Buffalo-Niagara Integrated Corridor Management

Final Report

final

report

prepared for

GBNRTC & NITTEC

prepared by

Cambridge Systematics, Inc.

March 2020

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draft report

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date

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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 reduce 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. 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 $11 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 2.25.

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. 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 $12.7 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 2.49.

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

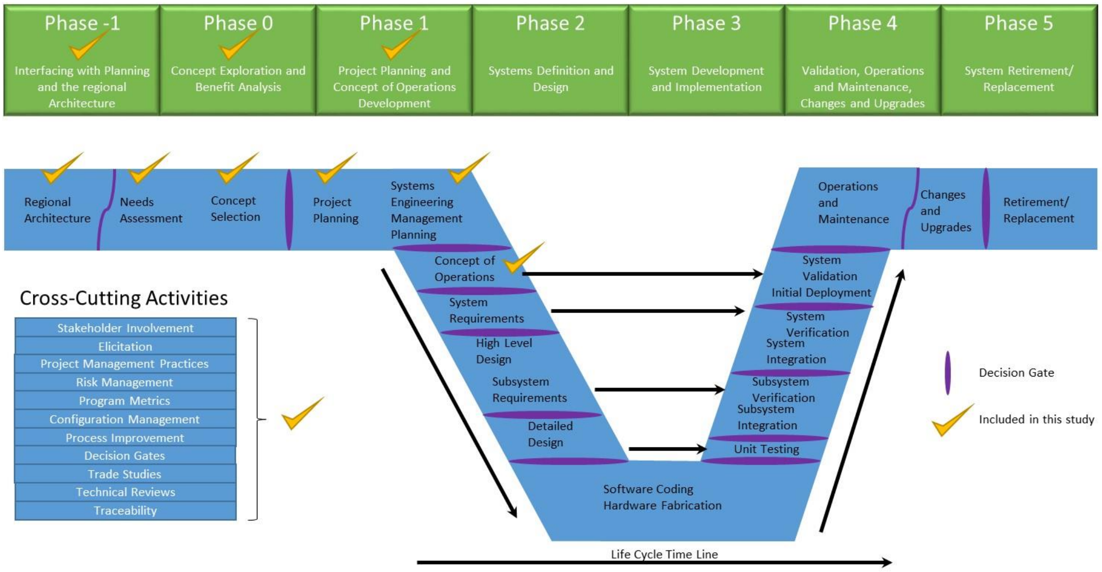
Goal Category	Goal Objective
Agency Coordination	Improve center-to-center communications
Traveler Information	Improve accuracy of congestion (travel time) information reliability
	Enable intermodal choices through improved traveler information
	Improve integration of weather information/data for traveler 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.

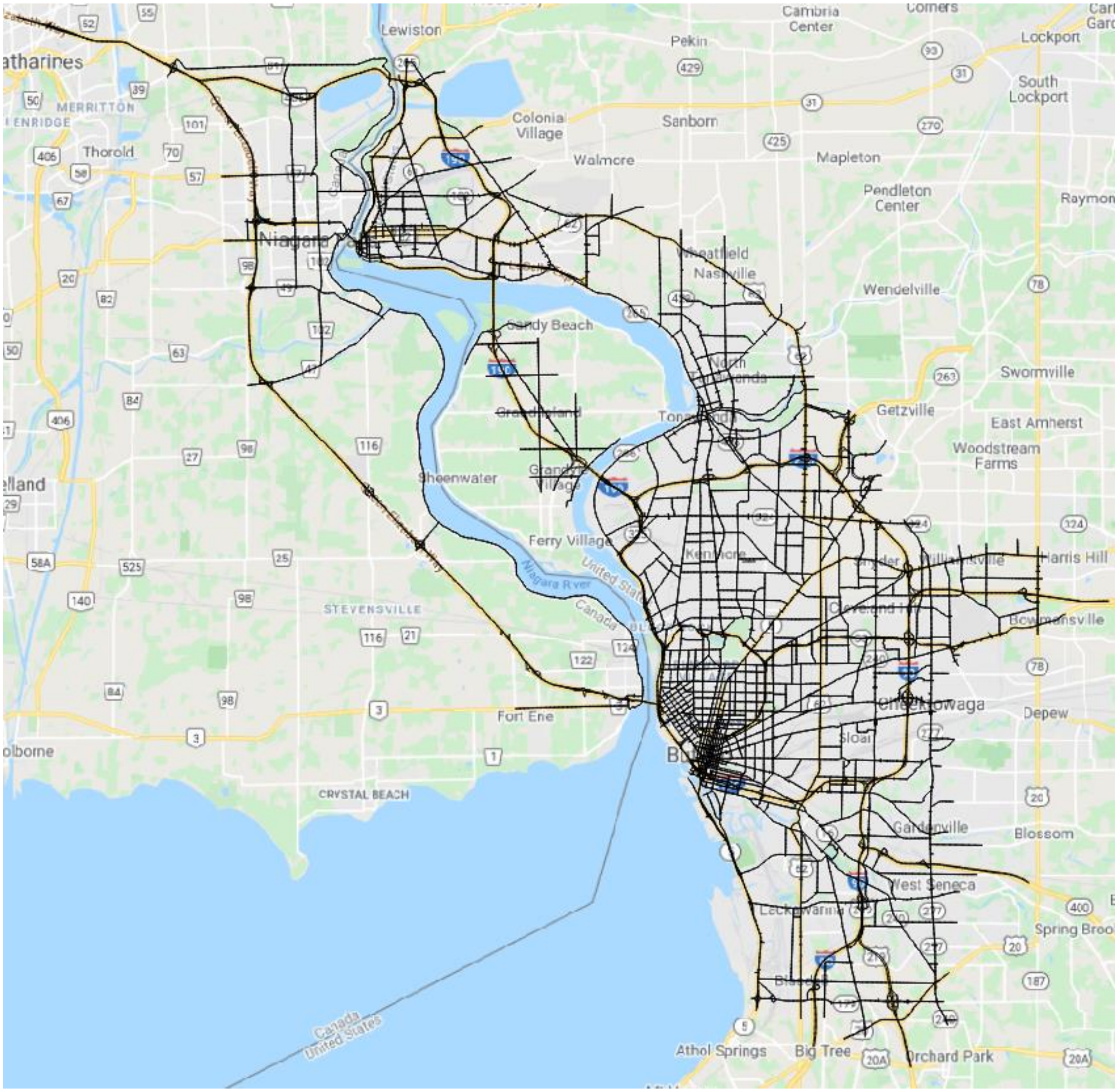
A multi-resolution modeling approach consistent with the existing GBNRTC simulation framework was adopted. The GBNRTC Regional Travel Demand model, a TransCAD-based model, provides the regional travel patterns while an Aimsun hybrid model simulates the regional traffic in mesoscopic and microscopic resolutions 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

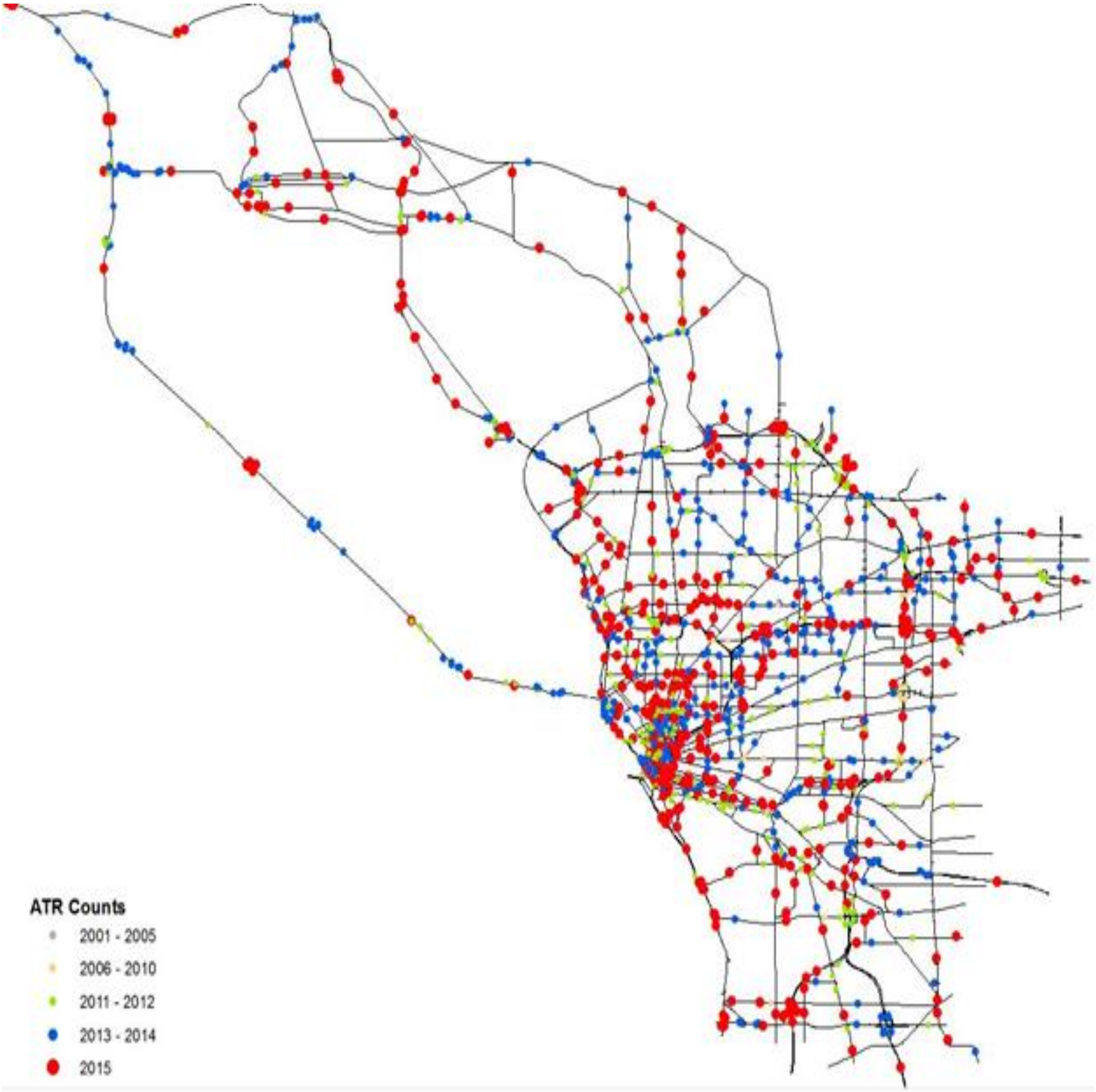


Figure 2.3 Short Term Intersection Turning Movement Counts

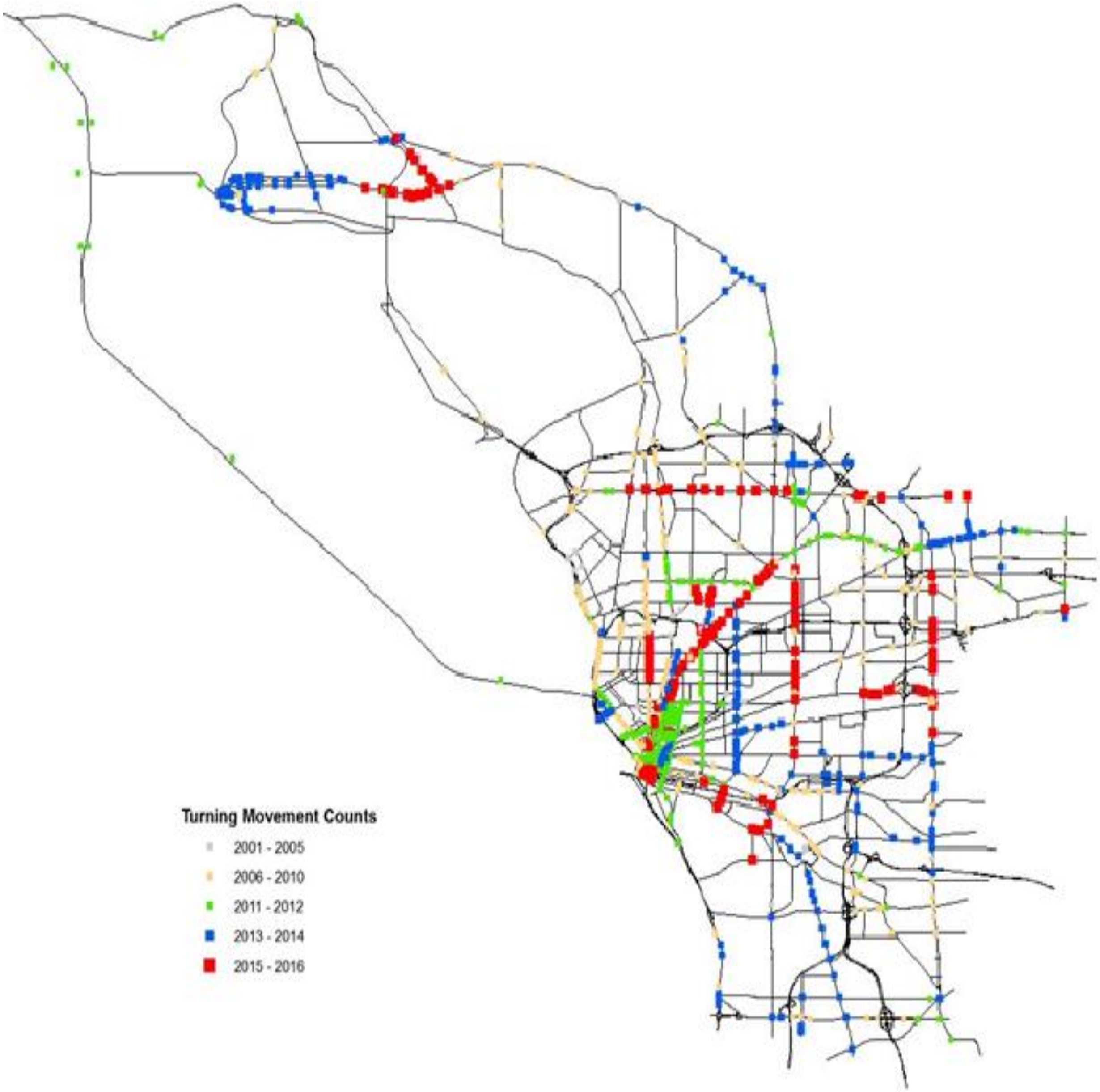
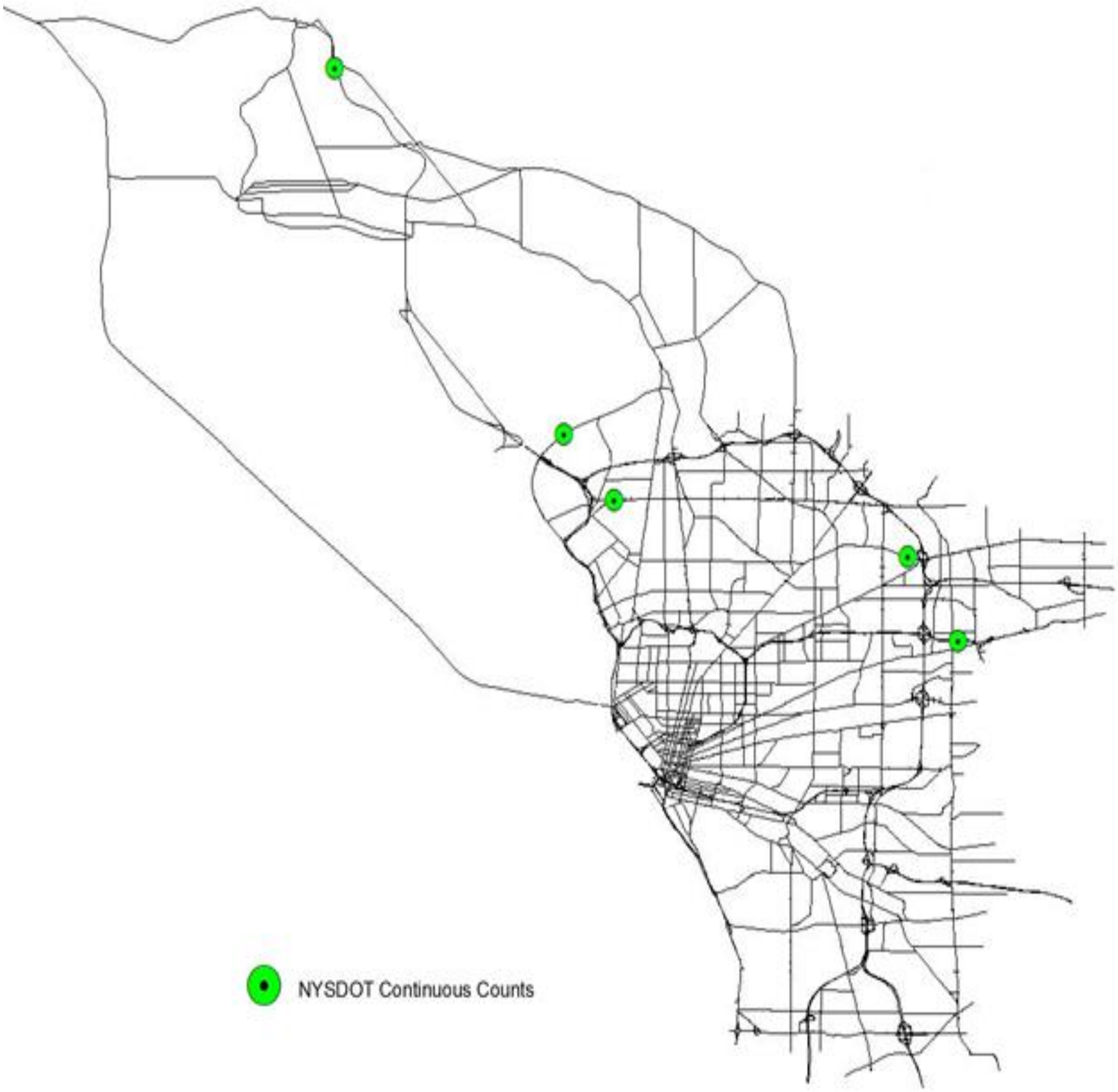


Figure 2.4 NYSTA Permanent Count Stations

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

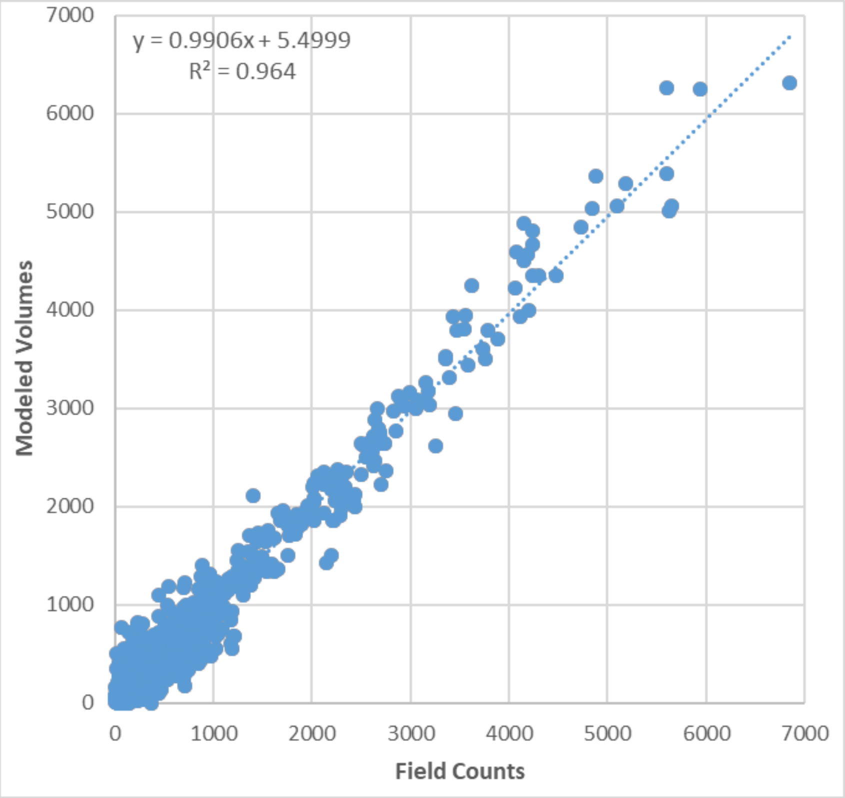


Figure 3.2 Simulated Volumes vs. Field Counts - 8 AM to 9 AM

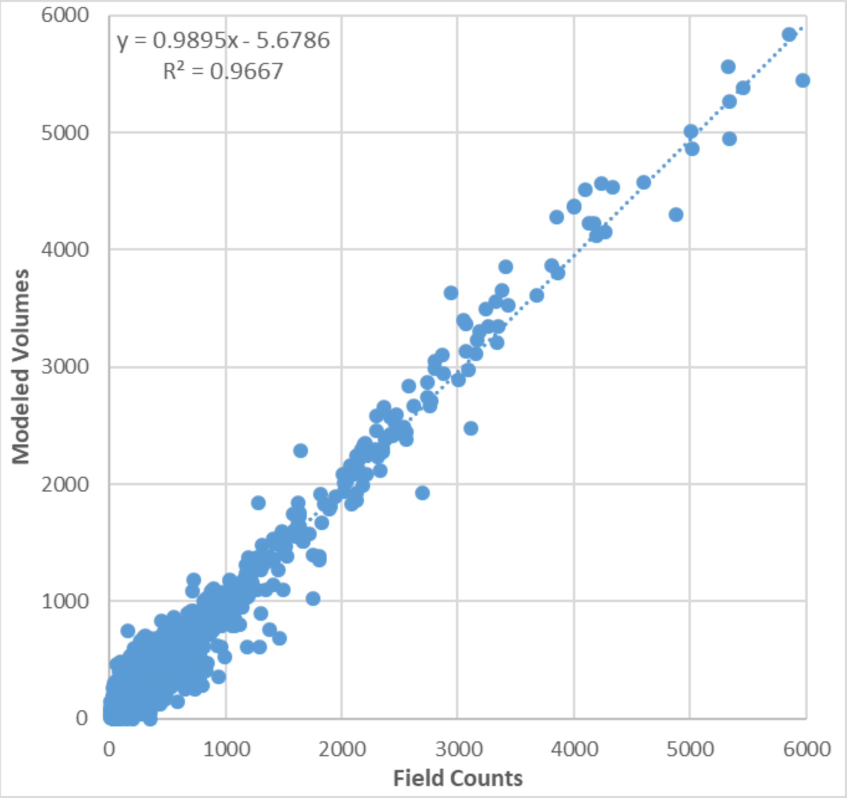


Figure 3.3 Simulated Volumes vs. Field Counts - 9 AM to 10 AM

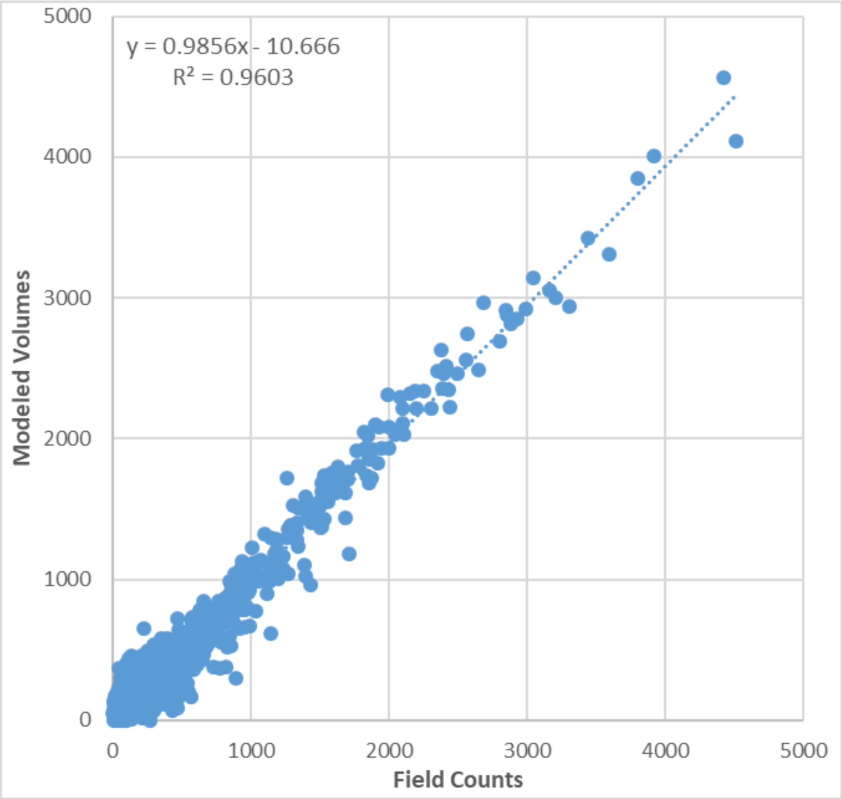


Figure 3.4 Speed Contour - I-190 Northbound AM

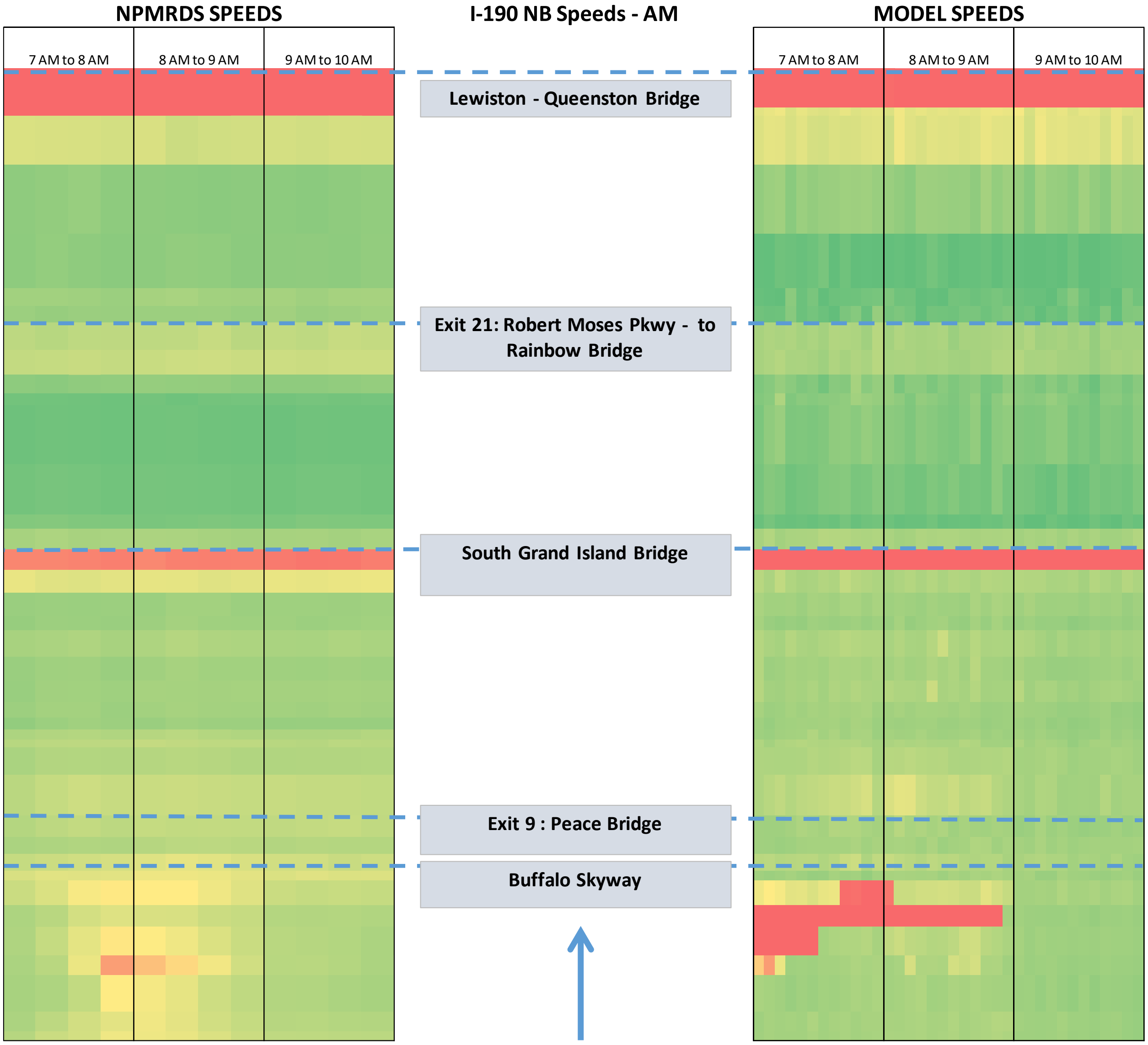
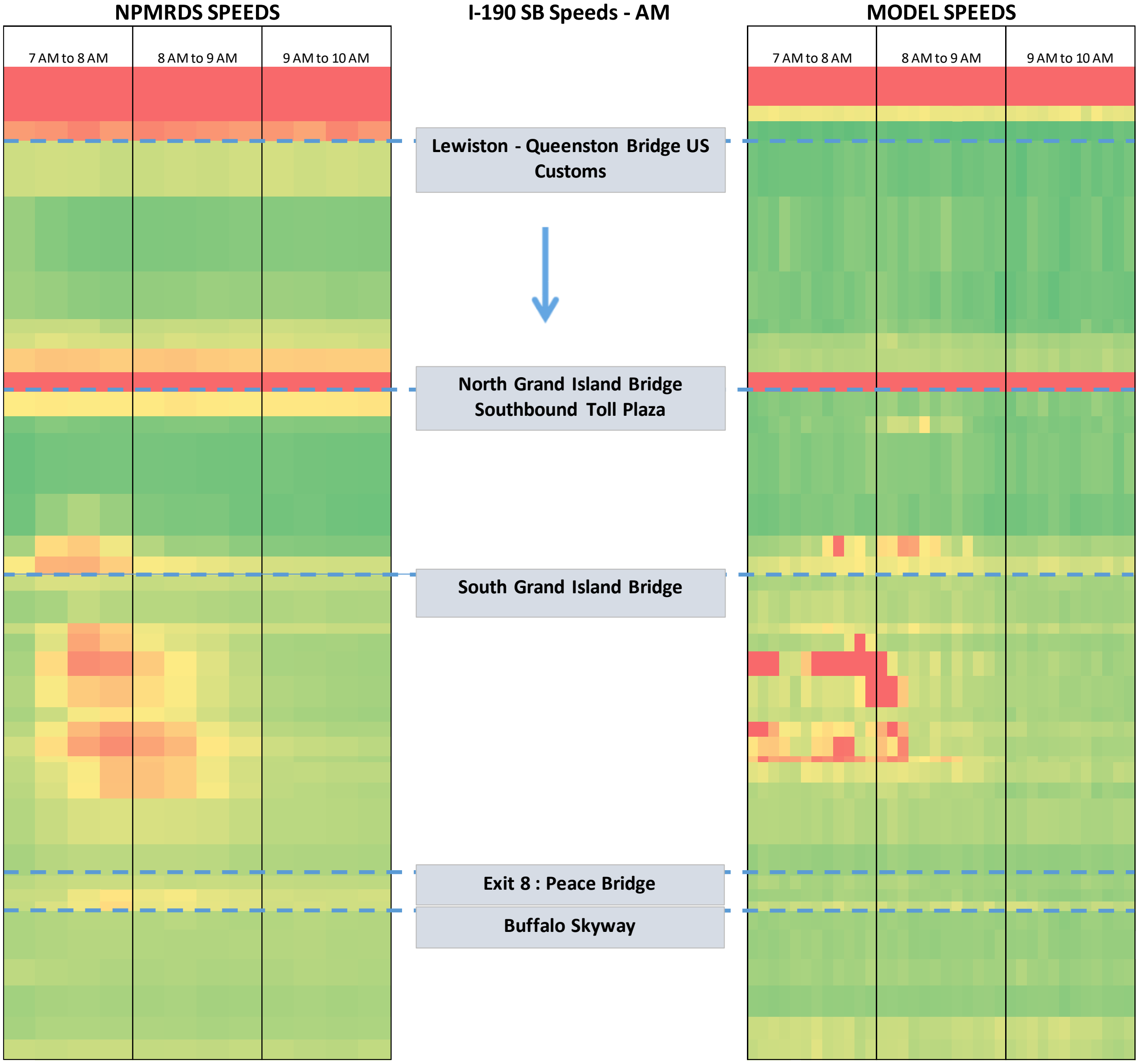


Figure 3.5 Speed Contour - I-190 Southbound AM



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

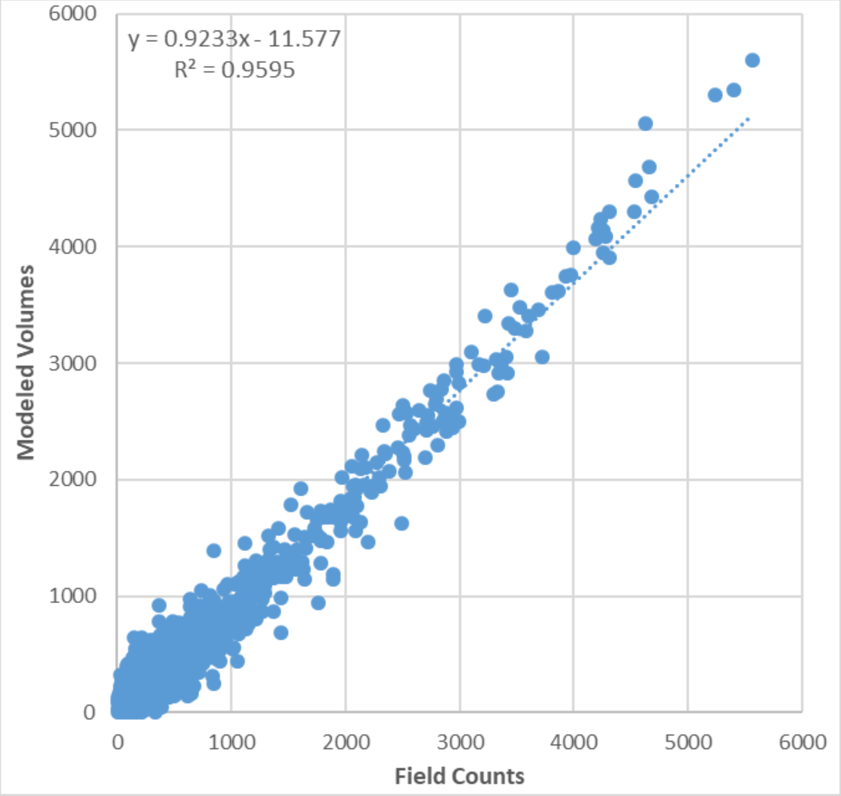


Figure 3.7 Simulated Volumes vs. Field Counts - 4 PM to 5 PM

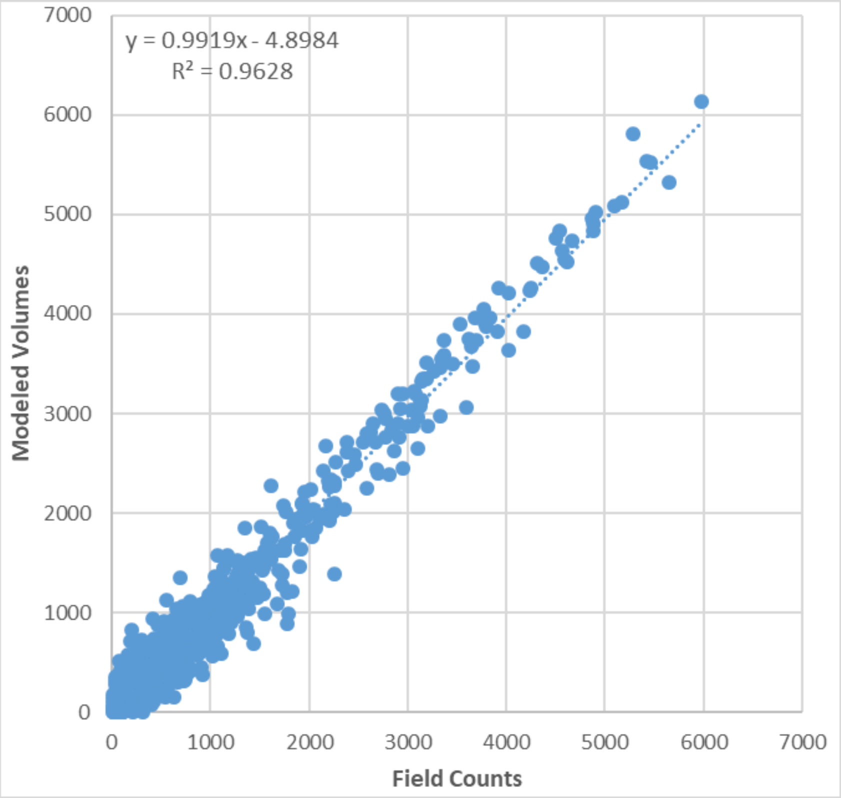


Figure 3.8 Simulated Volumes vs. Field Counts - 5 PM to 6 PM

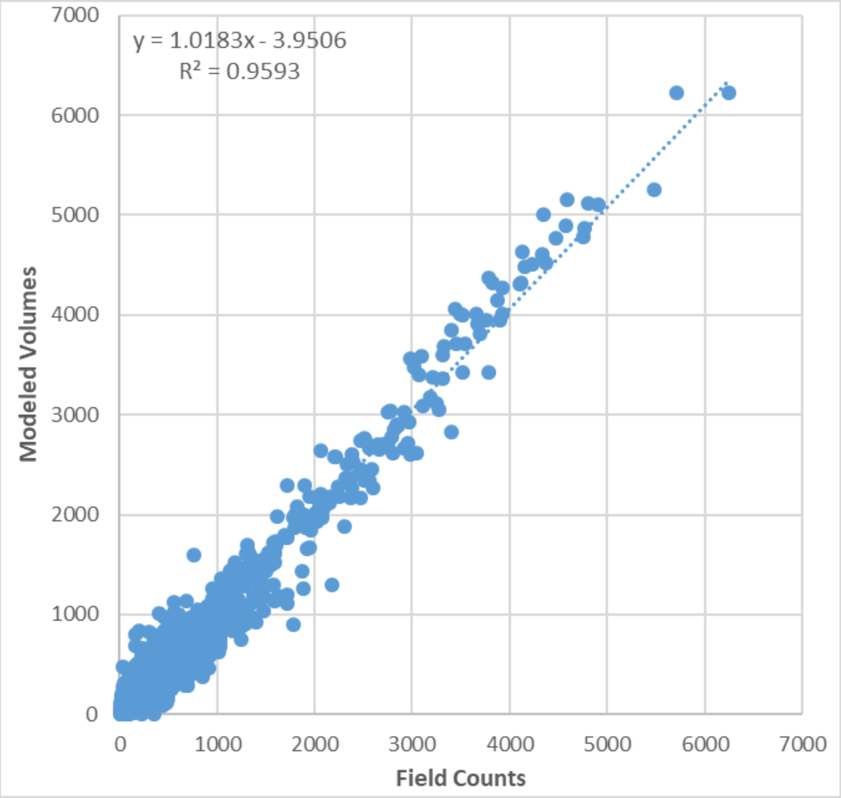


Figure 3.9 Speed Contour - I-190 Northbound PM

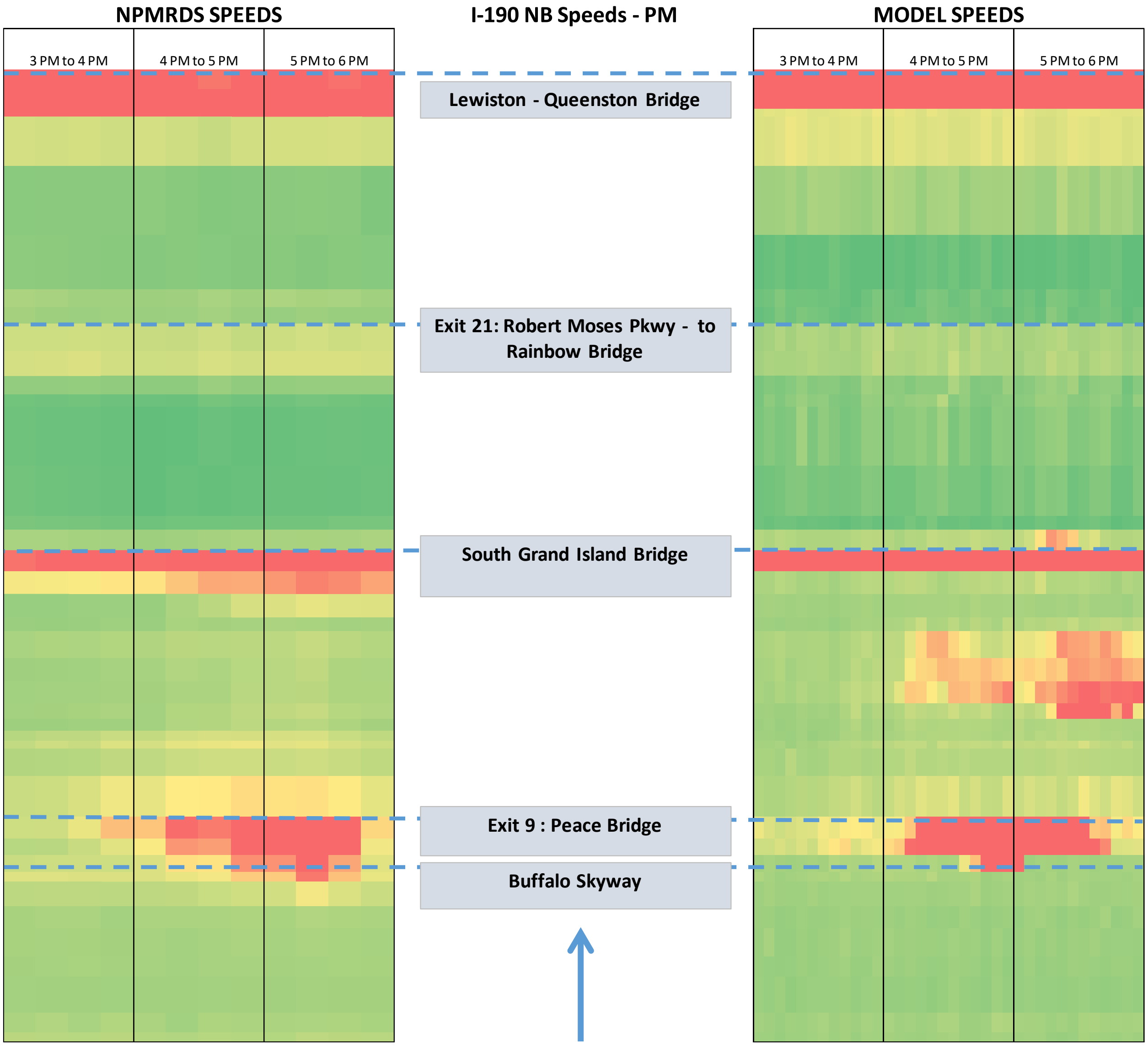
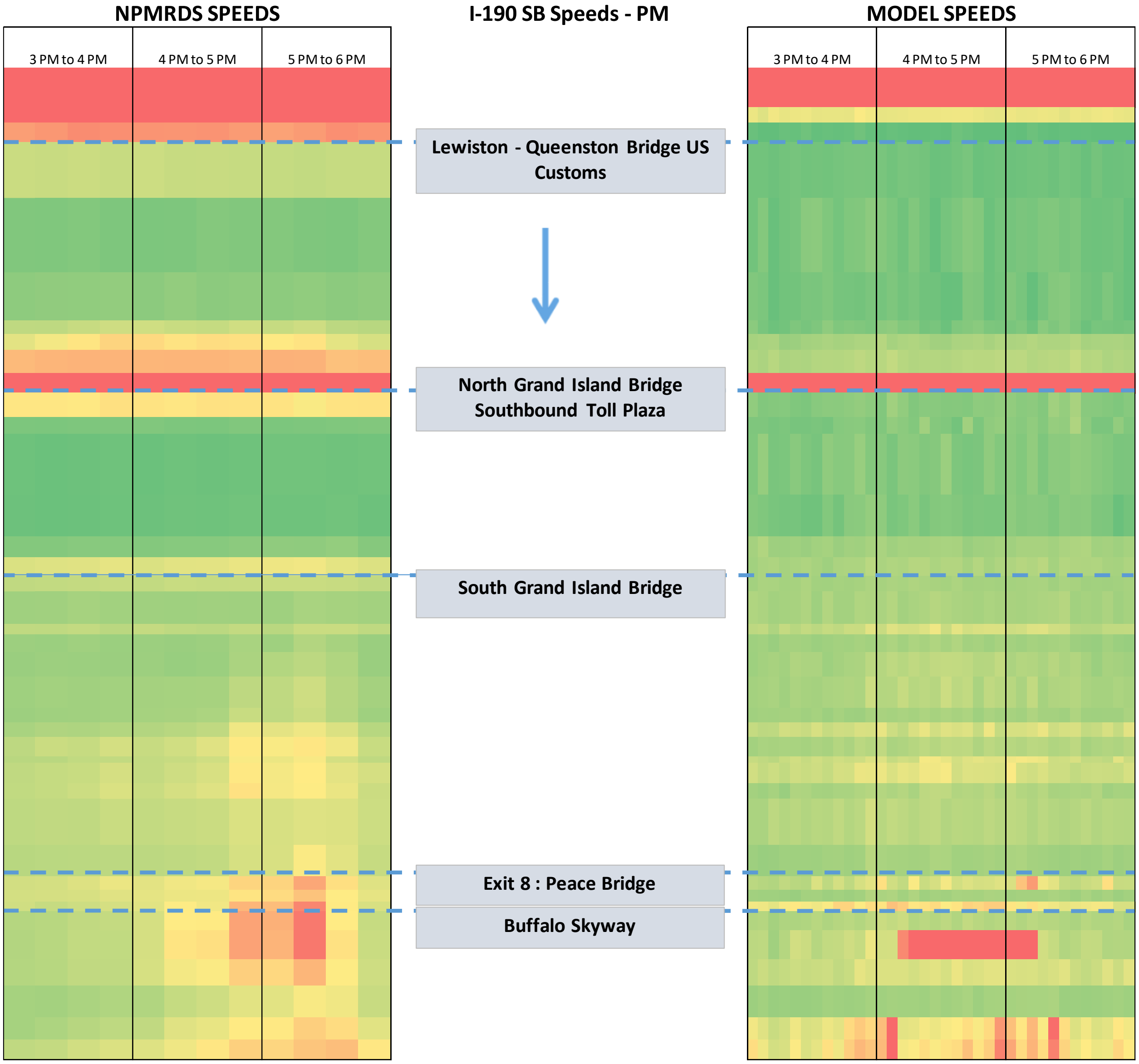


Figure 3.10 Speed Contour - I-190 Southbound PM



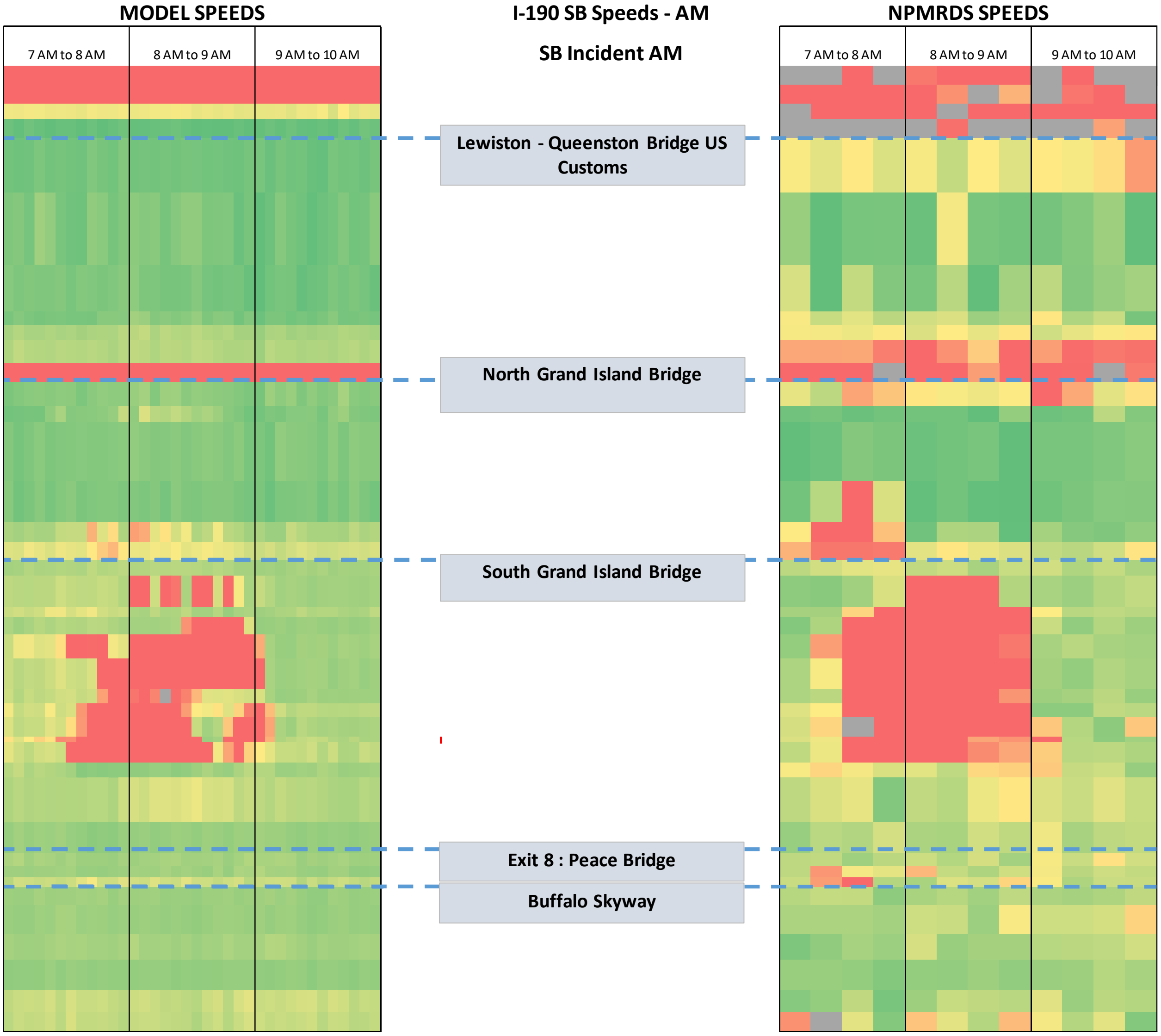
3.3 Crash Condition: AM Peak Period

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



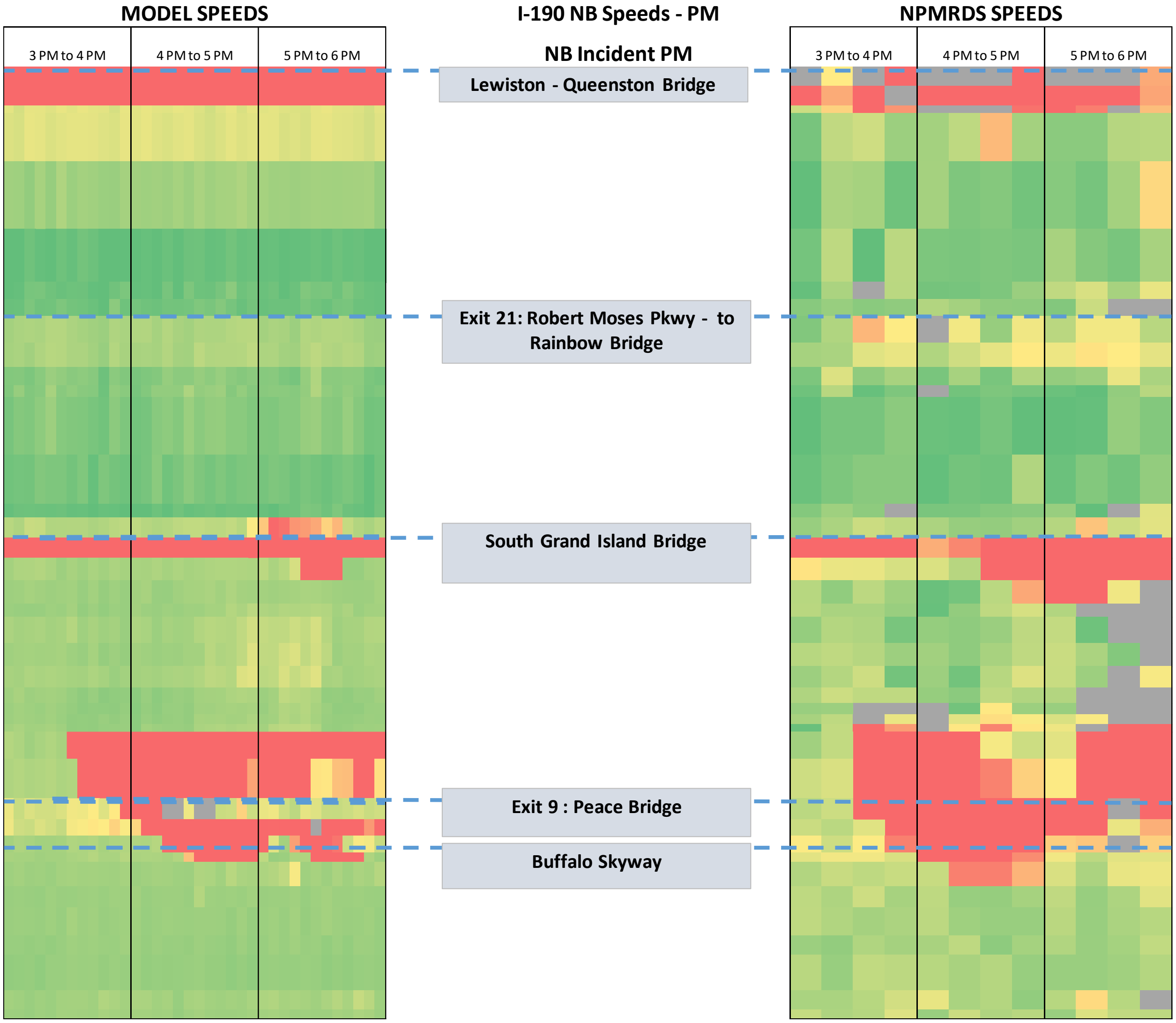
3.4 Crash Condition: PM Peak Period

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

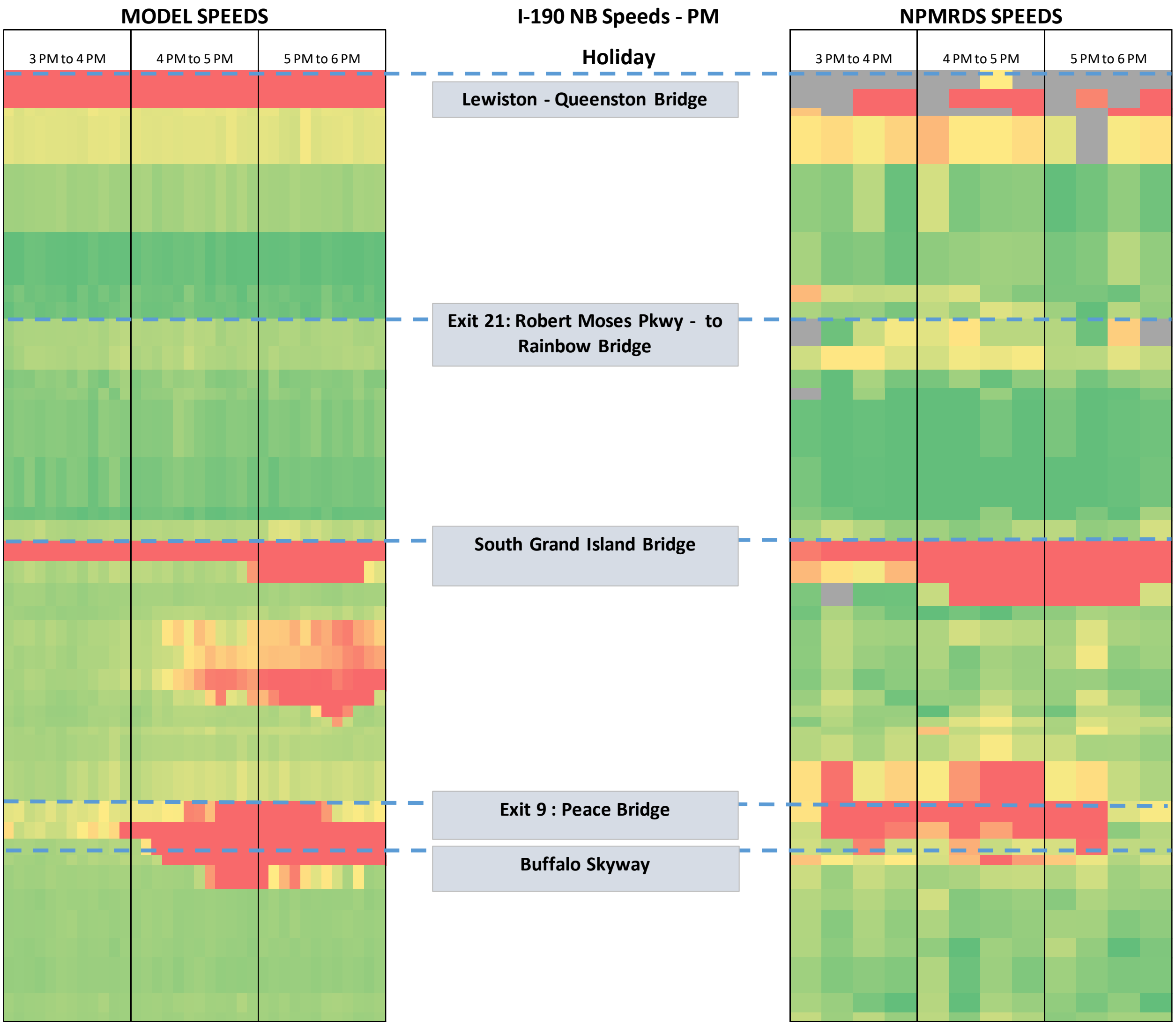
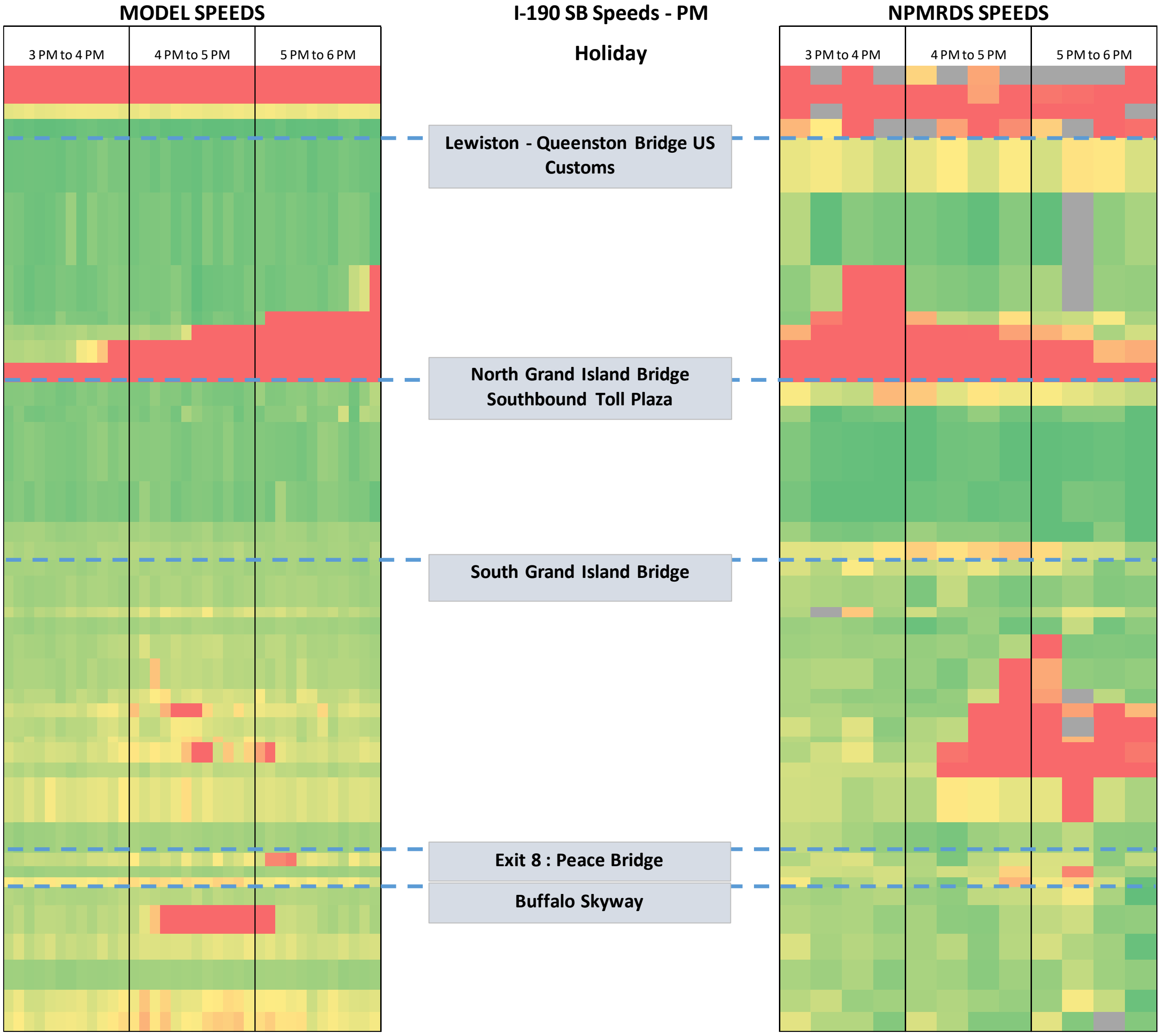


Figure 3.14 Holiday Scenario Speed Contour - I-190 Southbound PM



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

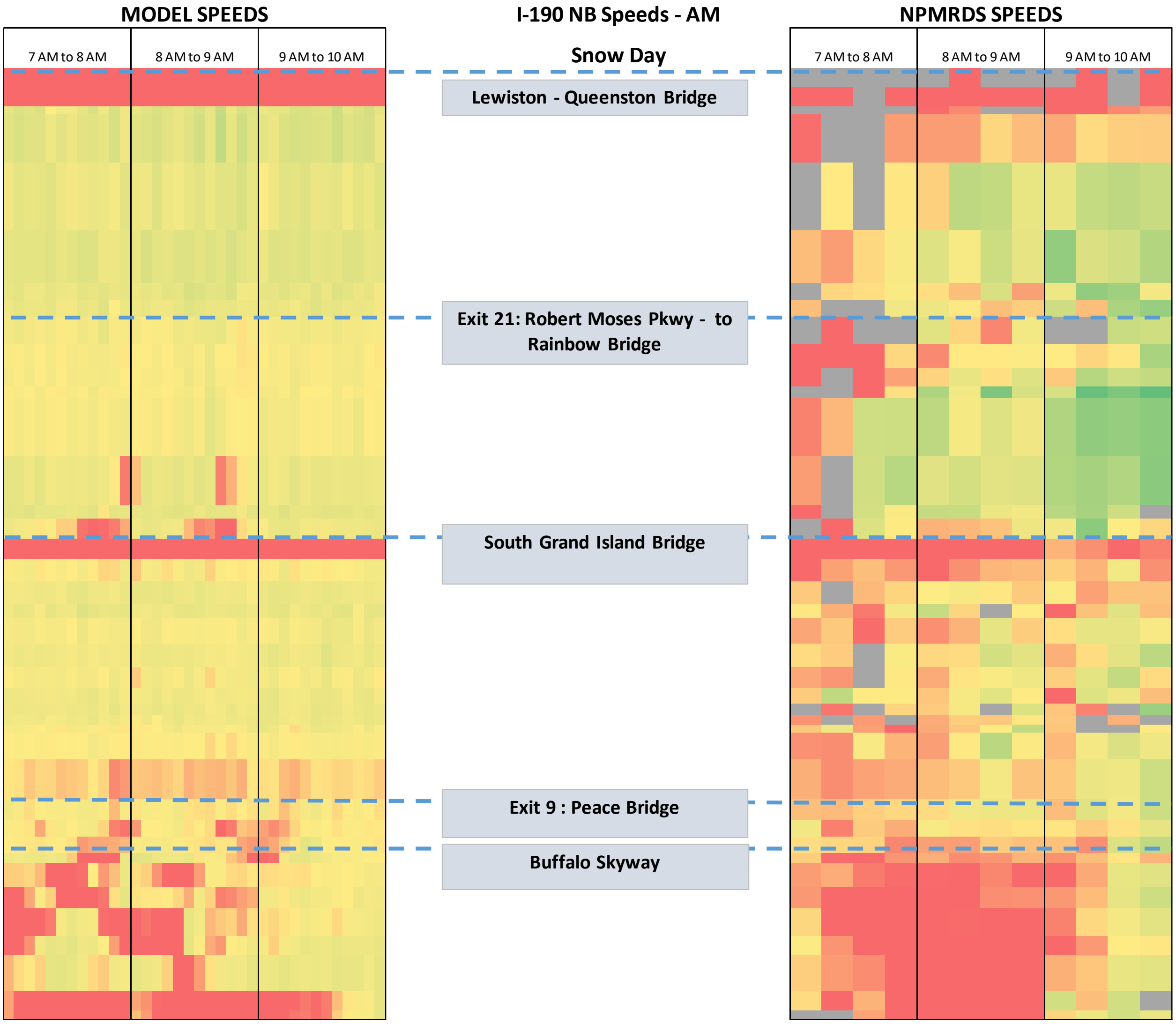
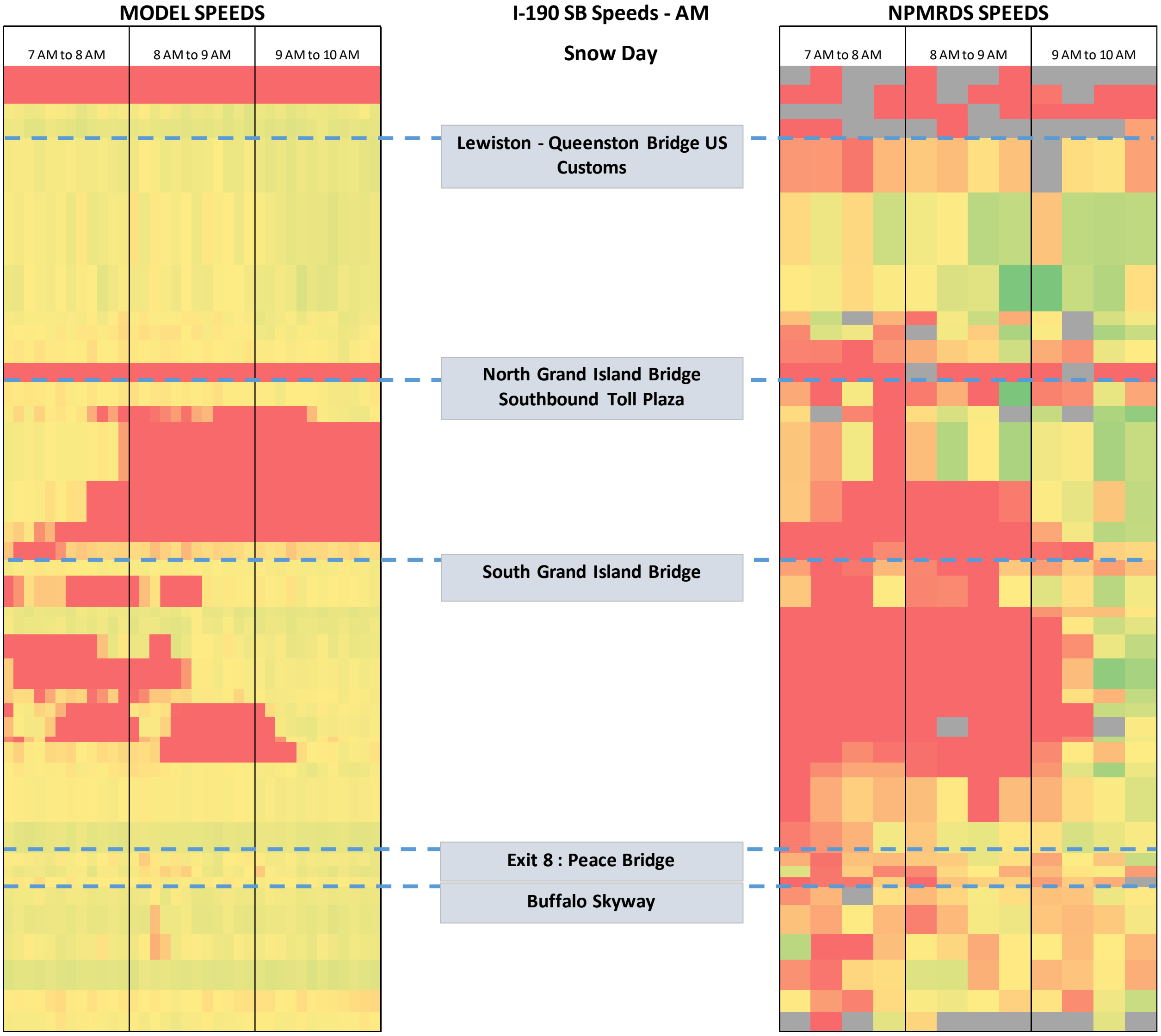


Figure 3.16 Snow Scenario Speed Contour - I-190 Southbound AM



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

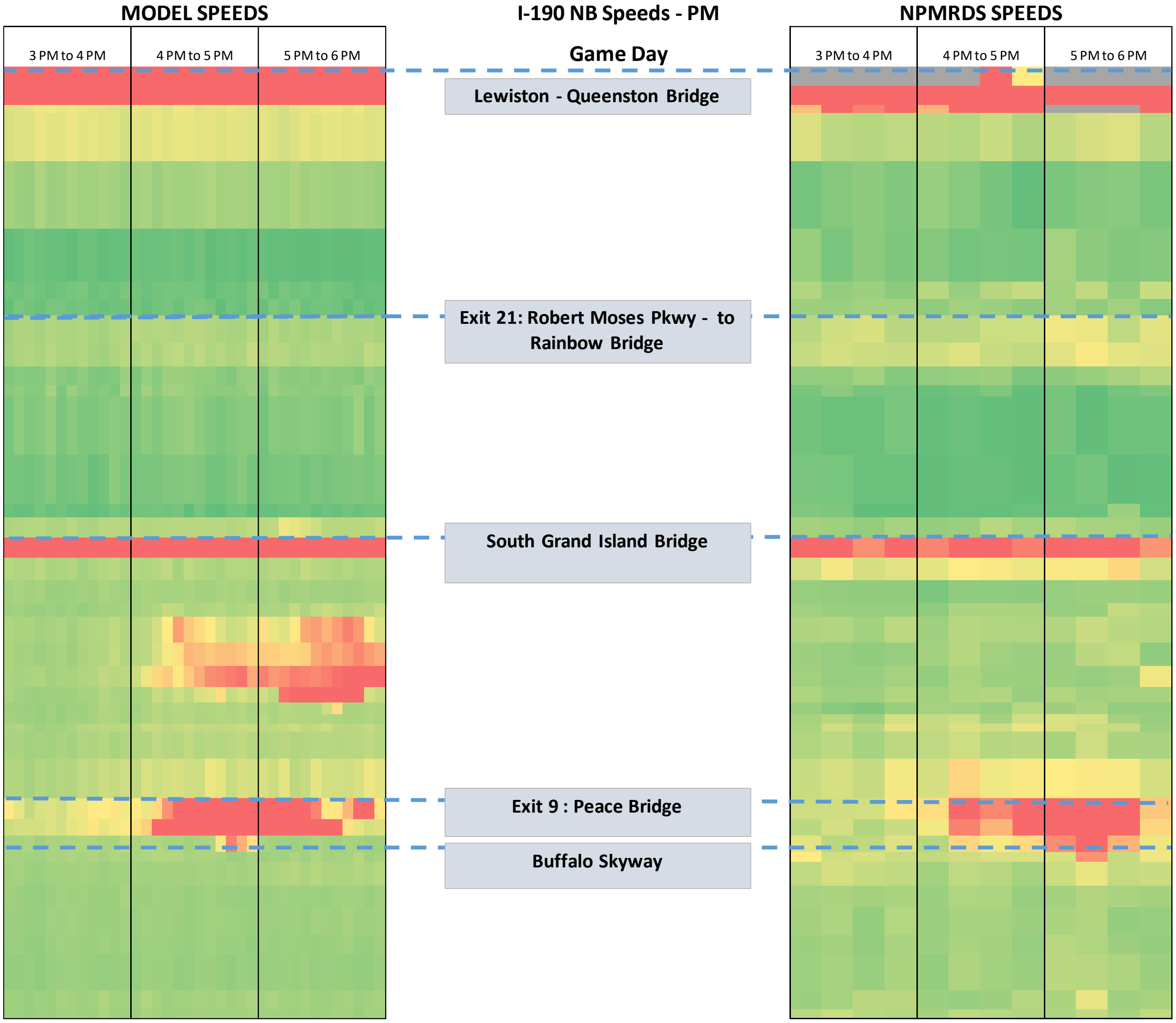
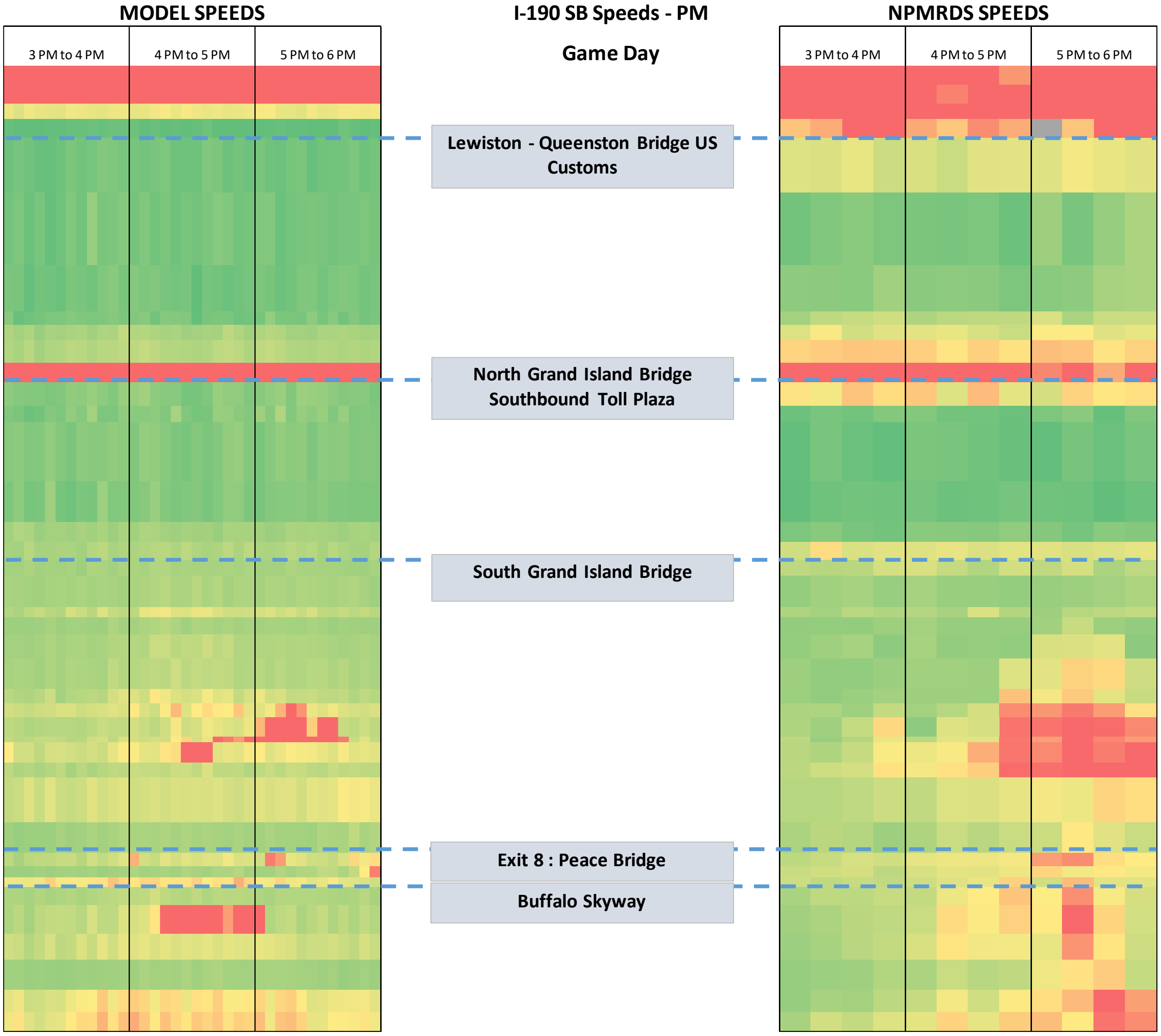


Figure 3.18 Game Scenario Speed Contour - I-190 Southbound PM



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.

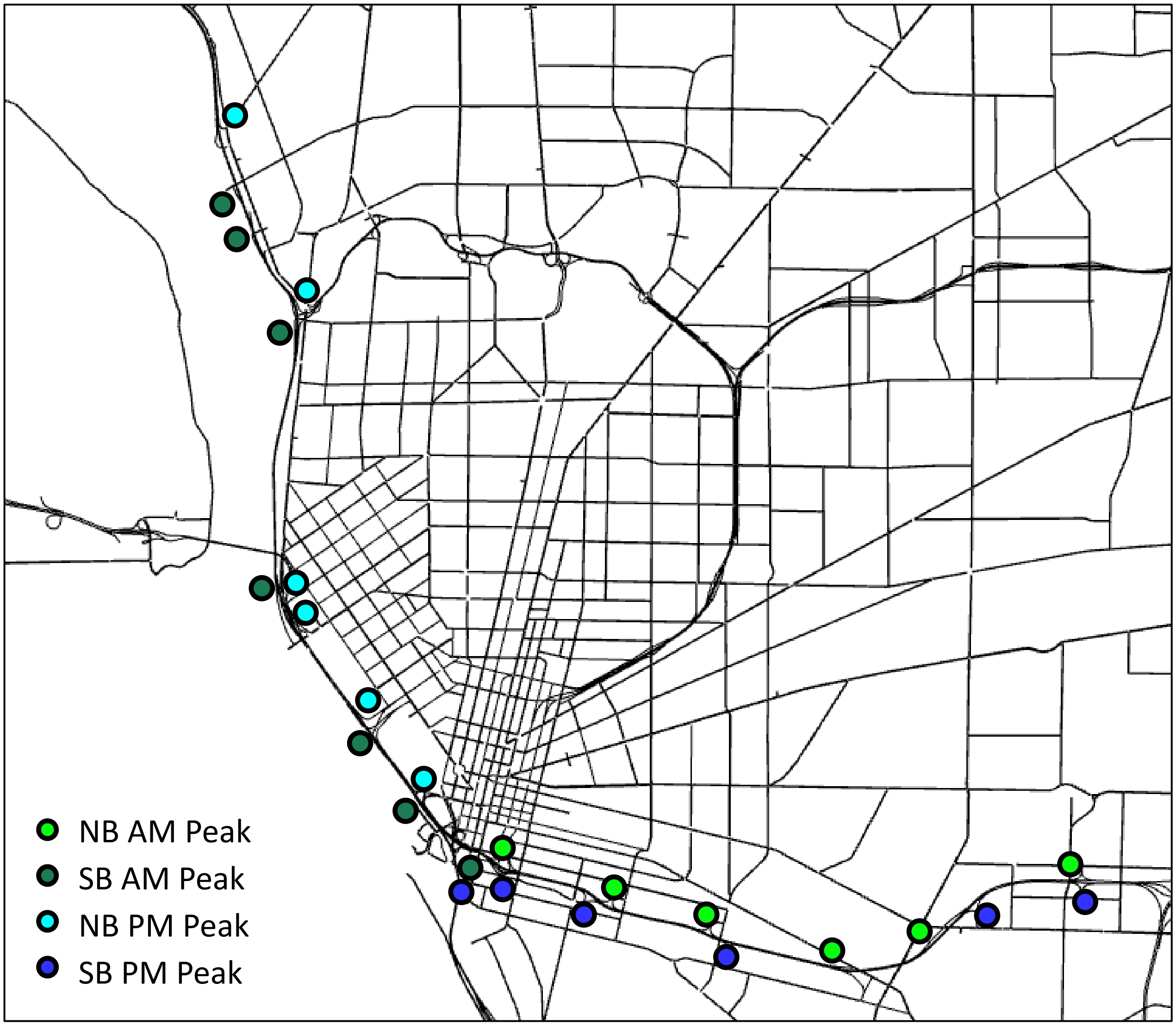
All ramp meters were coded into the BNICM simulation model using the Aimsun built-in flow metering logic. This is a simple logic that adjusts the timing of the metering to release vehicles at flow rate (vehicles per hour) input by the modeler. The input flow rates for the meters for each of the ICM scenarios 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.

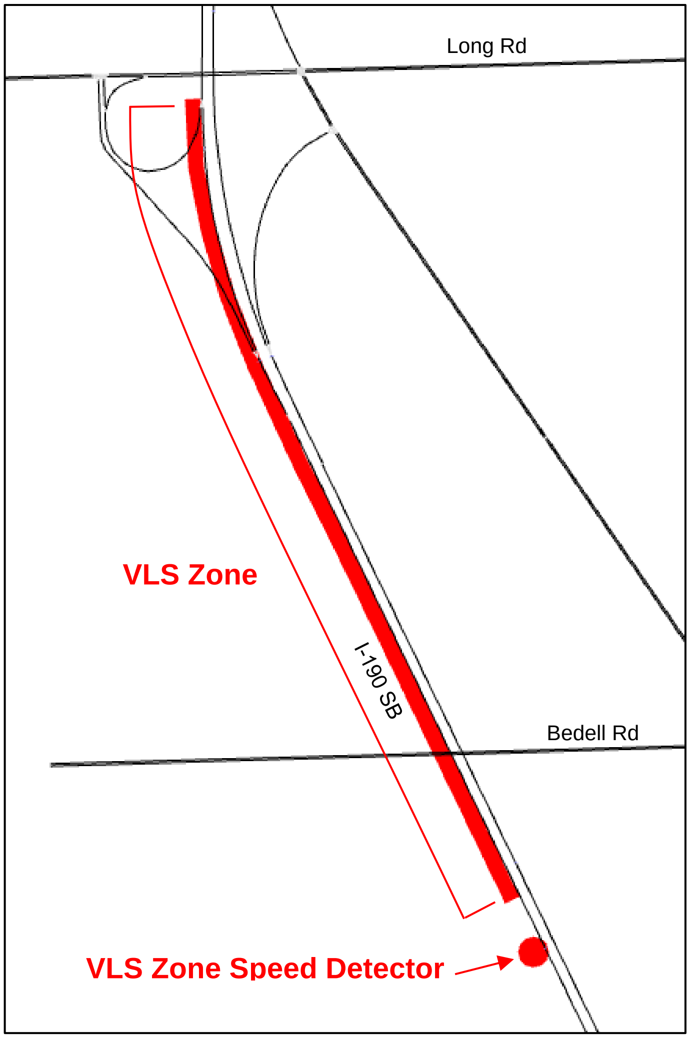
While some metering effects from a VLS system could in theory increase throughput at bottlenecks and improve travel times (similar to a ramp metering system) by limiting the size and severity of that bottleneck, here a VSL system is considered for deployment here to instead improve safety by warning 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

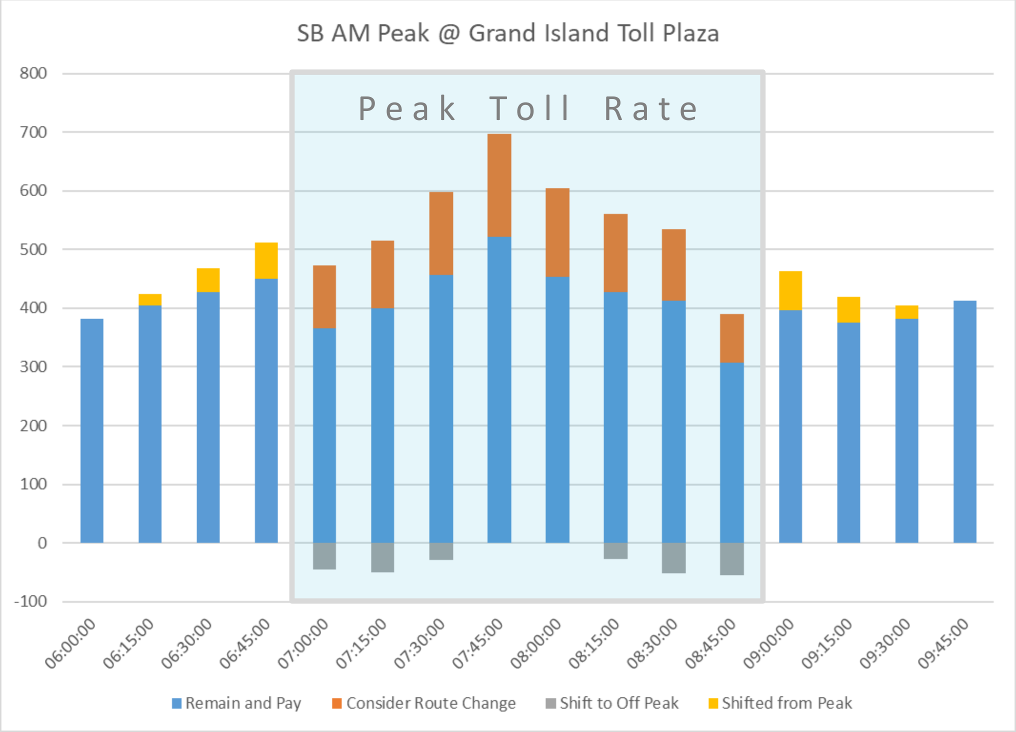
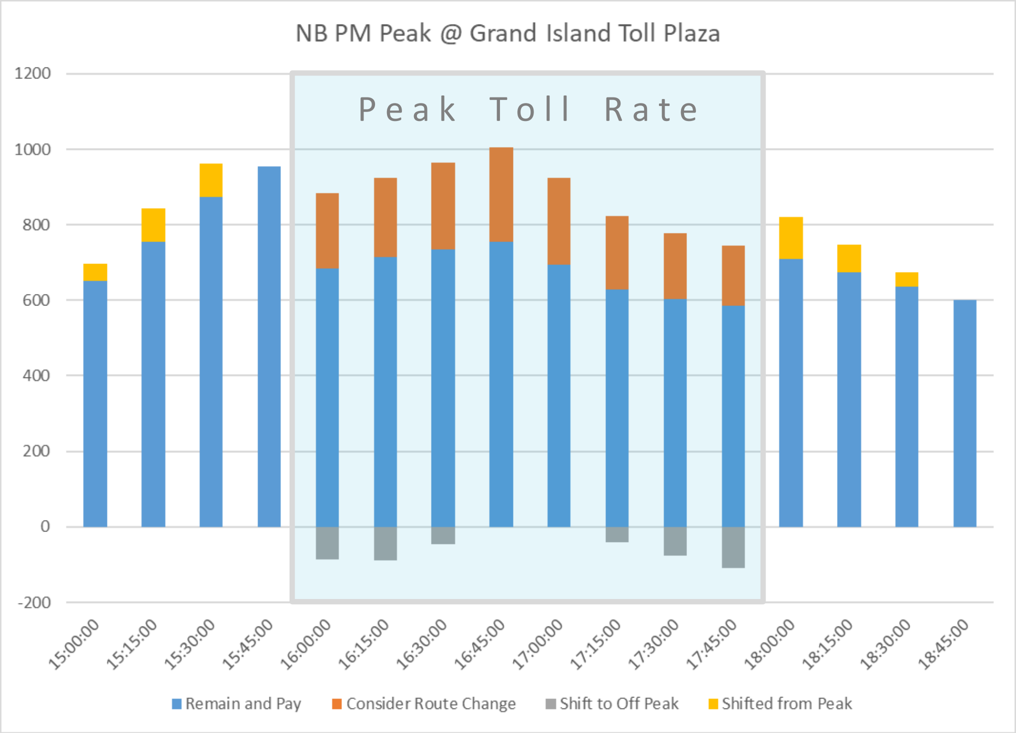


Figure 4.4 Variable Toll Impacts for Northbound PM Peak Period Traffic



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.

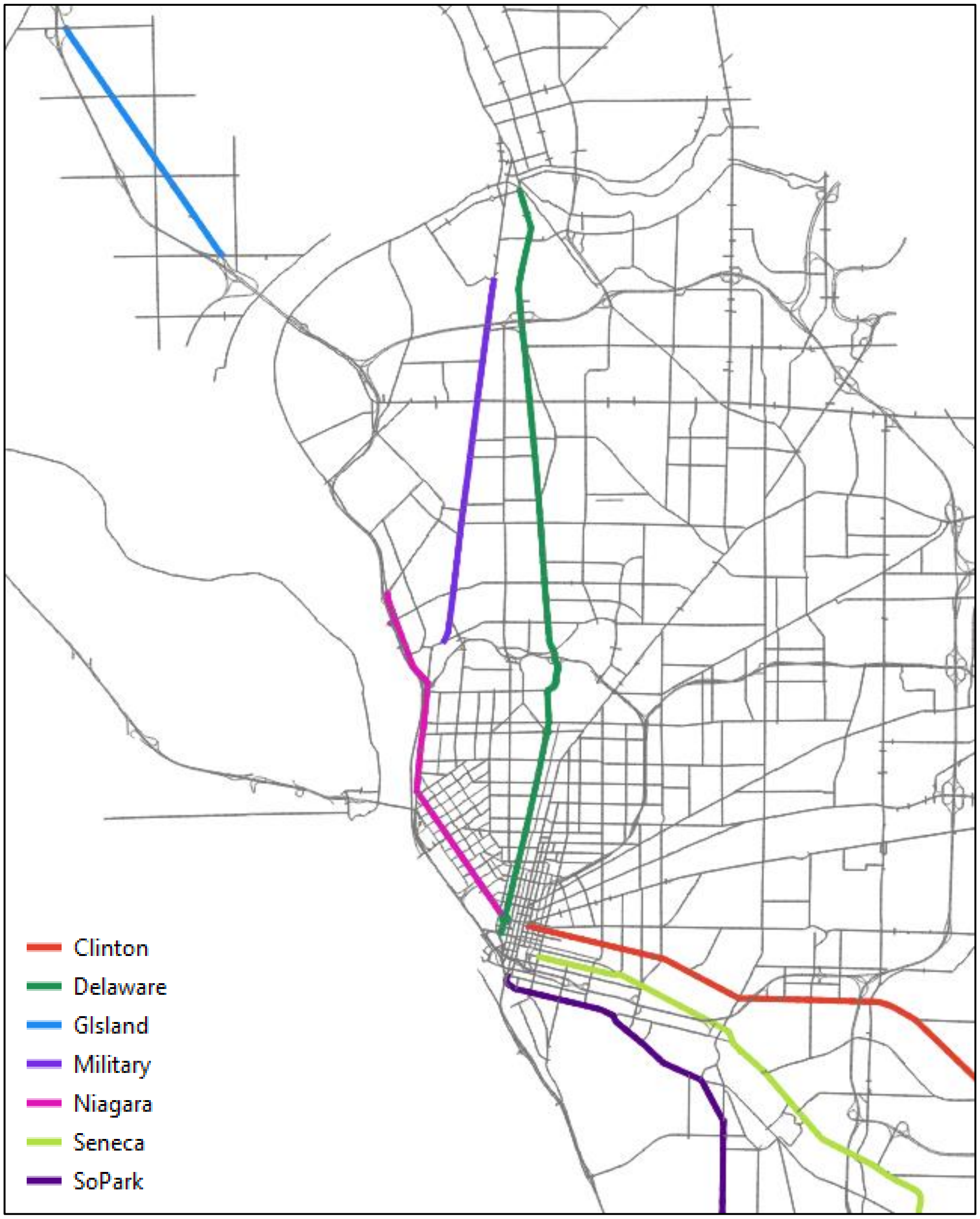
For these reasons, potential response plans should be developed and evaluated well ahead of any actual event occurring in the field and the implementation of the response plans in the field. While the exact timing and nature of the crash or disruption in the field cannot be known, a variety of response 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

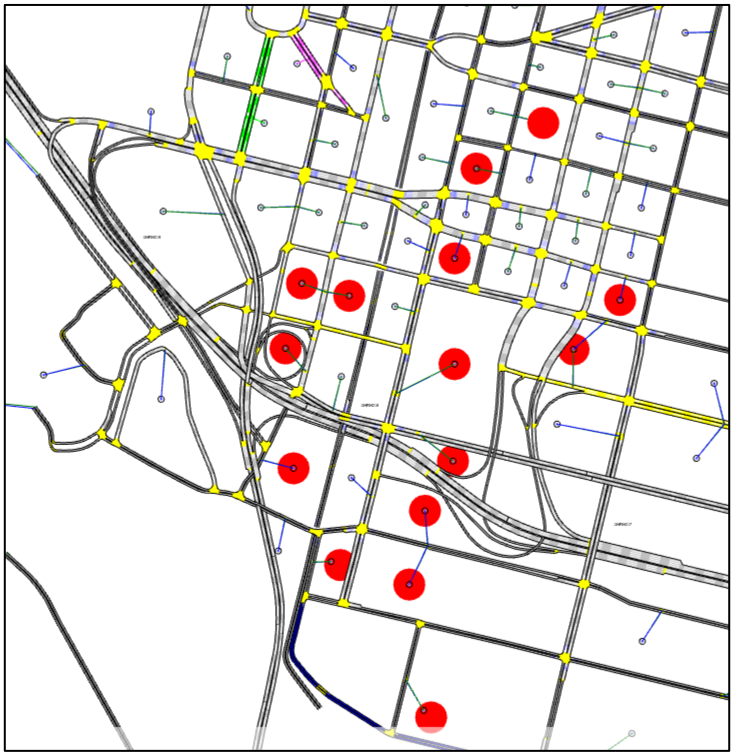
In addition to the above selected ICM strategies, a handful of other potential ICM strategies were selected for consideration under certain base conditions. However, at this stage of the BNICM analysis, these strategies were not directly tested or evaluated for effectiveness or benefit to cost efficiencies 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

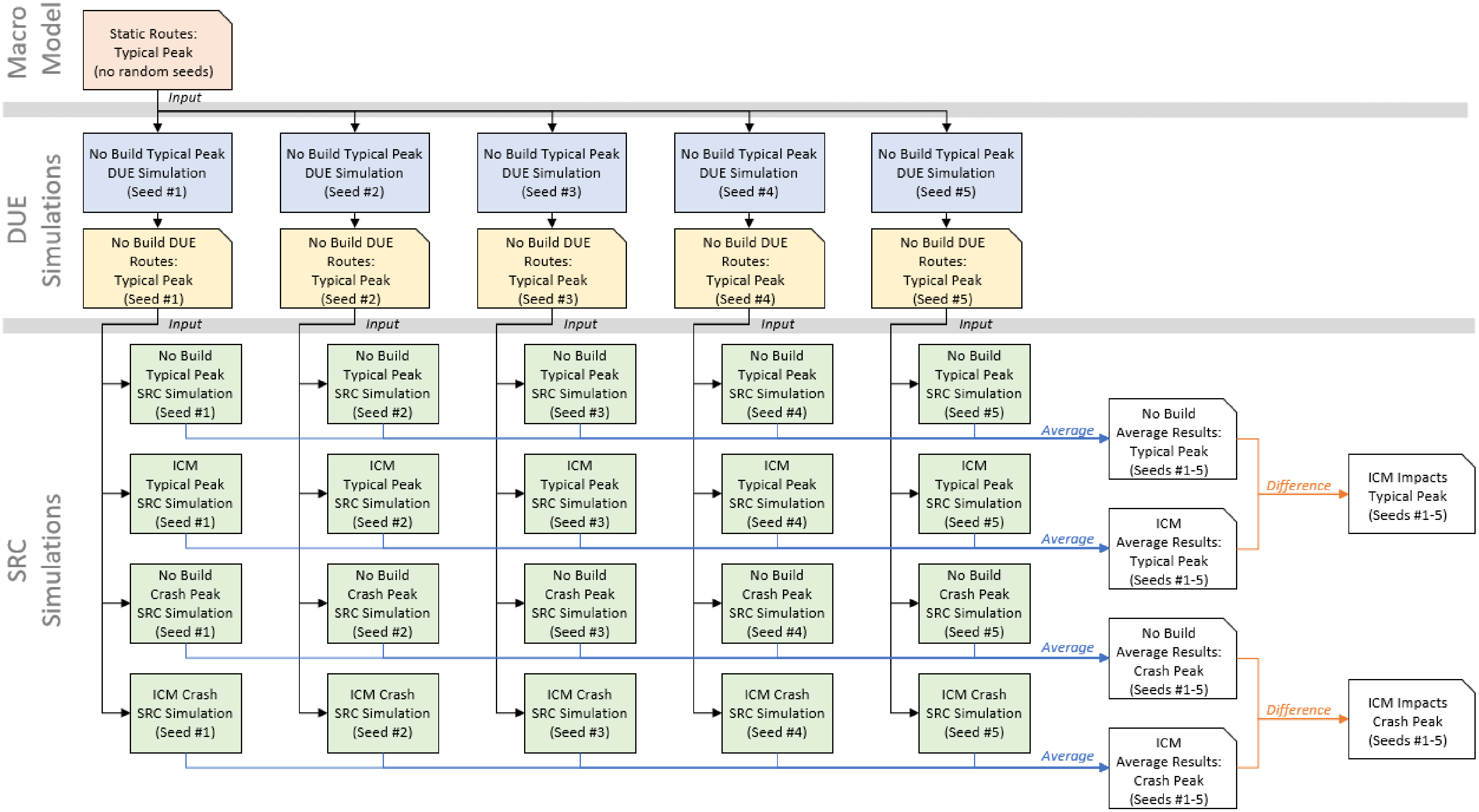
While the assumption of no demand changes was made, there remained the possibility that drivers would adjust their travel routes given these two changes to the roadway network. To reassess these potential changes in route choices, the No Build models for the typical AM and PM peak period congestion were 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 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.

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
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*[5]. 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 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[6] 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

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[5] Crash Costs for Highway Safety Analysis (FHWA-SA-17-071), Federal Highway Administration, January 2018

[6] 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

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 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			Total Annual Benefits ($)
	Costs Per Crash		# of Prevented Crashes	Costs Per Crash		# of Prevented Crashes	
Simulated Crash	**veh-hrs**	**$**		**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

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	Variable Speed Limits and Queue Warning	Variable Toll Pricing	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.

5.3.2 Benefit-Cost Analysis

The previous section presented the changes in the mobility benefits that could be seen during one weekday peak periods under various different based 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 5.8 presents the annualized benefits and costs and 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.

Table 5.8 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**

These user benefits are in addition to the annual safety benefits that the ICM deployment would create in the form of crash costs savings ($2.75 million) and the removed vehicle time in congestion ($0.76 million) associated with the prevented crashes (as discussed in the previous sections). Collectively, Package A of the ICM deployment would provide annual benefits of over $11 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 2.25. Details of each component of the Package A ICM deployment benefits and costs are presented in Table 5.9.

Table 5.9 Benefit Cost Ratio for ICM Deployment Package A

Item	Annual Value ($)
Recurring Mobility Benefits (Weekday Peak Periods)	$ 7,572,628
Mobility Benefits from Prevented Crashes	$ 765,021
Prevented Crash Costs	$ 2,757,205
Total Benefits	**$ 11,094,854**
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	**2.25**

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

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 5.10 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 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 5.10 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.

5.4.2 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 5.11 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 benefits.

Table 5.11 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 5.12 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 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 $12.7 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 be deployment increase to approximately $5.1 million. Both increases combine to produce a benefit cost ratio of approximately 2.5, or about a 10% increase over the Package A efficiency.

Table 5.12 Benefit Cost Ratio for ICM Deployment Package B

Item	Annual Value ($)
Recurring Mobility Benefits (Weekday Peak Periods)	$ 9,210,516
Mobility Benefits from Prevented Crashes	$ 765,021
Prevented Crash Costs	$ 2,757,205
Total Benefits	**$ 12,732,742**
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	**2.49**

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 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

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.