following the simulation of the Package B ICM deployment for the crash scenarios, performance metrics were extracted from the scenarios and compared those from the No Build (without ICM) scenario simulations to assess the overall Package B deployment impacts under each of the base conditions simulated.
Table 5.14 presents the overall Impact of the Package B ICM deployment on the VHT on the daily basis. It is noted that only performance metrics for the crash conditions were simulated and adjusted. The response plans and signal coordination is expected to provide the most benefits under a crash condition, when significant additional demands can be expected on select arterial roadways. While there is the potential for further improvement under the non-crash conditions, the potential for these benefits have not yet been evaluated. However, all base conditions are still presented here to provide a complete picture of the benefits estimated for the Package B deployment.

Table 5.14 Daily VHT Benefits from ICM Deployment Package B

Base Condition	Peak Period	Dynamic Traveler Information, Incident Detection & Freeway Service Patrol	Ramp Metering	Variable Speed Limits and Queue Warning	Variable Toll Pricing	Signal Coord. During ICM Events	Combined Strategies	Combined Percent Reduction for Base Condition
Typical Commute	AM	1,457	-658	235	418	n/a	**1,452**	**4.3%**
Crash	AM	-240	106	-64	n/a	215	**18**	**0.1%**
Snow Condition	AM	800	172	53	n/a	n/a	**1,024**	**2.3%**
Typical Commute	PM	1,768	-97	-92	331	n/a	**1,909**	**4.4%**
Crash	PM	309	-215	-997	n/a	1589	**686**	**1.6%**
Holiday Demand	PM	209	-171	143	n/a	n/a	**-237**	**-0.6%**
Game Day	PM	312	-464	381	n/a	n/a	**-396**	**-0.9%**

As compared to the Package A results, mobility impacts seen under a Package B ICM deployment in the crash conditions improve significantly. In the AM Crash scenario, previously seen disbenefits are removed and the net overall impact on VHT of the Package B ICM deployment shows benefits, albeit minor. In the PM Crash scenario, the improvements over Package A performance are more significant and positive benefits are seen across the network.

The implemented signal coordination response plans during the crash events improve on the operational performance of Niagara Street; both increases in the demands able to be served and reductions in delays per vehicle were seen. Additional delays seen on the side street approaches to Niagara Street can be expected with the shift of some green time to the Niagara Street phases, but the net overall impact on mobility during the crash scenarios was still positive and was far improved over the Package A simulation results when signal coordination response plans were not included as part of the ICM response package.

5.4.1.2. Vehicle Miles Traveled

Table 5.15 shows that during the AM crash condition VMT are increased, but during the PM crash period VMT are decreased much more (~5,000 vs. ~70,000 VMT). The former result is due to the increased traffic-moving capacity of the arterial system enabling more drivers to find suitable longer-distance alternative routings to their preferred routing in the typical condition when there are no crash incidents.

Table 5.15 Daily VMT Benefits from ICM Deployment Package B

Base Condition	Peak Period	Dynamic Traveler Information, Incident Detection & Freeway Service Patrol	Ramp Metering (marginal impact beyond column to left)	Variable Speed Limits and Queue Warning (marginal impact beyond column to left)	Variable Toll Pricing (marginal impact beyond column to left)	Signal Coord. During ICM Events (marginal impact beyond column to left)	Combined Strategies	Combined Percent Reduction for Base Condition
Typical Commute	AM	-11,554	-90	6,300	35,360	n/a	30,016	1.3%
Crash	AM	-8,219	-2,570	1,792	n/a	-5,224	-14,221	-0.6%
Snow Condition	AM	-128,383	-17,707	18,443	n/a	n/a	-127,647	-6.1%
Typical Commute	PM	-307	1,938	-422	29,064	n/a	30,273	1.1%
Crash	PM	-11,506	-19	-25,513	n/a	70,226	33,188	1.2%
Holiday Demand	PM	-12,747	1,347	-3,941	n/a	n/a	-15,341	-0.5%
Game Day	PM	-2,778	8,668	-2,211	n/a	n/a	3,679	0.1%

5.4.1.3. Carbon Emissions

Table 5.16 shows that the effect of the signal coordination strategy is to increase emissions marginally during the AM crash condition, but decrease it more during the PM crash condition. This closely tracks the results from the VMT impacts (see Table 5.15).

Table 5.16 Daily Emissions Benefits (metric tons CO_2) from ICM Deployment Package B

Base Condition	Peak Period	Dynamic Traveler Information, Incident Detection & Freeway Service Patrol	Ramp Metering (marginal impact beyond column to left)	Variable Speed Limits and Queue Warning (marginal impact beyond column to left)	Variable Toll Pricing (marginal impact beyond column to left)	Signal Coord. During ICM Events (marginal impact beyond column to left)	Combined Strategies	Combined Percent Reduction for Base Condition
Typical Commute	AM	-2.37	-1.52	3.06	11.36	n/a	10.53	1.0%
Crash	AM	-2.82	-1.61	1.67	0.00	-1.36	-4.12	-0.4%
Snow Condition	AM	-46.10	-5.93	4.59	0.00	n/a	-47.44	-4.6%
Typical Commute	PM	-0.11	-0.37	1.82	9.30	n/a	10.64	0.8%
Crash	PM	-5.48	-0.45	-9.84	n/a	28.71	12.94	1.1%
Holiday Demand	PM	-5.51	-0.72	0.97	n/a	n/a	-5.27	-0.4%
Game Day	PM	-1.44	1.11	2.08	n/a	n/a	1.76	0.1%

5.4.2 Benefit-Cost Analysis

As was done for the Package A evaluation, the daily VHT performance metrics extracted from the BNICM simulation models were annualized and monetized to project the total system benefits of the Package B scenario. Table 5.17 presents updated annualized benefits for each of the analyzed base conditions under a Package B ICM deployment. As a result of the addition of the signal coordination response plans under Crash AM and PM base conditions, the total annual mobility benefits increase by more than 20% from the Package A benefits, with a total of over 617,000 vehicle hours traveled, or an equivalent $9.2 million in mobility (VHT) benefits. The benefits from VMT benefits are $4.3 million, and the net reduction is carbon emissions is monetized at a value of $128,000.

Table 5.17 Annual VHT Benefits from ICM Deployment Package B

Base Condition	Peak Period	Number of Days per Year	Monetized VHT Benefits per Occurrence (veh-hr)	Annual VHT Benefits (veh-hr)	Monetized Annual VHT Benefits ($)
Typical Commute	AM	190	1,452	275,827	$ 4,115,341
Crash	AM	45	18	793	$ 11,838
Snow Condition	AM	15	1,024	15,359	$ 229,150
Annual Weekday AM Peaks		**250**	**n/a**	**291,979**	**$ 4,356,328**
Typical Commute	PM	154	1,909	293,926	$ 4,385,376
Crash	PM	63	686	43,210	$ 644,690
Holiday Demand	PM	8	-237	-1,896	- $ 28,285
Game Day	PM	25	-396	-9,892	- $ 147,594
Annual Weekday PM Peaks		**250**	**n/a**	**325,348**	**$ 4,854,188**
Annual Recurring Mobility Benefits (Weekday Peak Periods)				**617,327**	**$ 9,210,516**

Table 5.18 Annual VMT Benefits from ICM Deployment Package B

Base Condition	Peak Period	Number of Days per Year	VMT Benefits per Occurrence (veh-mi)	Annual VMT Benefits (veh-mi)	Monetized Annual VMT Benefits ($)
Typical Commute	AM	190	30,016	5,702,975	$ 2,604,117
Crash	AM	45	-14,221	-639945	-$ 292,214
Snow Condition	AM	15	-127,647	-1914705	-$ 874,301
Annual Weekday AM Peaks		**250**	**n/a**	**3,148,325**	**$ 1,437,602**
Typical Commute	PM	154	30,273	4,662,042	$ 2,011,927
Crash	PM	63	33,188	2,090,844	$ 902,314
Holiday Demand	PM	8	-15,341	-122,728	-$ 52,964
Game Day	PM	25	3,679	91,975	$ 39,692
Annual Weekday PM Peaks		**250**	**n/a**	**6,722,133**	**$ 2,900,970**
Annual Recurring Mobility Benefits (Weekday Peak Periods)				9,870,458	$ 4,338,572

Table 5.19 Annual Emissions Benefits (metric tons CO_2) from ICM Deployment Package B

Base Condition	Peak Period	Number of Days per Year	Emissions Benefits per Occurrence (tons CO_2)	Annual Emissions Benefits (tons CO_2)	Monetized Annual Emissions Benefits ($)
Typical Commute	AM	190	10.53	2,000.7	$ 72,025
Crash	AM	45	-4.12	-185.4	-$ 6,674
Snow Condition	AM	15	-47.44	-711.6	-$ 25,618
Annual Weekday AM Peaks		**250**	**n/a**	**1,103.7**	$ 39,733
Typical Commute	PM	154	10.64	1,638.6	$ 58,988
Crash	PM	63	12.94	815.2	$ 29,348
Holiday Demand	PM	8	-5.27	-42.2	-$ 1,518
Game Day	PM	25	1.76	44.0	$ 1,584
Annual Weekday PM Peaks		**250**	**n/a**	2,455.6	$ 88,402
Annual Recurring Emissions Benefits (Weekday Peak Periods)				3,559.3	$ 128,136

Table 5.20 presents the summary of the benefit cost analysis of the Package B ICM deployment. While the addition of the signal coordination response plans during an ICM crash event improved the mobility benefits of the deployment, it was assumed (conservatively) that no additional safety benefits would be produced. As such the change in the total benefits seen under a package be deployment are solely from the improved mobility benefits, with a net annual benefit of approximately $17.2 million to be expected under a Package B ICM deployment. Annual costs also increase, as the inclusion of signal coordination elements as part of the ICM system require an upgrade of signal controllers and the addition of additional sensing equipment at the intersections to monitor the arterial performance in real time. In considering the costs to upgrade the Niagara Street corridor, the total costs for a package B deployment increase to approximately $5.1 million. Both increases combine to produce a benefit cost ratio of approximately 3.37, or about a 20% increase over the Package A ratio.

Table 5.20 Benefit Cost Ratio for ICM Deployment Package B

Item	Annual Value ($)
Recurring Mobility Benefits (Weekday Peak Periods)	$ 9,210,516
Recurring VMT Benefits (Weekday Peak Periods)	$ 4,338,572
Recurring Emissions Benefits (Weekday Peak Periods)	$ 128,136
Mobility Benefits from Prevented Crashes	$ 765,021
Prevented Crash Costs	$ 2,757,205
Total Benefits	**$17,199,449**
Additional DMS	$ 144,978
Ramp Metering	$ 356,791
Variable Speed Limits / Queue Warnings	$ 4,137,343
Freeway Incident Detection & Patrol	$ 296,998
Signal Controller Upgrades	$ 173,306
Total Costs	**$ 5,109,416**
Benefit/Cost Ratio for ICM Deployment Package B	**3.37**

6.0 Recommended Deployment Priorities and Implementation Plans

The previously presented analysis results show the potential benefits from the ICM deployment for the weekday peak period conditions under various conditions that are seen in the periods over the course of a year, with benefits of the deployment returning more than double the installation and operation costs of the ICM system. This was true even when making some conservative assumptions about the benefits of the ICM deployments. These findings indicate that there are positive benefits from the deployment of the ICM system, and further efforts to design and deploy ICM systems on the region's roadways is justifiable.

However, ICM benefits are typically measured in inches and not yards; further testing of refined ICM deployments and response plans may be able to further extract benefits from the deployment of ICM strategies. Additionally, the examination of staged deployments of the ICM systems and equipment may also be prudent to distribute initial deployment costs while still seeing benefits from the initial staged deployments.

An additional needed step towards deployment would be more detailed design and a more robust analysis of the costs to deploy and operate field equipment needed to implement ICM response plans. While annual costs for deployment and operation were estimated as part of this study using the best information at hand, more detailed implementation plans should include more detailed cost estimates to ensure the estimated costs are reasonable and do not greatly affect the resulting benefit to cost ratios of the ICM deployment.

6.1 ICM Deployment and Implementation Next Steps

As the next steps in moving towards the deployment of ICM in the region, it is still recommended to revisit the details of the ICM deployment plans that were evaluated in this study and expand the analysis effort as the design efforts are undertaken. While different base conditions were examined, the further analysis of the ICM benefits under even more base conditions under which ICM response plans might be executed is recommended.

One such further refinement should include the analysis of the impacts of ICM under additional crash conditions, with different severities of crashes in different locations on the region's roadways to further refine the ICM response plans. This analysis of additional ICM event conditions would better identify the potential benefits of the ICM deployment by including additional scenarios which were not tested to this point of ICM deployment planning for the region.

The further refinement of ICM strategy deployments under certain studied base conditions should also be considered. For example, while safety benefits would be seen from the deployment of the ICM strategies, under certain base conditions mobility disbenefits were also created from the deployments. Additional refinement of the ICM response plans to the ICM strategies in those conditions could result in even further improved benefits. Additionally, should further refinement of strategies not be able to be discovered, during those selected conditions it may indeed be best to not deploy select ICM strategies to prevent creating disbenefits.

Additionally, there could still exist the potential for additional benefits from the operation an ICM system outside of the weekday peak periods, especially under crash conditions where slower operating speeds and unanticipated congestion are experienced on the roadways. The installation costs for deploying equipment in the field to operate during the weekday peak periods would already be incurred and minimal additional costs would be needed to operate ICM strategies during the off-peak periods. Therefore, the addition of potential benefits from off-peak period ICM operations would increase the benefit cost ratio beyond the current levels, but the degree to which it would increase is not currently known. Additional analysis of the potential off-peak benefits could be examined as part of more detailed planning and design efforts leading to the deployment of the ICM systems. It is noted that to analyze the potential benefits of off-peak ICM operations, the development of off-peak BNICM models would be required.

While the analyzed ICM deployment yields positive benefits, it is recognized that the costs of deploying the systems as a whole may be prohibitively expensive, and a more staged deployment of the ICM strategies and field equipment could be considered to the specific costs as well as the projected benefits of different subsystems. An example of such a staged deployment could be the deployment of the variable speed limit and queue warning system. As tested, the variable speed limit and queue warning system included the entire I-190 corridor in order to provide benefits not only in the I-190 corridor larger cross border corridor as well. However, given accident records, safety benefits are not expected to be uniform across each mile of roadway as the majority of crashes on the I-190 corridor currently are seen to occur between I-290 and I-90. A staged deployment of the variable speed limit and queue warning system between I-290 and I-90 may be considered to lower the initial overall deployment costs of building out roadway gantries and dynamic signage for the entire I-190 corridor and to target the areas where safety benefits are more likely to be seen. A second stage of deployment to extent the system to other portions of I-190 or even onto other freeways in the regions could follow. It is recommended that additional simulation analysis of any proposed staged deployments be conducted first to reinforce the impacts on the potential benefits and costs from a staged deployment prior to detailed design and field implementation.

Any future ICM deployment considerations should ensure a constant monitoring and evaluation process is included. While good real-time speed data is already available, similar real-time volume data should also be considered in selecting in real time ICM deployment plans is lacking. While some of the proposed ICM deployments include the ability for such monitoring (e.g. signal system upgrades), the deployment of additional volume monitoring systems should be considered for deployment prior to the full deployment of the ICM field response equipment and systems, especially on the freeway facilities. The initial deployment of the additional sensing equipment prior to the full ICM deployment could also help with further refinement of the ICM response strategy for further evaluation prior to ICM deployment.

Finally, a performance evaluation program that evaluates the effectiveness of ICM response plans as they are implemented in the field is needed. This will require additional efforts to better tune the BNICM simulation model to better predict real-world responses to the implemented ICM strategies. This is useful to better design ICM responses to given events, to better prepare for additional future ICM events. This is true regardless of whether a future ICM effort includes the BNICM model in a real-time support role or only in an off-line planning role. Further details are included in Chapter 7.0.

6.2 I-190 Corridor Implementation Plan

To further the deployment of an ICM system on the I-190 corridor, the previously discussed recommended prioritizations and refined response plan strategies should first be conducted. Additionally, the following key steps specific to the I-190 corridor should be undertaken.

Benefits were seen for all analyzed ICM strategies. The further development of all analyzed strategies should be considered, while still considering prioritization and follow up refinement efforts as discussed above.

The analysis completed under this study should be further refined and detailed as future efforts move towards system design and deployment. This specifically includes:

- Refinement of deployment costs should be undertaken with initial designs for implementation
- Refined ramp meter algorithms may yield further benefits then those estimated in this study. Efforts recently undertake to deploy ramp metering in other areas in New York can be included and details of those deployments can be leveraged to potentially reduce design costs.
- Refined evaluations and testing of projected benefits for partial or staged I-190 deployments should be tested. For example, considering the high costs associated with deploying overhead gantries and dynamic signage needed to operate the variable speed limit and queue warning system throughout the entire corridor, a partial deployment targeting only the areas with routine congestion and/or increased crash histories may be more cost effective
- Further testing of the potential for signal coordination and ICM response plans for arterial corridors other than the Niagara Street corridor that could be used as part of an ICM response plans for crashes or other incidents along other portions of I-190 than those that were analyzed. The short list of arterial corridors presented in Section 4.6 should be examined to determine the potential benefits for signal retiming and coordination as part of any response plans to ICM events.

6.3 Border Crossing Implementation Plan

The advancement of ICM to support border crossing operations can also be advanced through the undertaking of the above general next steps, as well as the I-190 corridor plans as the corridor provides the predominant connection between the border crossings.

Since the initiation of the BNICM study, improvements to cross border operations have already been undertaken since this effort was initiated. Many of these efforts would fall under the increased traveler information sharing and includes the expansion of the border crossing delay monitoring system and the refined and more detailed reporting those border crossing delays via NITTEC’s internet systems (website and mobile phone applications) and via DMS across the system.

Further investigations into the potential for trans-border truck operations should be investigated as well. While private autos can use the crossing of their choice, trucks are often limited in their choice at the time of an event given the paperwork and credentials needed to cross the border with commercial goods. While the control of such changes are well beyond the extents of what NITTEC or even MTO can implement by themselves, the allowance of truckers to select which crossing is best to use in response to a real-time event will help ensure that truckers and autos can be served by an ICM deployment.

Specific to the border crossing operations, continued efforts to coordinate with the MTO on an international ICM response plan approach should be undertaken. This will prevent each agency from implementing conflicting strategies at the same time. As much as possible, this coordination should also include the U.S. Customs and Border Protection (CBP) and the Canada Border Services Agency (CBSA) so that the operations of the border crossings stations are included in the determination of an appropriate response plan. While all of these agencies are already involved with NITTEC and routinely share information, most ICM efforts completed to date show that there is increased benefit in more detailed formal stakeholder agreements and cooperation, including the automation of data sharing and potentially even ICM response plan selection and approval during an ICM event. For the border crossing ICM deployment, even further between both nations' responsible agencies to consider unified response plans to ICM events on either side of the border should be developed and formalized for a coordinated ICM system and streamlined responses to events along I-190, the Queen Elizabeth Way (QEW), and at each of the border crossing stations.

7.0 Performance Monitoring & Reporting Plan

While the previous simulation and benefit-cost analysis demonstrates the feasibility and viability of an ICM deployment within the region, any potential deployment should also include a data driven process to continually monitor the performance of the ICM system and its response plans that are implemented in the field. The results of that performance monitoring should also carry forward into a continuous improvement framework to ensure that the ICM response plans implemented in the field are as beneficial as they can be for the given conditions as an ICM system operates over time.

During previous phases of planning for ICM for the region, a series of performance measures were developed to track individual objectives and goals for an ICM system. These objectives, goals, and performance measures are presented in Table 7.1. The presented performance measures are a mixture of agency performance, stakeholder engagement, degree of system deployment, and measures of operational conditions and performance of the region's roadway networks. These metrics are well suited to tracking the goals and are generally measurable with minimal additional data collection efforts beyond the data collection and tracking already in place today. It is recommended that these metrics are computed and tracked across time to assess the deployment, agency and stakeholder integration, and performance components of a future deployed Buffalo-Niagara ICM system. There are, however, two shortcomings of the performance measures listed that can be improved upon.

First, many of the operations based performance metrics listed in this table are designed to track the overall effects and impacts of an ICM system deployment. This cumulative impact of the ICM system is really the sum of the impacts of each action taken and each response implemented in response to each ICM triggering event. As can be seen in the analysis presented in Chapter 5, there is the potential for response plans to be implemented that have opposite impact of the intended effect on these system operations. This creates the need for a new category of performance measure to evaluate the impacts of the individual response plans, not just the system as a whole.

Second, the key to measuring the operational impacts of an ICM response plan to specific event is to assess the impacts on improving mobility (reducing travel times and improving travel time reliability), safety (reducing the severity of or outright preventing a crash), and environmental impacts (reducing emissions and fuel consumption). Unfortunately, some of these metrics can be exceedingly difficult or impossible to truly measure these changes in the field for specific ICM events. Even when surrogate measures can be used (e.g. corridor travel time or speed as an indicator of all vehicle hours traveled), they still can not truly evaluate the difference between the performance measures when an action is taken and when an action is not taken by the ICM system. Since each event and the conditions surrounding an event are essentially unique and only one action can be taken in the field (enact a response plan or do nothing) at a time, a true comparison of a set of performance measurements for a different response for that event can not truly be obtained.

To resolve these issues, two solutions can be deployed. First metrics can be tracked both over time, but in more detail and in consideration of the operating conditions present and when the ICM system implements a response plan. Second, a simulation based approach to evaluate response plan impacts for the elements that cannot truly be measured in the field. The following describes those in more detail.

Table 7.1 ICM Goals and Objectives

Category	Objective	Short Term Goal	Long Term Goal	Performance Measure
I. Agency Coordination	Improve center-to-center communications	1. Center-to-center (C2C) communications is functioning among all transportation related agencies in the corridor	1. Center-to-center (C2C) communications is functioning among all transportation related agencies in the corridor	1. Evaluate the use of established center-to-center communication links a. Number of agencies b. Monthly activity c. Monthly down time
II. Traveler Information	A. Improve accuracy of congestion (travel time) information reliability	1. Reduce the variation in travel times experienced by travelers throughout the corridor by 25 percent 2. Posted travel times are within 20 percent of measured travel times 3. Travel time information sources have an up-time of 99 percent 4. System element down time averages less than 12 hours per element failure 5. System (as a whole) down time averages less than four hours per system failure	1. Reduce the variation in travel times experienced by travelers throughout the corridor by 35 percent 2. Posted travel times are within 10 percent of measured travel times 3. Travel time information sources have an up-time of 99.9 percent 4. System element down time averages less than 10 hours per element failure 5. System (as a whole) down time averages less than four hours per system failure	1. Monthly variation for selected times and links 2. Compare posted travel times with measured travel times for selected time periods and links 3. Monthly up-time 4. Monthly down time per element 5. Monthly system down time
	B. Enable intermodal choices through improved traveler information	1. Transit information has been integrated into the highway information network 2. Traveler information usage has increased by 150 percent 3. An 85 percent customer traveler information satisfaction rating has been achieved among local commuters and border crossing commuters receiving information 4. Travelers are provided with various modal and route options to effectively travel throughout the corridor that enable them to make choices regarding: Departure time, Mode and route	1. Transit information has been integrated into the highway information network 2. Traveler information usage has increased by 200 percent 3. An 90 percent customer traveler information satisfaction rating has been achieved among local commuters and border crossing commuters receiving information 4. Travelers are provided with various modal and route options and are also provided with the current conditions facing each option	1. Traveler information is integrated 2. Evaluate the use of traveler information monthly a. Traveler surveys are conducted b. Web site hits c. 511 telephone service calls 3. Yearly traveler surveys 4a. Static traveler information is in place 4b. Dynamic traveler information is in place

Category	Objective	Short Term Goal	Long Term Goal	Performance Measure
II. Traveler Information (con't)	C. Improve integration of weather information/data for traveler information, and for maintenance operations	1. Weather information/data sources is integrated into all traveler information services 2. Relationship with weather information/data sources has increased by 5 percent 3. Weather information/data is integrated into all maintenance call-out procedures and systems for managing operations	1. Weather information/data sources is integrated into all traveler information services 2. Relationships with weather information/data sources has increased by 10 percent 3. Weather information/data is integrated into all maintenance call-out procedures and systems for managing operations 4. Integration of the RWIS between the region and the province is functioning 5. RWIS is integrated into all traveler information services	1. Successful integration has been accomplished 2. Number of relationships with weather information/data sources 3. Successful integration has been accomplished 4. Successful integration has been accomplished 5. Successful integration has been accomplished
	D. Improve integrated operations based on real-time data	1. Use of real-time data has been determined 2. The system has an up-time of 99 percent 3. New technology is integrated at least every four years	1. Real-time data is used to improve operations 2. The system has an up-time of 99 percent 3. New technology is integrated at least every four years	1. Use of real-time data has been determined and is in use 2. Monthly up-time 3. Frequency of system element updates
III. Mobility (Arterial, Border, Freeway, Transit)	A. Maximize the free flow of traffic and reduce congestion	1. 50 percent of the identified arterials within the ICM corridor are coordinated across jurisdictions. 2. A central source directly or indirectly manages and operates 50 percent of the corridors in the ICM 3. Key signals in the corridor are retimed every three years	1. All identified arterials within the ICM corridor are coordinated across jurisdictions 2. A central source directly or indirectly manages and operates all corridors in the ICM 3. Key signals in the corridor are retimed every three years	1. The percentage of coordinated corridors 2. Percentage of the ICM corridors operated by a central source 3. Number of key signals retimed every three years
	B. Provide transit alternative and park-and-ride facilities	1. Transit ridership has increased 1 ½ times the percent of traffic volume increase 2. The number of park-and-ride facilities has increased by 10 percent	1. Transit ridership has increased 2 times the percent of traffic volume increase 2. The number of park-and-ride facilities has increased by 20 percent	1. Percentage of ridership increase 2. Number of park-and-ride facilities
	C. Enhance border crossing clearance	1. Total border delay time has decreased by 5 percent from existing demand levels	1. Total border delay time has decreased by 15 percent from existing demand levels	1. Monthly total border delay time during selected times and periods

Category	Objective	Short Term Goal	Long Term Goal	Performance Measure
III. Mobility (con't)	D. Facilitate ITS and operational improvements that will facilitate ICM mobility	1. The VMS, Travel Time readers and CCTV have been deployed in accordance with the ICM	1. The VMS, Travel Time readers and CCTV deployed is maintained 2. The HAR system fully covers the ICM corridor	1. Number of VMS, Travel Time readers and CCTV deployed per year 2. HAR system coverage in the ICM corridor
	E. Enhance alternative route management capabilities	1. Develop one arterial signal system and integrate with related freeway management systems 2. Operate signals and freeways in one corridor as a system 3. Provide additional instrumentation on three primary arterials 4. Provide additional instrumentation on one parallel arterials that may be designated as diversion routes	1. Develop three arterial signal systems and integrate with related freeway management systems 2. Operate signals and freeways in three corridors as systems 3. Provide additional instrumentation on five primary arterials 4. Provide additional instrumentation on three parallel arterials that may be designated as diversion routes	1. Number of integrated systems 2. Number of corridors operating as a system 3. Number of arterials instrumented 4. Number of parallel arterials instrumented
IV. Incident Management	A. Establish incident classifications and severity guidelines	1. Develop agreed upon definitions for minor, intermediate, and major incidents 2. Define incident severity guidelines based on: Incident Severity, Field Conditions, Resources needed, and Estimated incident duration	1. Utilize agreed upon definitions for minor, intermediate, and major incidents 2. Utilize incident severity guidelines	1a. Incident definitions agreed upon 1b. Incident definitions universally used 2. Incident severity guidelines are defined

Category	Objective	Short Term Goal	Long Term Goal	Performance Measure
IV. Incident Management (con't)	B. Improve and coordinate incident management	1. Meetings are held among transportation agencies monthly	1. Meetings are held among transportation agencies every month	1. The number of meetings held per year
		2. Average incident detection to arrival time is less than 8 minutes	2. Average incident detection to arrival time is less than 6 minutes	2. Monthly average incident detection to arrival time
		3. Average incident detection to lane clearance time is reduced by 20 percent	3. Average incident detection to lane clearance time is reduced by 30 percent	3. Monthly percentage reduction of average incident detection to lane clearance time
		4. Average time from detection to back to normal conditions is reduced by 15 percent	4. Average time from detection to back to normal conditions is reduced by 20 percent	4. Monthly percentage reduction of average time from detection to back to normal conditions
		5. All incident measures are uniform for all jurisdictions	5. All incident measures are uniform for all jurisdictions	5. Incident measures are uniform
		6. Responder training exists, which provides guidance on relaying accurate information on what equipment is needed for various incidents	6. Responder training exists, which provides guidance on relaying accurate information on what equipment is needed for various types of incidents	6. The number of training and exercise sessions held yearly
		7. An integrated corridor approach is established for:	7. An integrated corridor approach is provided during:	7. An integrated corridor approach is functioning for:
		a. Incident management	a. Incident management	a. Incident management
		b. Special or planned events	b. Special or planned events	b. Special or planned events
		c. Emergencies within the corridor	c. Emergencies within the corridor	c. Emergencies within the corridor

Source: NITTEC Transportation Operations Integrated Corridor Management Requirements Document, January 2010

7.1 Detailed Field Performance Monitoring

For the established performance metrics listed in the above table, several include elements that can be directly measured in the field. Many are in fact already measured and reported in NITTEC's Annual Reports. These measures include:

- The number of crashes occurring by corridor strategy,
- The response time to incidents,
- Corridor specific travel times,
- Border crossing times and delays, and
- The number of different types of events that the TMC or partner agencies respond to.

These reported metrics are already excellent measures of the system performance, and provide a valuable set of metrics to compare the system performance over time. It is highly recommended that this reporting continue to allow a comparison of these individual metrics through time to compare pre-ICM deployment metrics to those post-ICM deployment through a before and after comparison to estimate the impacts of the ICM deployment.

There are, however, a number of confounding factors (economic activity, land use developments, roadway improvement projects, etc.) which can influence these metrics over time apart from the deployment of an ICM system. These combined with the relative rarity of crashes to the number of millions of vehicle miles traveled on the regions roadways can make a comparison over time difficult. That said, this time based set of performance metrics still provides an extremely valuable data set to track the performance of ICM deployment on improving the mobility, reliability, safety and environmental performance of the region.

It is also recommended that this performance tracking and reporting not only continue, but be expanded with additional details such as more robust recording of the location of the crash or congestion event, reporting of roadway volumes and throughput on the roadways (noted this will require additional sensing equipment), and details of the special event demand generators that are experienced and noted in the TMC. Additionally, once the ICM system is deployed, additional details of the nature of the ICM response plan(s) implemented in for each event should be recorded.

By having detailed records of corridor travel times and speeds, crash records, border crossing times, regional high demand events (e.g. sports events), weather data, and TMC events, a combined cluster analysis of these datasets can be undertaken to determine the interrelated aspects of these metrics (e.g. crash or weather impacts on travel times). This can help identify specific combinations of events and types which happen most frequently and which have the most impact on the performance of the transportation network, and thus potentially can see the most annual benefits from deployment on an ICM system.

This is in fact a similar process to what was undertaken during this study to identify the specific base conditions which were analyzed and potential benefits developed, however, having this database tied to the specific ICM responses plans implemented during each event can allow for a more robust analysis of the overall performance of the ICM deployment in the future under the wide variety of conditions that the region sees day-to-day throughout a year. By comparing the performance measures of when ICM response plans are implemented to when they are not or to pre-ICM conditions, it can also help identify which specific combination of events or response plans may be underperforming and may need to be revised in attempts to improve on the benefits from the ICM deployment under those conditions.

7.2 Simulation Performance Monitoring

During day-to-day operations, only one specific ICM response plan (or set of plans) can be implemented by the TMC and it's partner agencies in response to the specific congestion, crash, weather, or other type of event at hand. While data can be collected from field sensors during that event, it is impossible to truly know how operational conditions may have been different if a different response plan was initiated, or if no response plan was initiated at all during that specific event. As mentioned above, comparing performance metrics for similar events with different responses are one way to extract the relative performance, but the day-to-day variations of traffic demand, weather, and the infrequent nature of many crashes seen on the roadways means that two events are truly never identical. Such comparisons of field measured performance must then be taken with consideration of these differences in mind.

While not as accurate as true field-based performance measurements, the BNICM simulation models can provide a virtual testbed for various response plans under the same identical demand, weather, and crash conditions. Much as was done with this study to evaluate the ICM benefits, a robust comparison of simulated performance measures from two simulations with and without the ICM deployment in place can be used to estimate the impacts of the ICM response plan enacted. The simulation model can be used in this manner regardless of whether real-time predictive simulation is employed or if simulation models are used in a more purely planning capacity to develop response plans.

As exemplified by the ICM deployment in San Diego, the use of simulation models as a predictive engine in real-time can be used to evaluate different response plans in a simulated environment. The relative performance of these simulations run much faster than real-time can be used to help select a response plan to be pushed to the field at the time of an actual event. As part of the decision support system, real-time simulations provide estimation of the benefits of the selected response plan strategy; it is the nature of the design to provide such relative feedback of a 'do nothing' simulation compared to different response plan simulation. These differences are direct estimates of the impact of the ICM deployment. While the ultimate design for a decision support system (DSS) within a Buffalo-Niagara ICM is currently still to be determined, if a real time predictive simulation engine is included it is recommended the results are logged and reported on an ongoing basis to assess the benefits of the ICM deployment.

In addition, it is recommended that the accuracy of those real-time simulated predictions of response plans actually implemented in the field be measured against actual field sensor data and reported for evaluated ICM event. By comparing the accuracy of the predictive simulation versus the actual field data following the same response plan implementation, the accuracy of the predictions of the simulation model can be assessed. With this data tracked and reported, the simulation models' accuracy can be examined and improved over time. This should lead to improved predictions of the response plan simulations used in real time within the ICM DSS, and more beneficial ICM system.

Even if simulation models are not used in a real-time predictive manner, off-line or planning level simulation models can still be drawn upon to simulate observed ICM events and the response plans implemented in the field. The resulting comparison of the simulation results and the field observed conditions following the implementation of the response plan can be assessed along with the accuracy of the simulation. While not as streamlined as with a real-time predictive simulation engine, the same learning process can be applied to an offline simulation model to improve the accuracy of the models in simulating the events and responses that occurred, leading to a more accurate simulation model for assessment of future conditions. While the improved accuracy is not seen in the selection of the response plans as in a real-time simulation engine, the more accurate simulation models can still be used to evaluate ‘do-nothing’ or pre-ICM deployment conditions to estimate the impacts of the deployed ICM system.

Overall performance metrics of the accuracy of the prediction of a simulation engine should be developed and reported after the deployment of the ICM system, with the goal of increasing the accuracy of those predictions as the ICM system and the simulation models mature. While this may have more bearing if the simulation model is used in a real-time manner within the ICM DSS, improved simulation accuracy can still provide great benefits in testing and evaluating new and changing response plans over time, to improve the overall performance of the ICM system on improving operational conditions across the network.

Finally, the use of a simulation model can also provide insights and estimates for performance metrics that cannot realistically be measured in the field. Such estimates include total hours of travel or delay, tailpipe emissions, gallons of fuel consumed, and trip level variabilities of travel times. These performance measures are recommended to be produced in addition to the field-based performance metrics of the ICM system.

7.3 Performance Reporting Summary

To aid in the tracking of the performance of an ICM system deployment over time, it is recommended that the ICM performance metrics listed in Table 7.1 are reported, in addition to additional performance measures to be extracted from the simulation models in a manner similar the results presented in Chapter 5. To the extent possible, the metrics should be stratified by different operational conditions such as the base conditions used in this report, or through a more robust cluster analysis of operational conditions from a more robust collection of field conditions in the future. The ICM performance reporting should be shared with all ICM stakeholders on a regular basis, either quarterly or annually.