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Development and Application of ITS Operations Evaluation Models (ITSOEMs)

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
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College of Engineering
University of South Florida

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DEDICATION

To my parents Amma and Bapu

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ABSTRACT

Intelligent Transportation Systems (ITS) play an important role in supporting motorists and first responders to handle major incidents, hazmat spills, security measures and other emergency operations. Increasingly, technology advancements and applications are providing invaluable integration opportunities to interconnect safety, maintenance, ITS, traffic operations, facilities, and transportation equipment programs to maximize available resources and achieve efficiency in transportation operations.

This research focuses on one of the prominent ITS devices: Dynamic Message Signs (DMS) operations. Using real time incident management operations data and ITS operations data, an attempt is made to develop ITS Operations Evaluations Models (ITSOEMs) that are capable of quantifying the operations value of DMS and their complementing ITS surveillance and detection systems, such as CCTV, Safety Service Patrol (SSP) and Computer Aided Dispatch (CAD) systems.

The I-95 corridor in the state of Virginia is selected as the Study Corridor. Operations data from the Virginia Department of Transportation (VDOT) on DMS and ITS detection systems and incident management is analyzed to accomplish four key research objectives: a) To collect, extract and evaluate real time operations data from VDOT ITS and incident management operations programs and identify the factors contributing to the successful operation of DMS for the duration of incidents and events occurring on the I-95 Study Corridor; b) To develop analytical models to determine measurable influence of incident detections in successfully disseminating messages on DMS; c) To develop ITS Operations evaluation models to determine the effectiveness of DMS messages during incidents by quantifying the influence of DMS messages in the deterrence of secondary incidents on the I-95 Study Corridor; and d) To develop guidelines on the application of these quantitative ITS evaluation models so that transportation engineers can effectively use these models to perform ITS evaluations at other ITS locations. The ITS evaluation framework developed in this research work is expected to assist transportation engineers in the prioritization, selection and implementation of operations and technology integration strategies.

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CHAPTER 1: INTRODUCTION

1.1 Background

Intelligent Transportation Systems (ITS) operations has become one of the core business functions for transportation agencies in the US. ITS provides real time situational awareness to motorists on a variety of aspects including traffic incidents, expected delays, estimated travel times, diversion routes, and lane closures. ITS also disseminates real time alerts on incidents, special events, and work zone traffic control and other information to motorists. Recent findings by US Department of Transportation (USDOT) indicate that use of ITS systems such as Dynamic Message Signs (DMS), integrated Safety Service Patrols (SSP), Closed Circuit Television Camera (CCTV) surveillance systems, and Vehicle Detection Systems (VDS) during non-recurring and recurring congestion events considerably enhances safety and results in optimal use of available capacity on the transportation corridors (1). Though ITS operations continues to gain prominence, very few studies attempted to capture and quantitatively evaluate the role of ITS in transportation system operations in general and, particularly, their effectiveness during incidents and other recurring and non-recurring congestion events. A few studies that attempted to evaluate ITS impacts during incidents and non-recurring congestion events have reported lack of availability of granular data on ITS operations and incident management.

As integrated operations within transportation operating agencies evolved, the scope of DMS and other ITS applications expanded to complement advanced operations strategies such as weather information dissemination and Active Traffic Management (e.g., variable speed limits, hard shoulder lane control operations and dynamic lane merge operations). When activated during non-recurring and recurring congestion events, ITS is considered to be effective in enhancing safety and optimal use of available capacity on the transportation corridors.

During the last 50 years several studies were conducted to evaluate DMS operations and attempts were made to quantify their usefulness in incident management and in mitigating congestion impacts. Additionally, several studies were conducted to estimate the influence of ITS and other detection methods on incident management and on DMS operations. However, a literature review indicated that due to the lack of detailed data on DMS operations and on other ITS elements and descriptive data on incident management, these studies were predominantly focused on ‘before’ and ‘after’ or ‘with’ and ‘without’ DMS scenarios. The literature review also suggested that findings from these studies limited the scope and usefulness of these evaluations methods and emphasized a need for more realistic and accurate assessment of DMS operations. For example, studies conducted in Minnesota, Texas, Wyoming and New York have cited lack of detailed data on DMS operations and on incident detection, response and recovery operations as one of the principal limitations in performing quantitative evaluation of DMS. In this research, through use of ITS operations data, incident detection systems data, and incident response operations data, an attempt is made to develop quantitative models to evaluate DMS operations during incident detection, verification, response and recovery operations.

The I-95 corridor in the state of Virginia is selected as the Study Corridor and the pertinent operations data required for this research is retrieved from the ITS and incident management operations programs administered by Virginia Department of Transportation (VDOT). VDOT planning methods and criteria are used, and the I-95 Study Corridor is delineated into urban and transition segments. For each segment of the I-95 corridor, the real time operations data is extracted for critical analyses time periods. Discussion with VDOT officials confirmed that DMS and other ITS operations are significantly matured and prevalent in use in the urban and transition segments of the I-95 Study Corridor. Based on discussions with VDOT operations engineers, the analyses scenarios are selected in such a manner that critical corridor operations characteristics such as HOV lanes operations, freight and passenger mobility trends, and prevalent maintenance and work zone situational conditions are well reflected and captured in the selected analyses time periods.

The DMS and ITS operations data elements include DMS messages, DMS location, direction, message start time and end time, message duration, and message type. Data on ITS detection systems includes CCTV detections, Safety Service Patrol detections and Computer Aided Dispatch System detections. The incident management data include incident type, lanes impacted, incident start time and end time, incident duration, incident location, direction, involvement of trucks in incidents, hazmat spills, weather impacts and incidents in work zones. Using this data, the analyses variables required for this research are identified and a set of quantitative ITS Operations evaluation models are developed for the I-95 Study Corridor. The models developed are expected to establish meaningful relationships between the analyses variables and provide measurable evaluation of DMS and ITS detection system operations during incident management.

1.2 Research Objectives

The main purpose of this research is to apply quantitative analytical methods to develop ITS Operations Evaluation Models (ITSOEM) using DMS operations data, incident detection system data and incident management data to evaluate a few of the prominent and widely used ITS systems namely: Dynamic Message System (DMS), CCTV, Safety Service Patrols (SSP) and Computer Aided Dispatch Systems (CAD). In this research, the ITSOEM will be developed using DMS operations and incident management and operations data for the I-95 Study Corridor in Virginia. Following are the principal research objectives.

1.2.1 Objective 1

Objective 1 of this research is to collect, extract and evaluate real time operations data from VDOT DMS and incident management operations programs and identify the factors contributing to the successful operation of DMS for the duration of incidents and events occurring on the I-95 Study Corridor.

The data required for this research is made available by Virginia Department of Transportation (VDOT). From this data, the likely factors that contribute to the success of DMS operations are identified which include number of detections by each category of VDOT detection systems (CCTV, SSP and CAD). DMS operations are considered successful when these detection systems accurately detect the incidents and relay them to the DMS operators, enabling them to disseminate messages on DMS.

It is necessary to note that there are several other factors that contribute to successful DMS Operations, including seamless hardware and software functioning and the efficiency of DMS operators; however, these factors are not evaluated in this research. For this research, it is assumed that the DMS hardware and software are intact and are subjected to VDOT routine and preventive maintenance protocols. It is also critical to underscore here that after upkeep of the DMS hardware and software components, it becomes a foremost requirement that the ultimate success of DMS operations solely depend on the extent the detection systems detect incidents and result in successful dissemination of messages on DMS.

The factors for successful DMS operations are identified for several types of incidents including High Profile HAZMAT incidents involving tractor trailers, Major Profile incidents involving fatalities and multi-vehicle collisions and Minor Profile incidents including disabled vehicles and other minor collisions. The following is a brief description of the data elements that are of interest to this research:

- Operations data on High, Major and Minor profile incidents such as incident location, incident duration, incident start time, incident end time, data on incident responders, number of lanes impacted, and lane miles backed up;
- DMS operations data which includes DMS messages disseminated during High, Major and Low profile incidents, message duration, and message updates;
- Incident detection system operations data including CCTV detections, Safety Service Patrol detections, Computer Aided Dispatch detections; and
- Other data such as incidents in work zones, incidents under severe weather conditions and incidents during special events.

The data extraction process and detailed descriptions of the above data and the analyses factors used in this research are presented in Chapter 5 of this dissertation.

1.2.2 Objective 2

Objective 2 of this research is to develop models and perform analytical assessment of incident detections and determine their measurable influence in successfully disseminating messages on DMS.

The detection systems to be evaluated by the models include CCTV operations, Safety Service Patrols operations and Computer Aided Dispatch operations. The urban and transition operating conditions, the High, Major and Minor profile incidents, peak a.m. and p.m. hours and other analyses periods will be included in the model development scenarios.

1.2.3 Objective 3

Objective 3 of this research is to develop ITS Operations evaluation models to determine the effectiveness of DMS messages during incidents by quantifying the influence of DMS messages in the deterrence of secondary incidents on the I-95 Study Corridor.

The model variables to be analyzed to achieve this objective will be derived from data on High, Major and Minor profile incidents and include data on primary incidents, primary incident duration, number of lanes impacted, distance of DMS to the incident location and traffic volumes approaching the incident location. Data on DMS operations include DMS messages and the message duration during the entire incident management operations. The models developed will be used to quantify the influence of DMS message dissemination in the deterrence of secondary incidents on the I-95 Study Corridor.

1.2.4 Objective 4

Objective 4 of this research is to develop guidelines on the application of these quantitative ITS Operations Evaluation Models (ITSOEMs) so that transportation engineers can effectively use and perform ITS Operations evaluations for a variety of operations strategies and analyses scenarios.

The developed models application framework is expected to be transferable through the use of suitable data syntheses methods identified in this research. Additionally, the guidelines developed in this research are expected to enable practicing engineers to apply ITSOEM framework to evaluate DMS and other ITS operations at locations outside Virginia.

1.3 Research Approach

To achieve the aforementioned research objectives, the data required for the I-95 Study Corridor are collected and extracted from VDOT operating systems and analyzed. The Study Corridor boundaries and analyses time periods are identified. For realizing the objectives, a set of hypotheses are established and analytical methods applied to develop ITSOEM to test the hypotheses.

Foremost, a comprehensive operations understanding of the I-95 Study Corridor is achieved and the prevalent roadway and roadside geometric and operations characteristics are identified. The corridor's peak and off-peak operating conditions are established based on the VDOT operations procedures and VDOT Six Year Operations Improvement Plan.

1.3.1 Data Extraction and Data Reduction

The procedures and protocols adopted by VDOT Traffic Operations Center to operate DMS and CCTV were reviewed to understand and identify the interdependencies and their limitations in the operation of DMS, CCTV and Safety Service Patrol for the I-95 Study Corridor. Further, the DMS, CCTV, Safety Service Patrol deployment locations and their coverage areas for the Study Corridor are established.

VDOT Advanced Traffic Management System (ATMS) architecture, its placement in Traffic Operations Center (TOC) operations and its role in the operations of DMS, CCTV and Safety Service Patrol on I-95 Study Corridor are identified. The cycle of message dissemination and its correlation with incident detection, verification, response and recovery operations are established. The

DMS message data features are identified and extracted from ATMS and used as analyses data. Extracted DMS data elements used in the analyses include messages, start time, end time, message duration, DMS location, direction, message type such as lane blocked, work zones, weather related etc, number of DMS activated for the same incident and message date. This extracted DMS operations data is assembled per the established analyses time periods and per identified urban and transition segments of the I-95 Study Corridor.

VDOT uses a relational database called VA Traffic and logs all High, Major, and Minor profile incidents and their pertinent incident management operations that take place on all transportation corridors in Virginia. VA Traffic relational database architecture, its placement in TOC operations, and its role in event logging functions during incident detection, verification, response and recovery operations on the I-95 Study Corridor are identified. The data logged in VA Traffic relational database is extracted for all High, Major and Minor profile incidents that occurred on the I-95 Study Corridor from September 2008 through December 2009. The role of Computer Aided Dispatch (CAD) system administered by Virginia State Police 911 Fusion Center, data sharing protocols with VDOT TOC and VA Traffic Relational database systems are reviewed and the data streams feeding from the CAD system to VA Traffic are identified and extracted for the I-95 Study Corridor.

In this research, the critical data reduction effort relates to the above mentioned data from DMS, detection systems and the High, Major and Minor profile incidents in time and space. Each data set from DMS operations, incident detection systems and incident management data is linked through time and space data and the Major, High and Minor profile incidents, that were successfully detected and verified and have resulted in disseminating the messages on DMS, are identified for urban and transition segments and established for all analyses time periods. This is done at a granular level and identified with respect to the individual detection systems including CCTV, SSP and CAD detection systems and for High, Major and Minor profile incidents and situational conditions on I-95. In the same manner, the granular level data related to secondary incidents and incident duration is identified for analyses time periods and situational conditions prevalent at the time of incident occurrence.

1.3.2 Modeling Methodologies

One of the principal objectives of this research is to develop models that are capable of quantitatively evaluating DMS operation. To achieve this objective, the model development is attempted in two distinct parts. The first set of models quantifies or measures the successful dissemination of DMS messages as outcomes resulting from detection and verification of incidents. The second set of models provide measurable influence of DMS messages in their deterrence of secondary incidents and on incident duration during response and recovery operations for situational conditions pertaining to High profile, Major profile and Minor profile incidents.

To achieve this modeling objective, it is imperative that the data sets used for this research are properly evaluated and understood. Preliminary evaluations of VDOT ITS operations and incident management data to be used for this research indicate that the nature of the data appears to be both discrete and continuous. Therefore, the use of modeling methods such as Logistic Regression analytical methods is deemed as more appropriate for this research. A complete discussion on evaluation of the data needs and the appropriateness of logistic regression analytical methods as suitable modeling methods for this study are presented in Chapters 4 through 6.

The models developed are tested and validated for accuracy by using appropriate statistical methods. The results are tabulated and quantitative ITS evaluations are presented for the I-95 Study Corridor. Finally, the models application methods are described and limitations and guidelines are developed for transportation engineers to use these models for DMS and other ITS operations evaluations for other corridors in Virginia.

Next steps for research are identified to extend the ITS evaluation methods to other ITS systems. Figure 1.1 shows the details of the research approach.

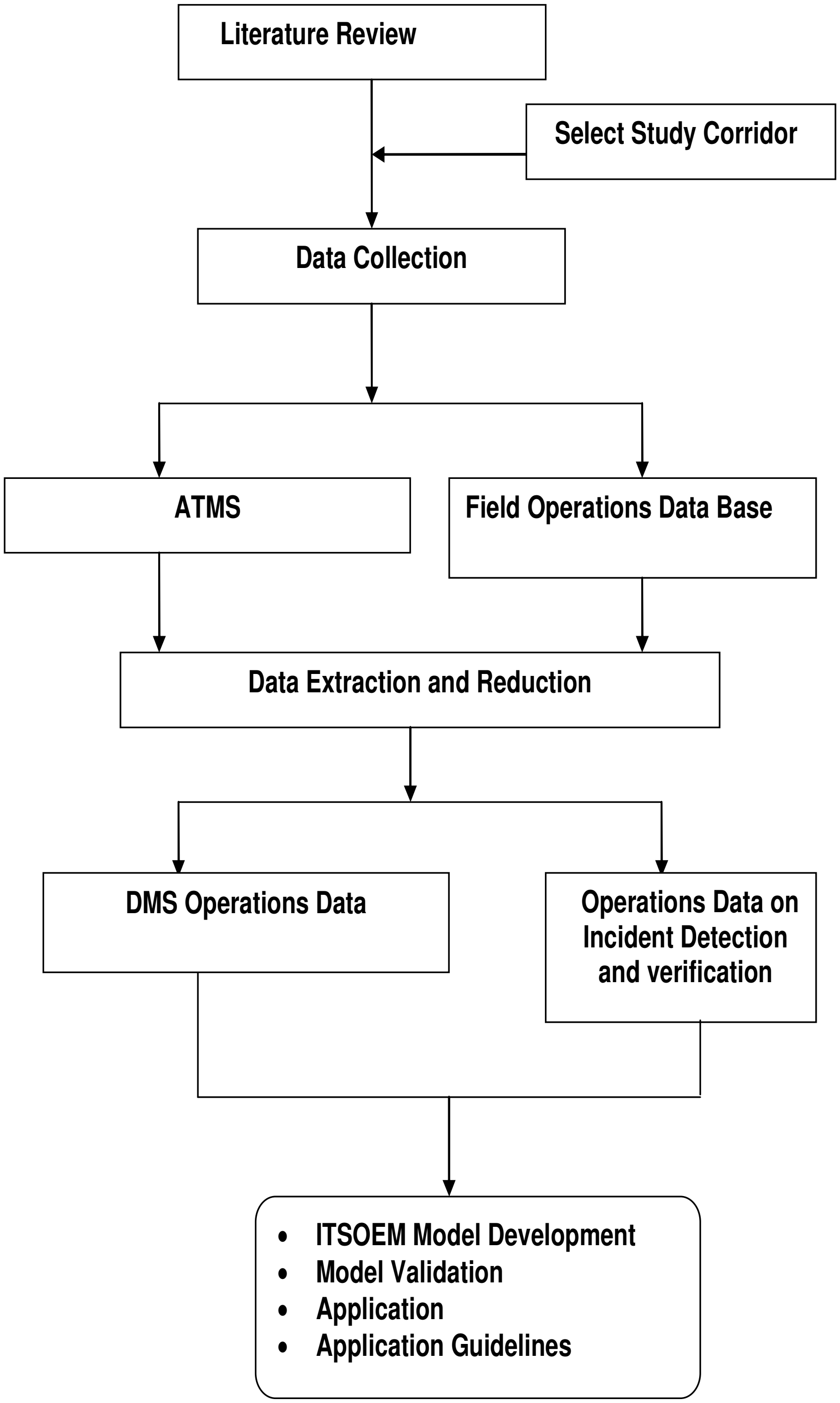


Figure 1.1 Research Approach

1.4 Research Tasks

The following tasks are performed to complete this research:

1. Literature Search and Review.
2. ITS Operations in Transportation Agencies – A State of Play.
3. Selection of I-95 Study Corridor.
4. Data Collection and Syntheses.
5. Modeling Methodology Selection.
6. ITS Operations Evaluation Models Development (ITSOEM).
7. ITSOEM Models Results Interpretations.
8. ITSOEM Models Application.
9. Summary of Research Findings, and Conclusions.

1.5 Organization of the Dissertation

The remainder of the dissertation is organized as follows: In Chapter 2 the literature review performed for this research is summarized and a full report is provided in Appendix A. Chapter 3 provides a State of Play of ITS operations and sequentially portrays various facets of ITS evolution and its role in corridor level operations amongst transportation agencies. Chapter 4 provides an overview of ITS operations on the I-95 Study Corridor. Chapter 5 is devoted to data extraction and analyses and in Chapter 6 the Modeling Methodologies developed for this research are discussed. In Chapter 7 ITSOEM models are developed and final model selection is presented. In Chapter 8 the ITSOEM model results and their interpretations are presented. In Chapter 9 ITSOEM application framework, guidelines and limitations are presented with extensive discussion on the role and application values of such models to assess the effectiveness of ITS operations in a tangible manner. In Chapter 10 conclusions and next steps for the research are discussed.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

For the last 50 years, significant research has been underway to address several aspects of ITS operations, ITS design elements, the optimum size of ITS (such as DMS) devices, their location, communication infrastructure, message types, format, content, display, etc. These research scopes have covered a variety of ITS applications for several roadway operations strategies. Additionally, several DMS and ITS application workshops and operating agency-based studies continue to examine DMS operating policies and procedures for their effectiveness and to efficiently operate DMS. The vast literature pertaining to all these issues has reinforced the fact that transportation agencies are constantly searching for methods to comprehensively improve ITS operations with accurate timely messages displayed on DMS, and strive to achieve the desired impact on traffic flow, incident management, overall improvement in motorist safety and convenience, and to make the best use of the available capacity on transportation corridors.

This literature review summarizes some of the ongoing research work on ITS and DMS evaluation and applications, and presents the distinct analytical methods and tools that are currently available to perform ITS evaluation. Specific review focus is also committed to assess the ability of ITS evaluation frameworks to use real time data from DMS operations, data from other ITS elements that support DMS operations and data on operations strategies where DMS are employed, such as incidents, events, etc. The review also identifies and discusses limitations and gaps in the current ITS evaluation methods and applications and summarizes additional research needs. Resultantly, a series of recommendations for next research steps are presented that are expected to form the basis for the development and application of a renewed and enhanced ITS operations evaluation methodology and framework.

2.2 ITS Operations - Non-Recurring Congestion

In their special report titled ‘Strategic Highway Research Program (SHRP-2) Special Report 296 to US Congress’ (2), the Transportation Research Board (TRB) has stressed the need for DMS usage during pivotal non-recurring congestion events that specifically include incidents, work zones, inclement weather, demand fluctuations, special events, and inadequate base capacity resulting from protracted congestion hours coupled with incidents and events. Ozbay et al (3), Thill and Yan (4), Thill, Rogova and Yan (83) used archived incident data to evaluate effectiveness of DMS in diverting traffic during incidents, and the associated use of Safety Service Patrols to detect and verify incidents. Sallman and Doug (5) in the DMS evaluation for Minnesota’s I-94 identified data gaps and stressed the need to integrate real time incident and operations data to develop effective realistic DMS evaluations. Ng et al (6) established the need for real time traffic information dissemination on DMS and effective truck mobility during incidents. Eidswick et al (7) evaluated pilot DMS deployment on State Route 64 in the Grand Canyon National Park and determined that DMS usage resulted in 250,000 vehicle miles reduction and a fuel savings of over 10,000 gallons. DMS effectiveness on the I-80 corridor between Laramine and Cheyenne in southeast Wyoming performed by Edwards and Young (8) and Snachez et al (9) concluded that lack of more continuous real time operations and DMS data has imposed limitations in determining the true DMS utility value. USDOT (10) evaluation of DMS and Highway Advisory Radio (HAR) effectiveness to address truck operations at various entry points to the ports in Colorado confirmed that DMS usage has made a huge difference in the Truck and port operations. Hardy (11) in a Bozeman wildlife channelization project on I-90 concluded that the DMS usage lead to reduction in animal-vehicle crashes. Yaw, Boddu and Stamatiadis (12) performed before and after DMS evaluations and determined DMS effectiveness for special event management for the events in Nutter Center in Dayton, Ohio. Hogema and Gebel (13) have used a driving simulator experiment to conclude that 2 or more DMS locations activated to the upstream of the incident location may prove more effective in achieving the desired behavioral change in motorists. Pigman and Agent (14) analyzed accident data in the vicinity of the I-75 Clays Ferry Bridge reconstruction project in Kentucky and evaluated the effectiveness of DMS operations and concluded that placing a message at unsafe locations was the best way to use DMS in this project.

2.3 ITS Operations - Recurring Congestion

2010 Urban Mobility Report by Shrank et al, (15), recognized the importance of DMS Operations and the dissemination of regulatory and advisory actionable information. Shah and Wunderlich (16) evaluated Michigan Department of Transportation's ITS deployment effectiveness to address congestion on the John C Lodge corridor of Detroit. This simulation based with and without DMS and ITS infrastructure evaluation revealed that the commuters who use traveler information via the pre-trip or DMS and HAR systems experienced delay reductions during non-recurring congestion resulting from incidents. Ding et al (17) determined that New York Staten Island DMS locations effectively disseminate travel times to guide motorists during hours of recurring congestion. Offerman et al (18) conducted before and after studies and confirmed DMS locations for their effectiveness. DMS operational effectiveness in terms of spatial and time-of-day characteristics under non-recurrent congestion is analyzed by Srinivasan and Krishnamurthy (19). Van and Malenfant (20) evaluated crashes and merging and diverging operations that were severely influenced by the DMS operations on I-4 for exit/entry traffic to Universal Studios Theme park events in Orlando, Florida, and determined flow rates to achieve ramp traffic balance and safe exit and entry operations on I-4.

Sinha et al (21) have carried out Logistic Regression modeling to assess impacts of ITS effectiveness and impacts on Indiana's Borman Expressway Network and quantified benefits in terms of travel time savings and secondary crash reductions. Levinson and Chen of UC Berkeley Transportation System (22) used regression analyses and evaluated DMS and Traffic Management System Performance that became the basis for further advanced modeling and analyses efforts and established the need for use of real time DMS operations data. Schuster (23) compared the effectiveness of DMS and permanent roadway signs in the context of dynamic speed limit information dissemination methods for Motorway Control Systems (MCS). The study identified the effects of permanent speed traffic signs and DMS posted speed limits and concluded that there is significant increase in safety measures such as crash reduction and speed variability when DMS is sued. Martin et al (24) and Tavvola et al (25) evaluated the use of DMS for advance lane closures and established that the variability in speed was reduced, which was considered as one of the primary causes of incidents. Tavvola further identified a 30 % reduction in queue lengths leading to lane balancing and enhanced operations at tapering points of the closed lane sections.

2.4 ITS Operations and Weather

During inclement weather, DMS messages provide critical updates on icy and freezing condition to motorists on bridge sections, at major corridors that trek across mountain passes and other such differing geometric alignments, and update visibility restrictions resulting from fog and a host of other such weather impacts. Transportation agencies rely on DMS to relay situational awareness on weather prone emergencies such as formation of black ice on pavements at freezing temperatures, flash flooding conditions resulting from heavy unpredicted downpours, etc. Several studies including Kiuru (26), Al Ghamdi (27), Kumar et al (28), Young et al (29) and Cooper et al (30) performed before and after analyses to determine the effectiveness of DMS usage during inclement weather conditions. The studies concluded that messages on DMS alerting motorists on visibility restrictions resulting from fog, adverse conditions resulting from high winds and icy conditions on pavement sections, etc. proved immensely significant. The speed reductions, crash rate reductions and traffic volume reductions for before and after DMS operations were used as the basis in these evaluations. Cooper et al (30) in their I-80 DMS Operation Study, estimated the benefits resulting from successful DMS operations during adverse weather event that averted a typical 1 to 8 hours weather related roadway closures to range from $222,000 to $8M.

2.5 ITS Operations and Work Zone Operations

DMSs play a very important role during work zone operations. Typically the transportation agencies use DMS to provide real time and programmed and planned information to motorists during work zone operations. The information on planned lane closures, hours of lane closures, options on diversion and detour routes, lane merge operations, dynamic lane merge operations, shoulder lane and ramp junction operations are all work zone operations strategies that are actively supported by DMS. Firman et al (31) confirmed that the work zones for maintenance and construction activities are the most common causes that greatly disrupt traffic flow and identified that speed and crash occurrence decreased through use of DMS operations in the work zones. Pinkerton et al (32) evaluated 40 portable DMSs in construction work zones along I-70 and I-44 corridors; the favorable results of the evaluation lead MoDOT to invest additional funds and replace the portable DMS with permanent DMS systems. Heaslip et al (33), and Pesti et al (34) of University of Nebraska performed similar studies. Pesti reported that from an on-line survey on work zones, 69 percent of respondents indicated that they would like delay time information, 49 percent prefer alternate route information, and 43 percent would like to see travel time information. Some studies reported ineffectiveness of DMS applications in work zones. A study by Sperry et al (35) for the Iowa DOT evaluated the use of DMS to enhance the traffic flows at two construction work zones. The study attempted to determine enhanced merge operations and did not see any significant impact on merging actions when the DMS messaging was activated as compared to free flow conditions with no messaging. Similarly, Huebschman et al (36) conducted a study for the Indiana Department of Transportation Pilot project for an I-65/US-30 interchange reconstruction project near Merrillville, IN. The study attributed significant reduction in the average speed observed at the US-30 interchange (heart of the work zone) to the installation of the fixed panel signs, rather than with the DMSs operations that was focused on displaying the number of tickets issued by law enforcement agency. However, Fontaine (37) evaluated the use of portable DMS in work zones based on vehicle speeds in work zones and indicated that the DMS use reduced speeds and traffic conflicts.

2.6 ITS Evaluation Methods

This section of the literature review focuses on the various evaluation methods employed to determine and quantify DMS effectiveness. The evaluation methods are presented in three distinct categories: a) evaluation techniques that are integrated to serve as sketch planning tools, b) customer focused user surveys, and c) widely used benefit-cost analyses.

2.6.1 ITS Evaluation - Sketch Planning Tools

As ITS deployments gained prominence, planning and evaluation tools currently in use were expanded to incorporate the evaluation of ITS elements. Studies in Florida, Indiana, New York, Michigan and several other states in the US and other studies elsewhere, have incorporated ITS evaluation methods as sketch planning modules within planning methods consisting of demand models such as Intelligent Transportation System Deployment Analyses (IDAS – that used outputs from the four stage modeling techniques) and the simulation traffic analyses models such as INTEGRATION, DynaSmart etc.

Hadi et al (38, 39, and 40) used FDOT field and ITS operations data and developed a framework to evaluate benefits and costs for advanced traffic management components. The research work illustrates the scope and extent of these sketch planning tools to determine the effectiveness of DMS applications. The study concludes that the use of methods and parameters identified in this study allow better pre-deployment assessment of DMS and other incident management systems and helps agencies to prioritize funding and resource allocation. The methods developed were successfully incorporated as sketch planning tools into the widely applied FDOT statewide demand forecast models. For DMS on I-95 and I-595 corridors in Fort Lauderdale, Florida, the authors used DMS activations as a base parameter and using standardized ITS Deployment Analyses (IDAS) methods determined that 2406 annual DMS activations in 2006 resulted in an average travel time savings of 11 minutes. The other noteworthy results from this research effort include development of parameters that are used as regular planning models for corridor assessment such as incident rates, total delay, service patrol benefit rates, etc. The developed parameters are converted into ITS sketch planning inputs to complement the FDOT statewide four-stage transportation planning model called Florida Standard Urban Transportation Modeling Structure (FSUTMS). The sketch planning tool serves as modules within FSUTMS to assess the effectiveness of ITS elements such as DMS, HAR, CCTV and Roadway Weather Information System (RWIS). The sketch planning tool attempts to provide computation capabilities within FSUTMS to include ITS impacts in the FSUTMS outputs such as vehicle miles of travel, vehicle hours of travel and average link speeds, fuel consumption and others based on the demographics, land use and similar planning data inputs for the modeling horizon years.

Thill et al (4, 41, 42) identified the scarcity of effective evaluation tools to assess ITS and developed a model to determine benefits of an effective incident management system with ITS and named the ITSOAM – ITS Operations Analyses Model. The ITSOAM was applied by NYSDOT as a sketch planning tool and enabled NYSDOT to make ITS capital investment decisions. The ITSOAM consists of a delay model based on the Bureau of Public Roads (BPR) capacity constraint equation which used the DMS-induced rate at which traffic diverts to an alternate route to avoid the bottleneck associated with the modeled incident. The ITSOAM was used to explore the potential safety benefits resulting from DMS operations and their effect in the reduction of secondary crashes through efficient utilization of roadway capacity achieved through traffic diversions from incident blocked roadway segments.

Wang et al (43) presented a Multi-attribute Utility Theory Approach for ITS planning to determine the appropriate ITS market packages consisting of DMS and other ITS elements for operations strategies. The approach involves calculation of utilities and ranking of ITS market packages. The same authors in their follow up research (44) used on Analytical Hierarchy Process to identify the best ITS alternatives among several candidates. Using the same multi-criteria approach, Gupta (45) presented a summary on how ITS has radically changed the way transportation problems are resolved and presented a framework for deployment of ITS applications that ensures effective management of incidents.

Guidelines for the evaluation of DMS performance were carried out by Mounce et al (46) of the Texas Transportation Institute. The study established performance-based measures of effectiveness of DMS based primarily on before and after DMS traffic characteristics data for urban and rural conditions. The report discusses both qualitative and quantitative benefits of DMS evaluation methods with field study observations for Houston (urban) and Amarillo (rural) areas in Texas. The study identified data constraints and limitations and presented several hypotheses-based analyses frameworks for data that is being collected for before and after DMS deployment conditions. Huo and Levinson (47) used real time operations data from the empirical loop detector system and a DMS evaluation study for Minneapolis to evaluate DMS effectiveness and benefits. The effectiveness of DMS is evaluated in two ways: (1) Using a discrete choice model to estimate the response of drivers to messages provided by DMS; (2) Statistical analysis on the variation of diversion rate with and without DMS. Additionally the authors further evaluated, using data before and after employing DMS, the improvement of performance on the network due to DMS operations. The benefits of DMS are comprised of: 1) travel time saving; 2) reduction of total delay; 3) safety improvement; 4) environmental improvement; and 5) providing information to travelers who choose not to divert. Lee et al (48) used fuzzy set theory, Eigen vector analyses, pair wise comparison and Saaty's Analytical Hierarchy Analyses to evaluate DMS effectiveness. The author attempts to build on the scope of the current evaluation framework and determine qualitative utility of DMS based on user survey data, and developed six performance criteria that define the degrees of DMS service effectiveness. The weighted averages are further converted into single percentage values thus defining the degree of satisfaction resulting from DMS operations. The significance of local conditions in evaluating benefits and costs associated with ITS and DMS operations was evaluated by Nielsen (49) and quantified benefits resulting from reductions in congestion, crashes, travel time, vehicle operating costs and freight costs. Smith et al (50) carried out a detailed performance assessment of the Virginia DOT operations program using operations data from VDOT's ITS, Maintenance, and field operations functions and concluded that the data available in real time is statistically significant to carry out further research to establish microscopic decision-resulting analyses. Haas (51 and 52) et al documented evaluations of i-Florida, a USDOT sponsored Surface Transportation Security and Reliability Information System Model deployment and discuss the benefits resulting from ITS deployment and operations, maintaining a network of ITS field devices, usage of toll tag readers to develop traffic monitoring, interfacing TMC and FHP CAD systems, benefits from using DMS for traveler information purposes, weather data, application of Variable Speed Limits for work zones and evacuation operations.

2.6.2 ITS Evaluation - User Surveys

Several research studies have relied on user surveys and complemented the DMS evaluations findings. The researchers analyzed user survey response data and developed quantitative and qualitative assessments of DMS and other ITS operations. Briglia (53, 54 and 55) used survey data collected on a questionnaire and developed and applied ITS evaluation frameworks to assess

17 ITS earmarked projects that consisted of DMS deployments as one of the principal options. The questionnaire addressed technical, management and organizational lessons learnt and the evaluation output included system usage and benefits, effectiveness of ITS architecture and standards, ITS benefits and costs, and respective challenges of ITS operations and maintenance. Jiang et al (56) identified the need to determine the driver's response to traffic information signs as one of the principal successful measures to evaluate the effectiveness of DMS. Using qualitative statistical analyses methods, the study evaluated effectiveness of messages for the city of Changchun in China. The analyses indicated that the motorists valued messages from HARs as more useful and DMS messages did not cause any driver distraction. Haitham, Al-Deek et al (57), evaluated the impact of DMS on toll road users in Orlando, Florida, by using a pre-deployment (one DMS operational) and post-deployment (29 DMS operational)by conducting user surveys. The user survey analysis confirmed that the reaction that travelers have to the real time messages on travel times, congestion, incidents, and other alerts that DMS provide define the user perception of the utility of the DMS. Ran et al (58) used driver survey data to evaluate DMS effectiveness in Wisconsin and concluded that drivers valued the DMS operations in adjusting their trips to match congestion, emergency response situations, and weather information and expressed the need for DMS to provide more updates on progression of incident clearance and weather impacts. Anund et al (59) evaluated the effectiveness and user acceptance of DMS that disseminated just the variable speed limits versus DMS that disseminated speed

limits along with a message for motorists to slow down or DMS operations that combined speed limit with the flashing beacons. This Swedish investigation confirmed that DMS with just variable speed limits were more effective and the speed compliance in variable speed limit DMS were more significant compared to the combination of operations with either a DMS message or with the flashing beacons.

Martin et al (60) in their evaluation of UDOT ATIS technologies including DMS, HAR, and 511 services focused on three key aspects: level of ATIS awareness in motorists, ATIS effects on driver behavior, and demographic factors. The study collected public information data from licensed drivers and statistically analyzed the responses. Western Transportation Institute (61) evaluated DMS effectiveness for Yellowstone Rural ITS applications. The user responses were tallied, qualitative analyses were performed and the effectiveness of DMS was rated as “satisfactory” to “very satisfactory”. Patten et al (62) used questionnaire responses to evaluate comparative effectiveness of DMS and HAR real time information dissemination to truck operators and motorists. A total of 1528 out of 5510 motorists and 889 truckers out of 3584 truckers responded to the questionnaire. The data analyses confirmed that DMS were significantly more effective compared to HAR.

The user feedback was used to evaluate DMS, HAR and toll free telephone information system by Lee et al of WTI (63) for Safe Passage

Commuter Information System deployed on interstate I-90 in Bozeman, Montana. Lee et al (63) explored the role of DMS in the user's decision making process. The authors developed driver utility functions with DMS related variables in the utility functions using game theory and user survey data. Dudek et al (64) summarized results of a laboratory experiment of 15 specific issues related to DMS operations and developed a framework for improved DMS messages and operations. Driver response survey data was used to make this assessment. The report concluded that of several DMS operations strategies, DMS with lane control messages were most effective. Martin et al (65) collected user surveys and analyzed the data to assess the effectiveness of Road Weather Information System and DMS usage to disseminate real time weather information to motorists and confirmed that DMS plays a significant and credible role. Son (66) used survey data to evaluate and measure DMS effectiveness on major urban freeways and the Olympic Expressway in Seoul, South Korea, and confirmed that DMS were helpful to motorists in making adjustments to travel routes based on real time traveler information disseminated on DMS. Hounsel et al (67) evaluated DMS effectiveness for London, UK and with particular focus on route choice by drivers and the roadway network performance under inclement weather conditions. The methodology used involves comparative assessment of observed and modeled traffic measurements under several "what if" scenarios developed for this study. The user survey data formed the basis for developing diversion patterns resulting from incidents and weather conditions and these diversion rates were assessed with respect to the messages posted on DMS.

2.6.3 ITS Evaluation - Benefit Cost Analyses Methods

The Benefit-cost (b/c) ratios are widely used in a variety of transportation operations projects and are in prolific use to measure effectiveness of DMS. Several research studies on DMS evaluation used b/c ratios as final conclusive research findings to quantify effectiveness of DMS other ITS operations strategies. Taylor (68), summarized how and to what extent a b/c based ITS evaluation may answer key questions such as: a) the full potential of ITS to realize tangible benefits, b) the capability of evaluation methods employed to rationalize ITS investments versus ITS benefits, c) and the ability of transportation agencies to use the benefits identified (the extent to which benefits are clear and concise) to determine future enhancements in ITS planning and deployment. Taylor used these principles and carried out ITS evaluations for portable ITS units, Safety Service Patrol operations and Dynamic Message Signs Systems.

Guin et al (69) conducted benefit cost assessments and determined an annual savings of 7.2 million vehicle hours of incident related delay, at an overall cost savings of $187 million for the two year analyses period of 2003-2004 at an annual benefit-cost ratio of 4.4 : 1. Sultana (70) evaluated the Montréal Freeway Traffic Management System and determined that a system consisting of 33 DMS, 1120 loops, 170 detector stations, 45 CCTV and a road weather information system collectively, over a 15 year life cycle project time frame, yielded a benefic-cost ratio of 5.5 to 1. Ozbay's (3) evaluation methods calculated costs and benefits for DMS and other ITS applications and determined a b/c ratio of 9.2 : 1 for DMS applications and 3.9 : 1 for reduction in incident detection verification and recovery times. A complete benefits and costs evaluation conducted by Jia et al (71) documented the ITS benefits and costs incurred for San Luis Obispo Transit System and determined that the b/c ratio of 3.9 : 1 indicated a stable economic viability for DMS and other ITS systems application for Obispo Transit System. Buisson and Ladier (72) studied the effectiveness of messages posted on DMS on recurrent congestion. Taking advantage of a national strike in Lyon, France that led to the shutdown of DMS operations they collected data without DMS operations and compared that to the data with DMS in operations and evaluated the DMS operations impacts for the 80 km corridor of congestion. The authors used qualitative and quantitative methods and complementing analyses were carried out to determine benefits and costs. It was concluded that benefits are approximately $1M per year.

Yang et al (73) have developed two methods to account for uncertainty in benefit-cost of evaluations of ITS using the Monte Carlo simulation, and determined b/c ratios and reported high levels of uncertainty in the values of ITS benefit and cost. Fontaine and Edara (74) evaluated benefits of ITS in work zones titled Smart Work Zones and established Smart Work Zone project duration thresholds so that a particular Smart Work Zone will be effective in realizing travel time and delay reductions. Somers et al (75) evaluated the application of DMS as a part of a complex and significant freeway management system for Monash City, Australia, and used whole-of-life costs and risks as evaluating factors and developed policy, guidelines and standards for this project implementation. Odeck et al (76) developed an ITS benefit-cost analyses framework with specific focus on comparing and replacing manual toll collection systems with ITS supported automatic toll collection systems for 19 toll collection points on Oslo Toll cordon and established that the electronic ITS-based toll collection coupled with DMS operations is more efficient and beneficial compared to semi and manual toll collection without DMS operations. Walton et al (77), in their study on ITS evaluations for TxDOT identified that b/c to assist Texas DOT staff in selecting the most beneficial ITS elements for arterial operations. James et al (78) at UK Highway Authority performed a benefit-cost assessment for one of the pioneer Active Traffic Management corridors and identified significant benefits in using DMS. Yao (79)'s study confirmed driver benefits of ITS for a motorway sector in Shanghai, A case study by Owens et al (80) for a Utah Commuter link earmarked project evaluation and a benefit cost based evaluation framework developed by Rausch et al (81), all stand as research efforts that exemplify the use of benefits and costs comparison to assess DMS and ITS operations. Further, USDOT (82) provided an overview of the use of ITS in work zones and presented a systematic benefits and costs assessment of the application of ITS components in work zones. Landers (83) used the ratings developed by USDOT to evaluate effectiveness of ITS. The investigative report includes technologies such as arterial management systems, freeway and incident management system, and electronic payment system. Morrow (84) used actual agency operations data to develop models and estimate costs and benefits derived from employing ITS for the Bus Transit Management Systems for Portland, Oregon. The evaluated ITS technologies include traffic signal priority systems for the city's tri-modal system which includes transit and light rail and para-transit services.

Additionally, planners used the ITS Deployment Analysis System (IDAS) to perform sketch planning analysis of ITS deployments. The analysis capabilities of IDAS will include: a processor to translate planning data and model results; an alternatives generator in which a graphical user interface can be used to deploy alternative projects; a benefits module to estimate benefits; a cost module to calculate costs; and, an alternative comparison module to perform benefit/cost results and sensitivity and risk analyses (85, 86, 87, 88 and 89). Yung et al (90) discussed the limitations of benefit–cost analyses of ITS that yielded mere point estimates of the benefit–cost ratios of ITS deployments and did not provide decision makers a comprehensive assessment of the true value of ITS. Kristof (91) analyzed benefits of ATIS projects through field studies, simulation software, and surveys and quantified benefits in vehicle miles traveled (VMT), vehicle hours traveled (VHT), volume-capacity (v/c) ratios, and vehicle speeds throughout a given network.

Florida Department of Transportation (FDOT) (92, 93, and 94) undertook a major task of developing planning scenarios to assess the utilities associated with ITS technologies in the Tampa Bay area. This research project investigated the quantitative benefits of ITS deployment through cost-benefit analysis of deploying programmed ITS technologies from the year 2004 through the year 2012 in the Tampa Bay region using IDAS. The Tampa Bay network showed an estimated $7.6 million in travel-time reliability benefits, and $78 million in user mobility benefits. Together these account for 48% of total benefits. A significant reduction in the impact on the environment was evident through reduced levels of gas emission and fuel consumption. Fuel consumption was reduced by a total of 102,681 gallons/day, amounting to $68 million in benefits annually, about 38% of total benefits. The outcome of this research provided valuable guidance to the FDOT ITS deployment program by demonstrating the benefits of ITS through comparative analysis of various ITS alternatives.

Choi et al (95) in their research employed IDAS and developed B/C ratio as a measure of effectiveness and validated that three to five kilometers is the most useful distance between DMS. Yun et al (96) conducted an online survey among metropolitan planning organization (MPO) staff in the U.S. and carried out case studies to examine the benefits of deploying several popular ITS options. This study concluded that the usage of the IDAS program was somewhat limited among MPOs. McHale et al (97) developed an improved method to assess the travel time impacts associated with emergency vehicle traffic signal priority systems. Emergency vehicle traffic signal priority systems allow emergency vehicles, such as fire and emergency medical vehicles, to request and receive a green traffic signal indication when approaching an intersection. While such systems have been in existence for a number of years, there is a limited understanding of the costs and benefits of these deployed systems. McGovern (98) documents an investigation of an ITS framework for congestion pricing and an analysis of the associated DMS and ITS benefits for congestion pricing performed using ITS Deployment Analysis System (IDAS).

2.7 ITS Evaluation Criteria

In this section, the review focuses on research studies that project effective evaluation criteria used to determine DMS effectiveness. The review emphasis is on operations strategies and their assessment criteria that were used as surrogate measures to determine DMS effectiveness. FHWA (10) conducted an evaluation of ITS elements including DMS and HAR and included several operational variables including: reduction of crashes, reduction of fatalities, increased throughput – people and goods, reduction of congestion-related delays, improved customer satisfaction, savings in cost to the public and private sectors and energy and emissions impacts. In another study, decrease in mainline delay, decrease in variability of delay, and their relation to congestion durations were explored for the I-205 corridor in Portland, Oregon, by Monsere et al (99). Lack of ramp demand data and relational data were cited as gaps and limitations of the evaluation framework. Similarly, the City of Espanola, New Mexico Traffic Management System evaluation by Magno et al (100) confirmed the improvements to traffic flow. The evaluation parameters included safety improvements and reduction in congestion. Further, the ITS evaluation indicated that due to efficient ITS services, the immediate need for building a relief/alternate corridor was mitigated. The ITS system evaluation confirmed reduction in crashes, congestion hours, delays variability, and increase in arterial and throughway input.

Van Der Zijpp et al (101) evaluated effectiveness of DMS on the Amsterdam Orbital Motorway and identified that DMS were instrumental in achieving travel time savings and reduced the variability in travel times. The research used changes in level and variability in travel time as the principal measures to determine DMS effectiveness. The research explored the relationship between messages disseminated on DMS with the congestion levels and with the travel times experienced in the corridor or network of corridors.

Collura and Fisher (102) used driver simulated analyses methods to evaluate the effectiveness of DMS in providing real time traveler information on delays ahead, alternate routes, etc. with specific attention to the impacts on aged drivers. The study focused on parameters such as the length of delay versus the diversion rates, effect of driver familiarity and the messages, effect of pre-trip information versus en-route information, and effect of age. The study concluded that the longer the delays, the higher the diversion rates, no effect of driver familiarity, and the older the driver age, the greater the diversion rate; also pre-trip information was more effective for younger drivers versus the older group.

A final report on a USDOT sponsored research on Computer Aided Dispatch (CAD) and Traffic management center operations were completed by Owens et al (103). The focus of this report was to evaluate effectiveness of CAD-TMC integration. The report concludes that CAD remains one of the effective complementing operations to successful incident and event management operations.

2.8 ITS Analytical Methods

In several of the research studies cited in the earlier sections, the research methods predominantly established operations regimes for ‘before and after’ DMS deployments or ‘with and without’ DMS conditions and scenarios, used base statistical methods and carried out analyses of variance studies to test hypotheses for several operations strategies and finally established DMS measures of effectiveness.

Limited research studies have expanded on these basic approaches and developed advanced analytical methods to determine DMS effectiveness. In this remainder of the section a review of research studies pertinent to three distinct analytical methods employed to carry out DMS evaluation research is presented. The three analytical methods as identified in this literature review and discussed here include: a) Probit, Logistic and Basic Regression Models, b) Qualitative, Utility Based Planning Models, and c) Simulation Models based ‘Before and After Studies.’

2.8.1 Probit, Logistic and Basic Regression Models

Regression models are widely used to quantify operations benefits and primarily consist of a response or dependent variable which is a function of one or more explanatory variables. For DMS and ITS evaluations, researchers have developed and applied alternate methods such as logistic regression methods to determine DMS and ITS effectiveness by considering the dependent variable as discrete and discontinuous variable assuming a binary value (0/1). This enabled the researchers to model the probability of occurrence of specific operations evaluation criteria that in turn enabled the researcher to quantify the effectiveness of DMS and other ITS elements operations.

Sinha et al (21) used binary logistic regression models to evaluate the safety impacts resulting from DMS and other ITS applications on the Borman expressway in Indiana. The authors' research of safety data for the Borman expressway indicated that 35% of all the crashes that occurred could be classified as secondary crashes. The research objective was to develop a methodology to test the hypothesis that secondary crashes may take place as a direct or indirect result of primary incidents and explore and establish models to predict the likelihood of a primary incident being followed by a secondary crash and quantify the potential role of DMS and other ITS technologies in reducing the likelihood of secondary crashes. The crash database was evaluated and explanatory variables associated with primary crashes that do and do not result in a secondary crash were demarcated as Code 1 and Code 0 respectively.

Dummy variables were used to cover seasonal variations and account for the day of the week. The model was designed to predict the probability of the secondary crashes based on the explanatory variables. One such explanatory variable used was incident clearance and the authors established that for an increase of 10-minute clearance time for a given primary crash, a corresponding increase of 28 % probability of secondary crash occurrence was determined. The models provided several additional detailed application assessments in terms of odds ratios for DMS, CCTV and Safety Service Patrol. These relate to the decrease or increase in clearance times of primary crashes that in turn were used to determine the corresponding likelihood occurrence values for secondary crash rates.

Peta et al (104) developed binary logit models to establish the relationship between the content of DMS messages and VMS effectiveness with the route choices of drivers and diversion rates. The authors collected and reduced the user survey data to determine DMS effectiveness by quantifying two distinct outcomes: if the messages posted on real time situations were effective to induce the trip diversion, and if these in turn resulted in better congestion management and corridor operations. The binary case of divert or not divert lead the authors to use a binary logit model to predict the probability of a user diverting under a DMS message that displayed real time message related to incidents and road way traffic conditions. The authors used Likert’s Scale to rank and process the survey data and reduced the survey data to 0 or 1 case with 0 indicating low degree of willingness to divert and 1 indicating a strong willingness to divert based on the messages disseminated on the DMS. A Likert scale is a psychometric scale commonly used in questionnaires, and is the most widely used scale in survey research, such that the term is often used interchangeably with rating scale even though the two are not synonymous. When responding to a Likert questionnaire item, respondents specify their level of agreement to a statement. The analysis results were conclusive and identified that there are other factors that induce trip diversions such as socioeconomic characteristics, network spatial knowledge, and confidence in the displayed information. Results also indicate differences in the response attitudes of semitrailer truck drivers compared to other travelers. These analyses provide substantive insights for the design and operation of DMS-based information systems.

Similar logit regression models were developed by Hounsel and Chatterjee et al (67) for the City of London. The authors, in this study reduced the user survey data on the willingness to divert resulting from the DMS messages, and developed similar binary logit models and determined DMS effectiveness. The authors analyzed the user response data and modeled the probability of diversion based on the route characteristics and DMS messages. For all 'yes to divert' responses the authors allocated a value of 1 and 0 for responses that stated 'no to divert'. The authors assumed a binomial distribution and using logit transformation developed a logistic regression model. The model used several independent variables such as location and proximity of incidents to the DMS deployed location, message types and specifics such as mere ‘congestion ahead’ message versus ’30 minutes’ delay messages, driver characteristics such as origin, destination, distance from destination from the time the message on a DMS was made available to the driver etc. The model results demonstrated the role and significance of the causal variables used and the corresponding probabilities to divert or not divert in turn were used to determine DMS effectiveness. The authors concluded that the analytical logistic model using the DMS messages and incident characteristics was effective and recommended further research to develop more detailed analytical methods using real time operations data and using traffic assignment models from the planning modeling methods.

Huo et al (47) used empirical data from inductive loop detectors and developed Probit models to determine the effectiveness of DMS for the twin cities of St Paul and Minneapolis. This study used empirical traffic flow and occupancy data on both mainline and ramps that were collected every 30 seconds to estimate the effectiveness of DMS. The variation of diversion rate before and after DMS messages was statistically tested. The authors developed a weighted Probit modeling method, and based on the DMS messages data, estimated the diversions caused by the DMS messages. From the loop detector data, for a 5 minute interval, for a flow ‘n’, the diverted vehicles y_i was recorded as success. The proportion of the diverted vehicles to the flow was modeled against the selected explanatory independent variables. The authors used user response survey data and performed detailed statistical analysis on the variation of diversion rate with and without DMS to determine DMS effectiveness using measures such as the travel time saving, safety improvement and diversion rates. The authors used statistical software to estimate the Probit choice model and the proportion of diversions at exits downstream of the DMS were determined. The coefficients for causal variables were evaluated to determine the influence of each of the causal variables (the categorical variables and dummy variables) on the diversions. Further, the authors used the t-test to test the null hypothesis that the means of diversion rate in two populations, i.e., all the vehicles in 10 minutes before and after the message, are equal. The result of the statistical analysis confirmed that the DMS are effective and increase drivers' diversion rate significantly by providing warning messages about the traffic conditions on the road. The study concluded that the Probit choice model is successful and provides a reasonable estimation of motorists' response to messages with different characteristics. The model developed was further applied to different scenarios and results were documented.

Kraan et al (105) evaluated seven new DMS around Amsterdam using regression analyses. The impact of real time messages on queue lengths, travel times and route choices resulting from these two message types were analyzed. The study showed DMS were effective in causing reduction in congestion levels and overall improvement in the corridor. The stable congestion hours in turn improved travel time reliability.

Levinson et al (22) used regression analysis models to evaluate long-run traffic management system performance of DMS and other ITS elements including, Ramp Metering System, Highway Helper Program, and High Occupancy Vehicle (HOV) System for the Minnesota DOT ITS system. The link speed and incident rates were used as causal variables. These two variables were assumed to serve as surrogate variables to measure the effectiveness of DMS and other ITS elements in addressing delay, capacity management, travel time savings, etc. The regression analyses were summarized and the limitations of the use of regression models were presented. The DMS effectiveness on traffic conditions was evaluated and conclusions indicate that DMS were effective in containing the speed variability during congestion hours and alleviated congestion impacts.

Baublys et al (106) evaluated statistical methods to evaluate DMS and other ITS elements and identified and evaluated the feasibility of applying several models including, a) Bayesian analysis; b) normal distribution; c) logarithmic-normal; d) non-parametric distribution; and e) Weibull distribution. For all these cases, algorithms for accumulating minimum statistical data were discussed and evaluation of their merits was presented. The author discussed that relational data base on the transportation system was essential to conduct non- parametric assessment and further opined that a non-parametric assessment of distribution density had higher computational efficiencies and were prone to be less sensitive to data errors.

2.8.2 Qualitative Planning and Utility Models

Wang et al (43) developed the Multi-Attribute Utility Theory (MAUT) that involved computed utilities for the ITS alternatives by assigning weights to the ITS operations goals that reflected the relative importance of the ITS alternatives. Using the standard ITS market packages provided by National ITS Architecture, the authors established a set of measures to evaluate the outcomes of the application of these market packages by assigning a set of relative importance in the form of weights and developed an additive utility function. Sensitivity analyses were performed to ensure that the allocation of weights tally with the relative importance of the application of the respective ITS strategies. DMS, one of the market packages analyzed in this study, received a utility value of 0.334 while the regional traffic control market package received the highest utility value of 0.886, and transit maintenance received a lowest utility value of 0.033.

Lee et al (48) evaluated the quality of DMS service perceived by an individual driver with the concept of Satay's Analytical Hierarchy Process methods and fuzzy weighted averages. The analysis used six DMS evaluation criteria which include visibility, legibility, and comprehensibility of message displayed accuracy of information, usefulness of information, and correspondence between information displayed and that expected by the driver. The survey was conducted with 42 subjects who were licensed drivers with some highway driving experience. Saaty's eigenvector method was used to develop the Fuzzy weights. Using Satay's methods, the relative importance of each criterion to the others was measured. The scales representing the relative importance of criteria were expressed by the reciprocal matrix form, called the pair-wise comparison matrix and by matrix mathematical manipulations the weighted rankings of each of the six criteria were determined. The authors determined 55.4% as the degree of satisfaction with VMS service as perceived by a group of participating drivers taking into consideration the variance of human perception and the degree of importance of the six criteria.

For the City of Düsseldorf (18) and the State of North Rhine Westphalia (NRW) the study used relational database and determined the extent to which individual incidents result in a DMS activation, as well as the extent to which the activation is blocked by a parallel incident on an alternative route. They determined the effectiveness of DMS using the planning models and the assignment results, based on a daily traffic-based OD matrix by the traffic planning model, were obtained. In order to determine a rerouting potential that is as realistic as possible at the time of an incident, different time periods characterizing the traffic situations were identified using a uniform traffic demand pattern.

For 19 DMS locations at major critical diversion locations, the volume of traffic that can be rerouted, the relevant incidents and the expected number of activations of the alternative route guidance system and the resulting time gains for travelers were estimated.

2.8.3 Simulation Models Based on Before and After Studies

Shah and Wunderlich (16) developed a mesoscopic model using INTEGRATION Version 2.0 simulation model to determine the effectiveness of DMS and ITS for the 2-hour PM peak period for scenarios with ITS, without ITS, and with potential variants of the existing ITS system for city of Detroit, Michigan. The simulation models were run for average traffic conditions (with no incidents and events) and for scenarios with and with-out DMS and other ITS elements. Data indicated that the presence of DMS and ITS elements did not yield any significant benefits and had no discernable changes in traffic flow conditions. The authors further confirmed that the simulation runs for event scenarios, delays between the No ITS and Existing ITS event scenarios were significantly different and an aggregate 320 vehicle hour reduction in delay was observed during peak PM hours.

Sinha et al (21) integrated DYNASMART and the time of day travel choice model and determined DMS and ITS effectiveness for the Borman Expressway in Indiana. The effectiveness of 18 DMS were evaluated for scenarios including: a) DMS providing downstream traffic conditions and information on alternate routes, b) the initial paths the users take were the same as in the base case, c) certain fraction of users who travel on the link on which DMS is located will be willing to divert to alternate routes if there exists a better path than the current one (myopic switching), and d) six different values were considered for the percentage of users willing to divert because of DMS. The values were 0%, 20%, 40%, 60%, 80%, and 100%. The study results indicated that the DMS were effective and the average travel time decreased on Borman expressway. Another significant conclusion was that alternate route diversions were found to occur only when DMS were in operations. Based on the model runs, the authors attributed additional measures such reduction in vehicle emissions during congestion hours, travel time and delay reductions during incidents and lane closures, to effective use of DMS and other ITS elements.

Srinivasan et al (19) used mesoscopic dynamic simulation model, DYNASMART, to investigate DMS effectiveness during non-recurrent congestion traffic conditions. This simulation-based analyses used incident attributes such as number of incidents, their location, time of occurrence; DMS message characteristics such as delay incurred form incidents, message update frequency, message compliance by motorists; and alternative operational strategies such as travel time based diversion rules, strategies accounting for travel time and capacity constraints and DMS coverage or zones of influence over the corridor and network in consideration. The authors built experimental designs depicting real time operations scenarios, with incidents and with alternate route options, and performance measures, such as reliability of messages and their accuracy measures, were established. The simulation model findings showed that the effectiveness of DMS was dependent on message dissemination lag from the time the incident was detected to the message disseminated on DMS, diversion rate to the alternative paths, how well the alternate routes were reported on DMS and the travel time variations between corridors with DMS and without DMS.

2.9 Literature Review Findings

This literature review research effort provides a comprehensive account of several key research applications that were developed and are currently in use to evaluate DMS operations and determine their operational effectiveness. The review also presents the current trends in DMS operations and their expanding role to support a variety of operations strategies including managing and mitigating recurring and non-recurring congestion, work zone operations, weather response and management, special events and in advanced operations such as Active Traffic Management. The evaluation criterion used to assess DMS is described and where feasible, an objective discussion on the evaluation and analytical methods that are currently in use is also presented. The literature review offered several critical insights related to: the DMS evaluation frameworks, modeling and analytical methods employed, validation and calibration limitations, the complexities related to scalability and transferability of these analytical and assessment frameworks, the importance of the operations data framework and limitations related to the availability and use of ITS operations data. The salient findings of the review are summarized below.

1. It is evident from the review that DMS operations and applications over the last 50+ years has expanded to include several operations strategies such as incident and event management, congestion

management, provide real time alerts during weather situations and special events, work zone management and play a critical role in the evolving Active Traffic Management strategies.

2. The review of various DMS evaluation studies confirmed the importance of real time field operations data and the ITS device and system operations data to carry out meaningful and accurate DMS and ITS evaluations.
3. With the advent of continuous data on traffic flows, speed, and density, DMS have become primary enroute travel time information providers and continue to play a vital role in congestion management. This is evident from the studies performed in Indiana, Minnesota, Amsterdam, Netherlands, UK, etc.
4. The review demonstrated limitations in the available operations data structures both in granularity and to the extent the data can chronologically and sequentially portray the key phases of incident and event management; incident detection, verification, response, clearance and recovery-restoration. This granularity in operations data is essential to determine the interdependencies amongst the DMS and ITS operational protocols that define the DMS's individual operations effectiveness and as a comprehensive suite of ITS operations infrastructure to successfully deliver the DMS operations strategies. Studies carried out in Minnesota (5) and Texas (46) and

several other research efforts cited in this report confirm this observation.

5. DMS evaluations carried out in Indiana (21), New Jersey (3), and New York (4) have competently used operations data on traffic flow, speed, crash data and travel time and delay as surrogate measures to define the effectiveness of DMS. The same approach was evident with variations in many of the studies in this review synthesis. Edwards and Young (8) and Sanchez et al (9) have established the framework to carry out DMS evaluation that requires corroborating the real time disseminated DMS messages with the incident and other field operations data to carry out DMS evaluation. The DMS message data is used to assess the user response data collected to assess the DMS effectiveness.
6. The review on DMS evaluations and analytical methods and criteria collectively indicated that the frameworks predominantly gravitate to 'before' and 'after' or 'with' and 'without' DMS scenarios in the traffic streams. This at times warranted significant data collection requirements and in some studies the data gaps lead to inconclusive results.
7. The evaluation methods validation is performed primarily through employing statistical significance tests on data collected from user response surveys. This subjective and qualitative evaluation of operations outcomes may benefit when complemented with

quantitative evaluations using real time DMS and ITS operations data and data from field operations on incident and event management.

8. The interdependencies amongst competing facets of ITS infrastructure elements such as role of CCTV and Detection systems, safety service patrol operations, interdependencies on dispatch and response operations data from other responding entities such as Computer aided dispatch data from 911 and law enforcement etc. and their collective and individual influence on DMS operations and their effectiveness is missing in several of these research studies.
9. Review confirmed a wide use and application of benefits-costs methods to determine the effectiveness of DMS. The benefit-cost methods provide good and conclusive aggregate indicators to define the DMS and other ITS systems performance. However, the results from benefit-cost analyses fall short of providing operations value contributed by DMS such as the DMS messages and their effectiveness (or lack thereof) at the location they were deployed. The message actuations rate tally with the rate at which incidents occur in the corridor, the DMS message actuations' influence during peak hours, their role in rural and urban corridor operations and their ability to support freight mobility by complementing commercial vehicle operations etc. are also inconclusive.

10. The analytical methods exercised in the reviewed research studies in this review report reveal that the DMS evaluations are more accurately modeled when the variability in DMS performance is quantitatively determined by treating the dependent variables as discontinuous variable and through non-linear transformation of causal or explanatory variables.

2.10 Literature Review Conclusions and Research Extensions

The DMS evaluations research works cited in this review offer prominent insights to further the research scope. They refine and build future DMS analytical and evaluation frameworks to determine DMS effectiveness by using real time DMS operations data, DMS messages data, and other ITS operations data in conjunction with field operations data on incident detection, verification, response, recovery and restoration.

2.10.1 Conclusions

Following are the conclusions from this literature review:

- Granular ‘field operations data’ on DMS and ITS operations is necessary for determining the true operational value of DMS deployments;
- Granular ‘field operations data’ on verification, response, recovery and restoration phases of incidents management is necessary for determining the true operational value of DMS deployments;

- The analytical methods identified in the literature review can be improved through the use of the granular field operations data on DMS and ITS operations and incident management data;
- The improved analytical methods that use the granular data frameworks need to be transferable such that they are easy to develop and can be easily applied to assess the DMS operations effectiveness; and
- The literature review confirmed the need for established guidance on the development and application of granular data frameworks and analytical methods to evaluate ITS operations.

2.10.2 Research Extensions

The literature review and the above summarized literature review findings and conclusions provided an in depth account of current state of the art of methods that are employed to perform ITS Operation evaluations. The review findings and conclusions formed the basis for continuing this research and the following next-steps will be undertaken to fulfill the research objectives identified in Chapter 1:

- Develop a new methodology for ITS evaluation framework for a Study Corridor to determine ITS and DMS effectiveness. The new ITS evaluation framework will be based on real time DMS and ITS operations data and field operations data;

- A comprehensive data collection, reduction and refinement methodology will be developed and applied to DMS and other ITS operations real time data, and data structuring will be performed for necessary inputs into the new and enhanced ITS Evaluation framework;
- The suitable analytical models to determine DMS effectiveness will be developed, applied, and validated;
- The developed ITS evaluation model application results will be discussed for their effectiveness in carrying out operations strategies for the Study Corridor; and
- The developed models will be assessed for transferability to other corridor applications and for development of real time operations data inputs.

CHAPTER 3: ITS OPERATIONS IN TRANSPORTATION AGENCIES A STATE OF PLAY

3.1 Introduction

Intelligent Transportation Systems (ITS) have enabled transportation system operations and management agencies to address a myriad of operational challenges resulting from recurring and non-recurring congestion events that plague and choke transportation corridors. At the same time, transportation system users have become increasingly dependent on the many efficiencies and services rendered by ITS. The advent of ITS services, such as Dynamic Message Signs (DMS), 511 and Highway Advisory Radios as Advanced Traveler Information Systems, and a host of in-vehicle navigation systems such as Tom-Tom, GPS-based devices including Garmin, web based trip planners etc. have enabled the user to reap immense benefits from getting state of the art updates on transportation systems' reliability and availability to realize their respective mobility needs.

To match this enormously growing customer focus and to meet and manage customer expectations and to effectively address recurring and non-recurring congestion issues, the transportation system providers and operators have effectively mainstreamed ITS into regular system operations best practices and established a suit of innovative and state of the art ITS operation strategies that include Active Demand Traffic Management (ADTM), Integrated Corridor Management (ICM) programs, High Occupancy Vehicle and Tolling Lanes Operations, Integrated Road Weather Information Systems, Connected vehicle Programs, Advanced Public Transportation Information Systems, Advanced Parking Management Systems, and Integrated Tolling and Variable Pricing programs.

In this chapter, an attempt is made to present a 'state of play' of ITS planning and operations that take place at transportation agencies through a sequential presentation of policy, strategic, and technical interdependencies that define the universe of ITS deployment operations. The objective of this chapter is to help make the connection with this research's context and elucidate the limitations that shape this research scope and the foundational underpinnings that lead to the development of ITS Operations Evaluation Models (ITSOEM).

3.2 Transforming Transportation Agencies into 24x7 Operations Using ITS

Transportation agencies have begun embracing ITS to meet the operations challenges and needs in a dynamic, new, 21st-century context, with a changing landscape of increasing population, vehicle travel, and resource limitations. This increase in overall travel demand has led to longer durations of recurring and non-recurring peak congestion on transportation corridors. Given these constraints, it is apparent that fulfilling a transportation agency's central transportation goals of mobility, safety, and security must, in the future, be substantially based on maximizing the effectiveness of the existing highway network. This requires aggressive and consistent operation and management in real time, utilizing best-practice combinations of management and operations strategies. These strategies include incident, emergency, and weather management; freeway and arterial operations; work zone traffic control; traveler information; active traffic management; as well as emerging approaches, such as vehicle-infrastructure integration. Following are the foundational ITS operations systems that are generally found to be in play nationwide in USA:

- Freeway Management Systems – These systems include field devices used to detect incidents and provide traffic information and include ITS detection, and Dynamic Message Signs.
- Highway Advisory Radio, 511 Telephone and Web Site Service.
- Road Weather Information Systems which include Environmental Sensor Stations, and Automated Vehicle Location systems for winter maintenance vehicles.
- Safety Service Patrols – These include the regular safety service patrols operating 24 x 7 shifts.
- Safety Service Patrol Emergency Services – These include the emergency on-call service provided to support stranded motorists and to clear the disabled vehicles off the roadways to a safer locations.

- Transportation Operations Centers – TOCs support virtually all other categories of ITS service but do not provide benefits by themselves.

3.3 Developing Intelligent Transportation System (ITS) Programs and Projects

Transportation agencies have undertaken several efforts to mainstream ITS operations into the agency's core business functions. Several agencies have incorporated ITS into transportation planning and programming processes that are critical in providing policy, budgetary and programming recognitions for ITS program creation and sustenance. Following is a brief description of some of the critical steps that helped shape the formation of ITS as one of transportation agency's core business functions.

3.3.1 Emergency Response Operations - ITS Deployment and Operations

Historically, severe natural and manmade catastrophic events such as hurricanes, snow storms, earthquakes, security threats to transportation critical infrastructure and lives of transportation users, have significantly impacted the flow of traffic at a regional scale and these challenging events propelled agencies to develop Emergency Response Plans that are studded with state of the art ITS and technology applications. These events lead the transportation agencies to focus attention on how important the highway system is for the lives of system users and emphasize that emergency response is one of the most important responsibilities for the Transportation agencies. Debriefing of such major incidents and events helped transportation agencies realize that ITS, when deployed at appropriate locations on transportation corridors and on critical infrastructures such a tunnels, bridges and ferry systems, will enable transportation agencies to perform to full capacity through providing and sharing real time situational awareness on roadway conditions and transportation operations.

Furthermore, ITS demonstrated that it can provide a framework for seamless sharing of data, video and voice information in real time on incident management as they unfold at actual incident locations on transportation corridors to the transportation agency incident management teams and to other participating first responding agencies such as law enforcement, fire and emergency medical services. Resultantly, several ITS field devices such as Roadway Weather Information Systems (RWIS), and Dynamic Message Signs (DMS), Closed Circuit Television cameras (CCTV), Safety Service Patrols and a host of other ITS devices were successfully deployed to support emergency response operations. To complement the emergency response operations, and to support ITS field devices operations, a communication back bone such as fiber optic cable network that is capable to haul high resolution video, voice and meta data from scene of the incident locations to a 24 x 7 operating command center, usually known as Transportation Operations Center, is constructed. Additionally, information dissemination on emergency response operations to the public has been improved through the adoption of new “push” technology, including 511 information dissemination systems and other mediums to target emergency communications to desktop computers, cell phones, PDAs, and mobile devices.

3.3.2 ITS Deployment Planning, Programming and Budgeting

Transportation agencies have developed long-range ITS plans to identify ITS needs to support regional mobility needs and to address recurring and non-recurring congestion challenges. The focus is on the selection of suitable ITS devices and technology upgrades to keep up with the changing trends, functional and strategic capabilities that ITSs are expected to deliver in a sustainable manner. For this purpose, the ITS Architecture is used as the basis to achieve standardization, consistency, and accountability in the development and deployment of ITS across the agencies' transportation network to achieve functional interoperability amongst several ITS applications. The ITS Long Range Plans focus on the systems requirements to support the development and use of travel time and incident management response as the key performance measures – both for internal investment decisions and to provide an external basis for accountability. In addition, travel time information is used to enhance existing and new traveler information systems. The technologies and initiatives covered in the ITS long range plan form the technical basis of an efficient and cost-effective deployment framework that will make the ITS deployments compatible, interoperable and strive to achieve the following key functionalities:

- Standardize definition of Incident Duration;
- Standardize definition for Reference Location;

- Standardize definition for Travel Time;
- Develop Inter-Regional Data-Exchange;
- Enhance Data Archiving;
- Develop existing Travel Time sources;
- Evaluate Travel Time sources;
- Develop Travel Time clearinghouse;
- Integrate Travel Time into 511;
- Develop Media Portal;
- Conduct periodic ITS Device and Operations Utility Studies;
- Coordinate ITS Applications for Transit;
- Coordinate ITS Applications for Freight;
- Coordinate ITS Applications for Security and Safety; and
- Coordinate ITS for Automated Enforcement.

3.3.3 Role of ITS in Transportation Critical Infrastructure Operations

Transportation Agencies have identified tunnels, ferry operations, long spanning bridges, and other braided system to systems multimodal transfer points and interchange ramp junctions as Special Critical Infrastructure Facilities. The Special Facilities, by nature, provide unique and challenging safety problems. Achieving a high level of safety for these facilities requires an expert understanding of system safety, including the regulatory environment, agency goals and objectives, and industry best practices. Furthermore, the special facilities are considered part of the critical infrastructure and as such they come under the Transportation Infrastructure Protection and Support Section whose remit is to enhance and align security services throughout the Agency's Districts and Regions, and manage programs to protect transportation infrastructure in accordance with the State Homeland Security Agency and the Transportation Sector Specific Plan of the National Infrastructure Protection Plan (NIPP). In addition, these facilities are subject to regulatory requirements such as the National Fire Protection Association NFPA 502: Standard for Road Tunnels, Bridges, and Other Limited Access Highways.

The Special Facilities provide essential links in the State's transportation network and as such their operations need to be integrated into the statewide view. They are complex systems and subsystems that require specialized expertise and are unique to each facility. These Facilities run as independent elements and operate somewhat separate to the rest of the network. Cost of operating these Facilities is very large as compared to other facilities in the network.

The ITS deployments and operations should consider the elements of a detailed safety and security program, specific to these Critical Facilities, which not only meet agency safety goals and objectives, but also utilize industry best practices from all modes of transportation, defense, shipping, energy and environment. To account for the afore described security, safety and critical infrastructure operations requirements, the transportation agencies have initiated employment of ITS operations to achieve, at a minimum, the following efficiencies from ITS deployments at transportation critical infrastructures:

- ITS deployments that support incident management and clearance that are customized to tunnel, bridge and ferry operations and at the same time align with the abutting highway networks' ITS operations in an integrated manner;
- Incorporate real-time special facilities operations data into over all ITS Traveler Information program for multi modal facilities;
- Provide uniform approach, from transportation agency wide perspective, to managing and operating the facilities while allowing for facility specific requirements and provide for uniformity in signs and instrumentation;
- Integrate with transportation agency Traffic Operations Centers (TOC);
- TOC to serve as backup operations (Continuity of Operations Protocols – COOPS) for the facilities in the respective region;
- Comply with state, federal and local requirements for statewide interoperability emergency requirements to share video, voice and data on situational awareness, incidents, events and emergency operations;
- Use of ITS to monitor traffic flows for evacuation and for a uniform and consistent traveler information dissemination protocol; and

- Conform to National Fire Protection Association NFPA 502: Standard for Road Tunnels, Bridges, and Other Limited Access Highways – ITS equipped submerged pumps to detect flooding in tunnels, smoke and fire detection, smart CCTV applications in tunnels and bridge abutments, fog and icing detection systems on bridges, and real time surveillance on ferry transpiration systems.

3.4 Mainstreaming ITS into Transportation Systems Operations

The success of mainstreaming ITS operations into prevalent Transportation Systems Operations is dependent on a variety of aspects. Figure 3.1 shows a schematic overview of inter-connections that are essential to the seamless operation of some of the commonly employed key ITS components.

Effective planning, programming, resource allocation, operational policies and strategies adopted, inter-jurisdictional governance coordination and operations protocols employed, technology limitations, manual and equipment hardware interface limitations and ergonomic demands warranted by ITS operations – all collectively pose a significant bearing on how well ITS operations are carried out.

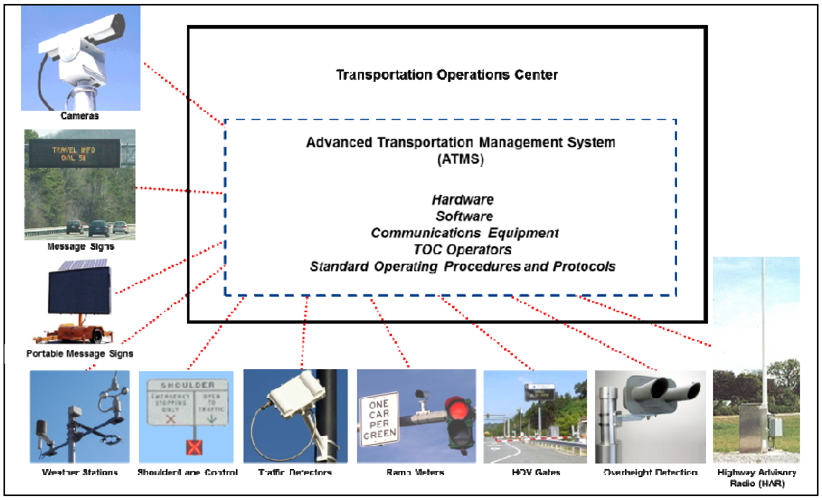


Figure 3.1 ITS Field Devices and Transportation Operations Center

As shown in Figure 3.1, the field ITS devices collectively support a multitude of operations strategies that are critical to the success of each individual ITS subsystem. The functionality of each of these ITS components can be fully realized to their potential only when all necessary hardware, firmware, network communications, and finally the manual interface with operators who man the TOC 24 x 7, is seamless and performed without any interruptions. For example, Closed Circuit Television cameras, widely known as CCTV, provide a seamless 24x7 surveillance and video detection capabilities, and aid in effective management of incidents on transportation corridors. A typical CCTV operation protocol includes transmission of live video feeds of traffic and roadway by CCTV located on transportation corridors to the video monitors housed in the Traffic Operations Centers. The video feeds are transmitted using fiber optic cable (FOC), wireless cell phone modems or via web communication technologies. TOC are manned 24 x 7 by operators who are dedicated and trained to observe, study, and decipher the information from the video feeds and generate responses to the traffic conditions as warranted by the live video feeds. These response actions may include posting of appropriate messages on DMS, inform and dispatch first responders to the incident scene etc. The operations protocols and data architecture as implemented by VDOT (107 and 108) for CCTV and for other ITS elements including DMS, Weather Information Systems, Safety Service Patrol (SSP), and Traffic Operations Center are presented in Figure 3.2. through 3.7.

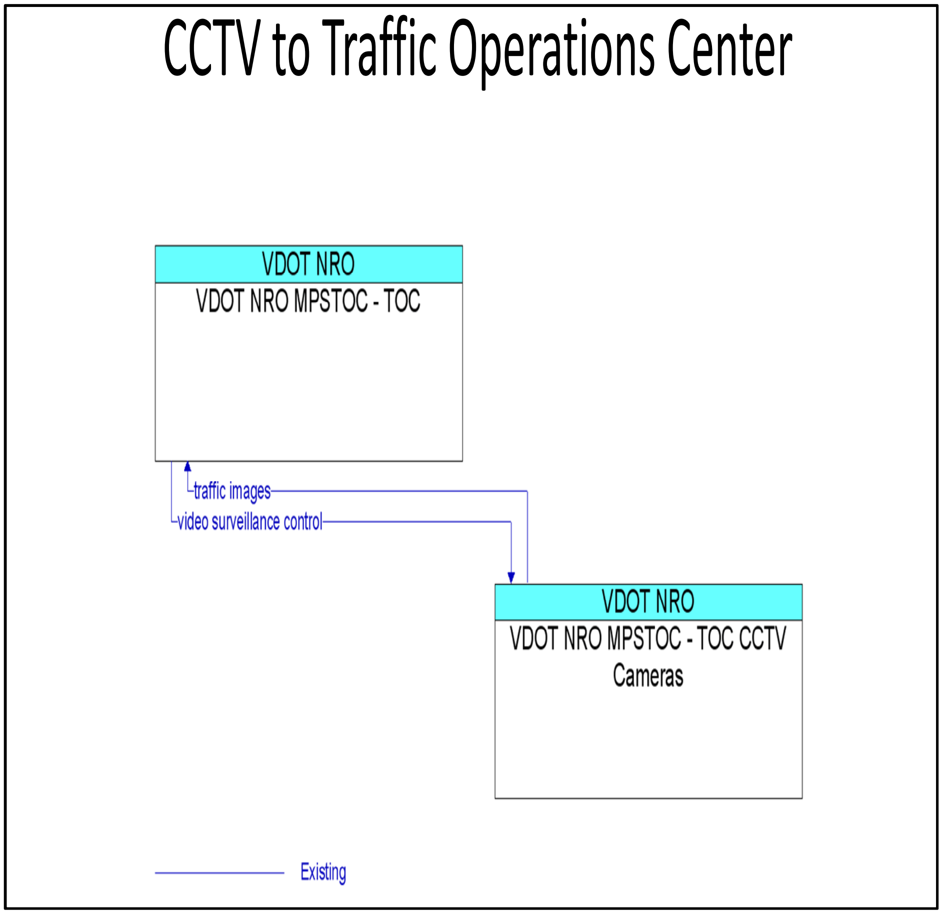


Figure 3.2 CCTV to Traffic Operations Center (TOC) Data Flow Diagram

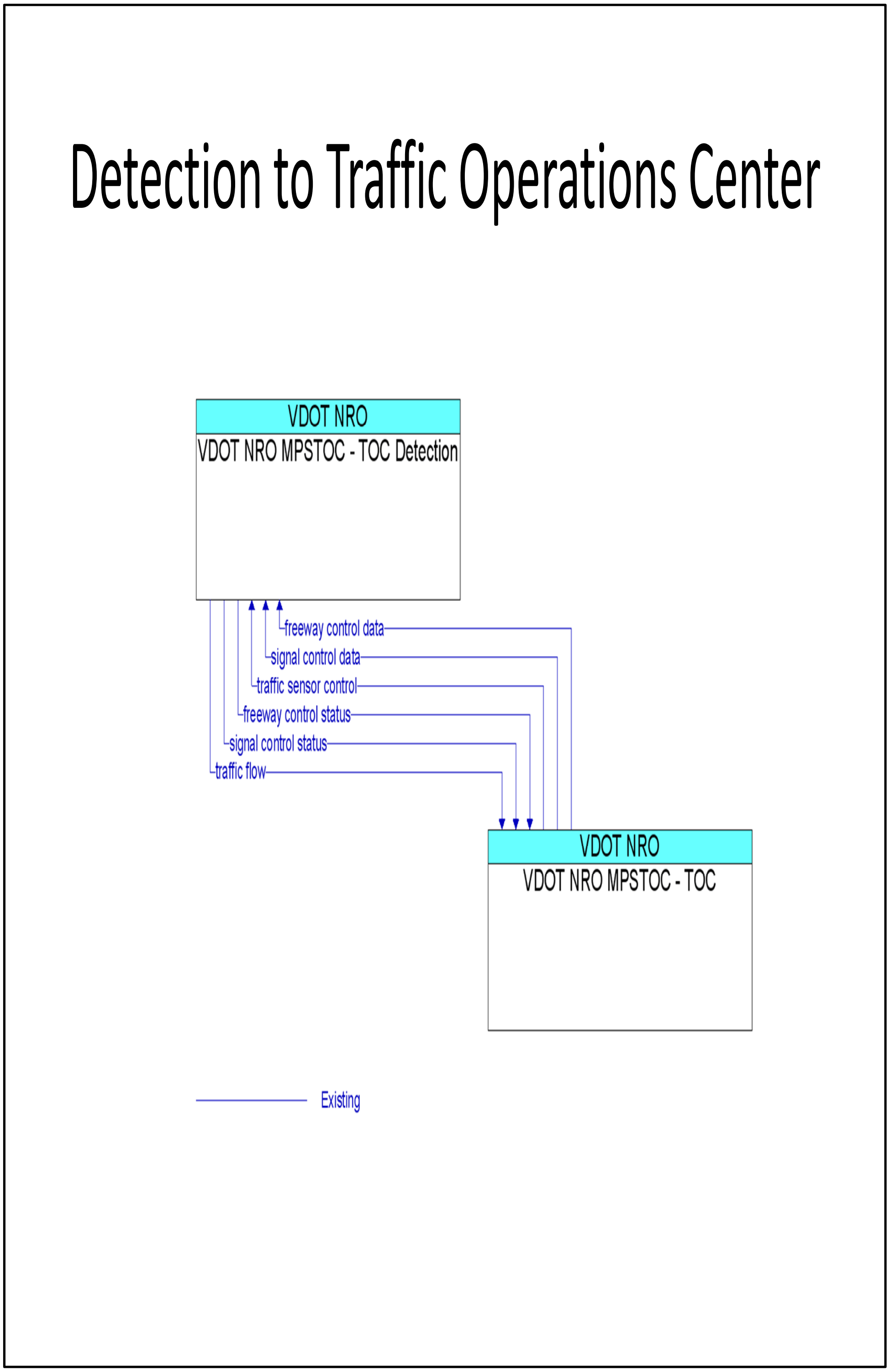


Figure 3.3 Detection Systems to TOC Data Flow Diagram

DMS to Traffic Operations Center

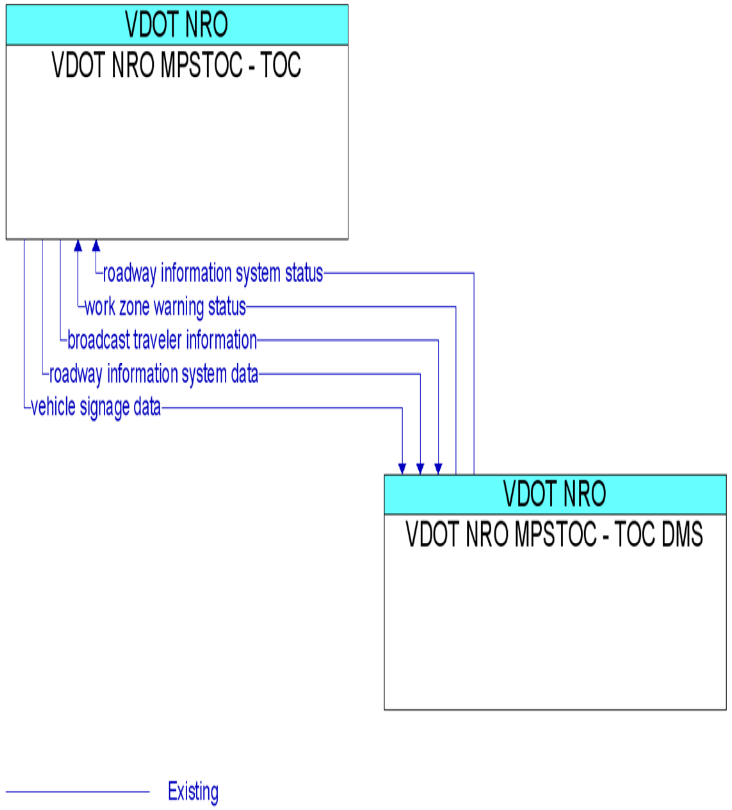
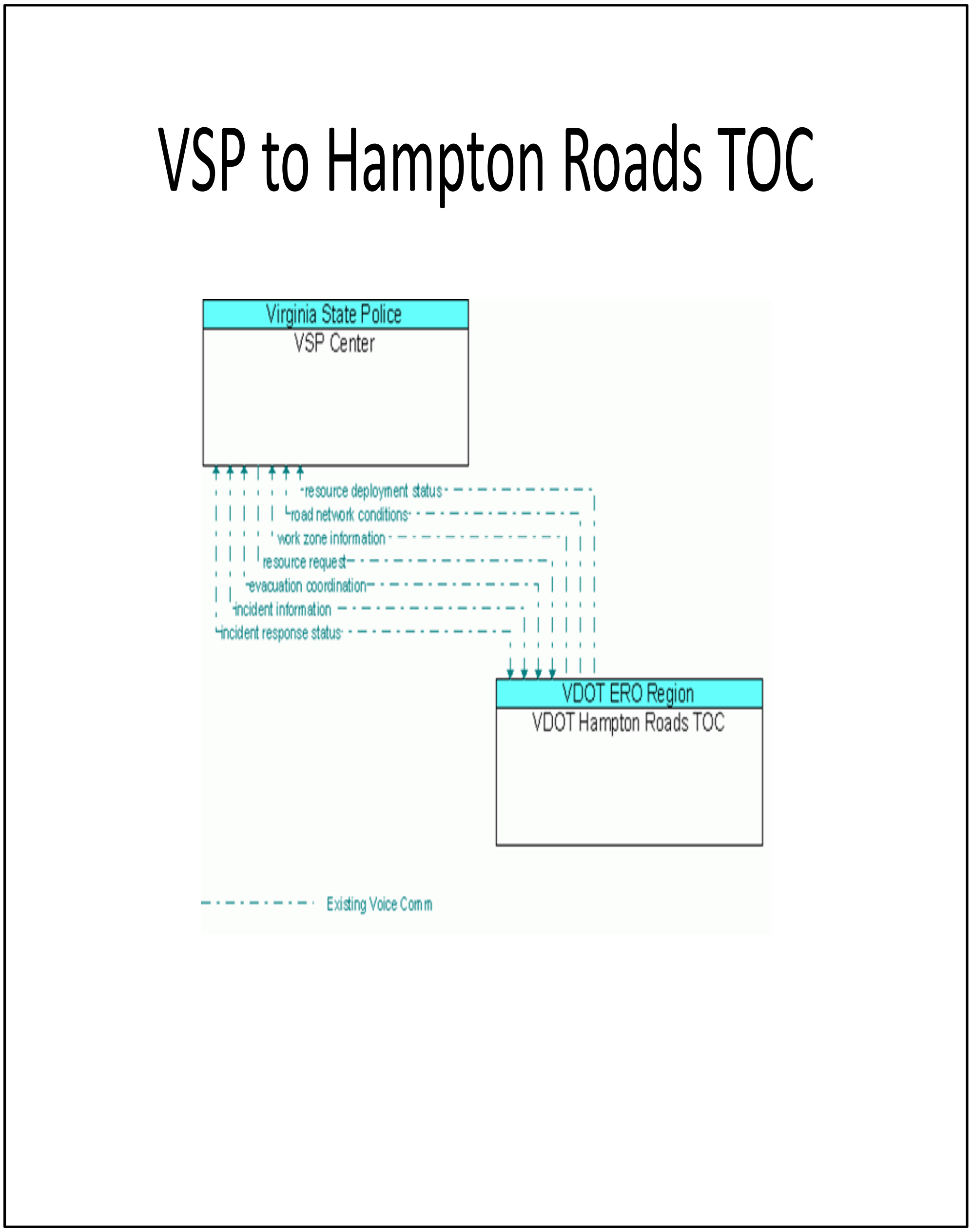
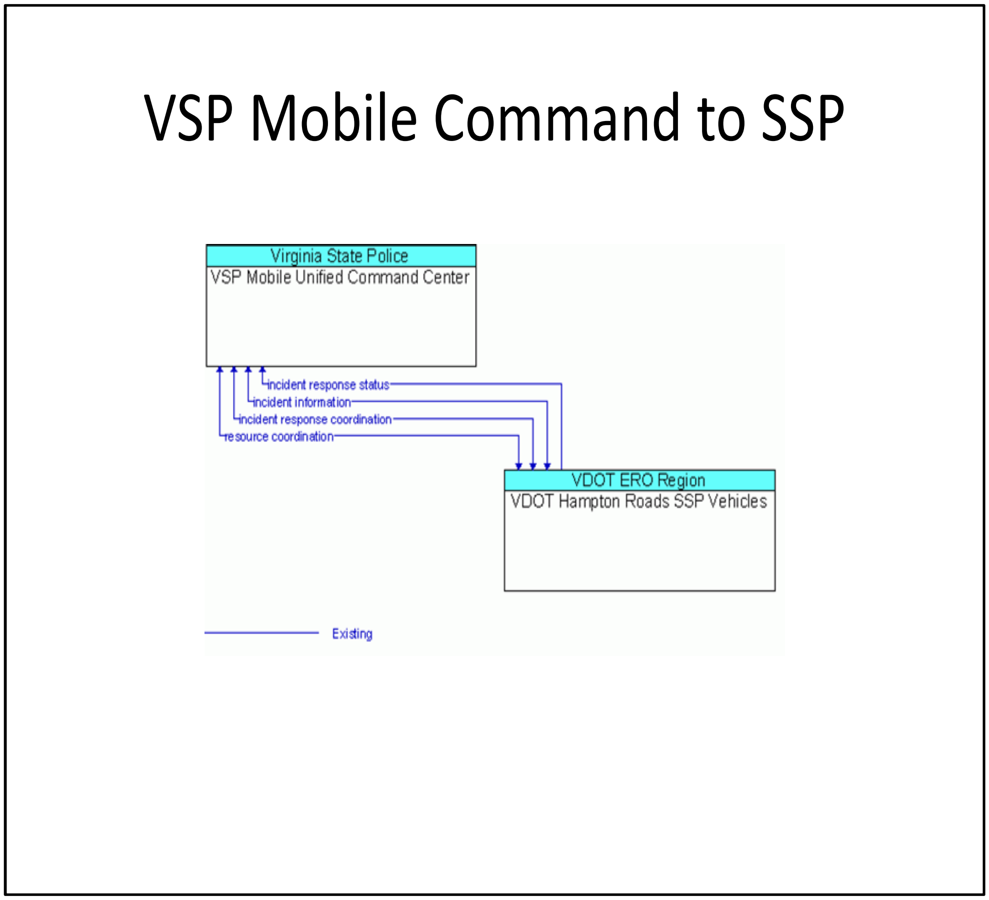


Figure 3.4 DMS to Traffic Operations Center Data Flow Diagram



VSP to Hampton Roads TOC

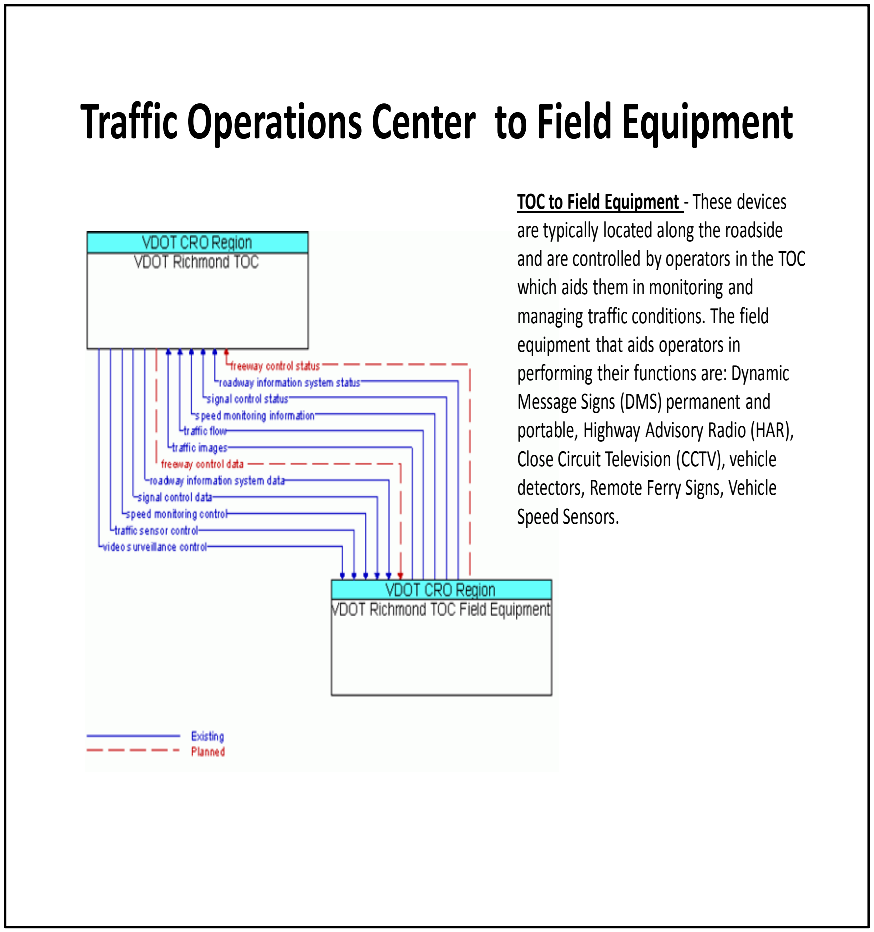
Figure 3.5 VSP to Traffic Operations Center Data Flow Diagram



VSP Mobile Command to SSP

Figure 3.6 VSP Mobile to SSP Data Flow Diagram

A typical TOC is presented in Figure 3.7. The TOC serves as a one-stop-shop for assimilating all the information arriving from ITS subsystems and through hardware, software, and manual interfaces, the actionable incident and event response plans are put into play. Therefore, to perform a comprehensive assessment of ITS operations effectiveness it is essential to have a thorough understanding and prudent consideration of all these interdependencies and independent characteristics that constitute ITS operations.



Traffic Operations Center to Field Equipment

TOC to Field Equipment - These devices are typically located along the roadside and are controlled by operators in the TOC which aids them in monitoring and managing traffic conditions. The field equipment that aids operators in performing their functions are: Dynamic Message Signs (DMS) permanent and portable, Highway Advisory Radio (HAR), Close Circuit Television (CCTV), vehicle detectors, Remote Ferry Signs, Vehicle Speed Sensors.

Figure 3.7 Traffic Operations Center to Field ITS Data Flow Diagram

From these data and operations protocols presented in Figure 3.2 through 3.7, it is evident that all the ITS field systems provide continued situational roadway and roadside information on incidents, impacts from inclement weather, fog and other emergency events, and impacts associated with regular recurring congestion to the Traffic Operations Center (TOC).

3.5 Research Context and Scope Limitations

From the discussions presented in earlier sections it is evident that the task of assessing such prominent and massively used ITS operations is a huge undertaking. However, as identified in the literature review findings as presented in Chapter 2, the pertinence of performing ITS operations assessment is essential and a very much needed research effort. Based on the literature review findings, and based on comprehensive consideration of data architecture, software, hardware, manual and ergonomic challenges and opportunities that govern the ITS operations, the scope of the research work are established with prudent understanding of the following limitations:

- Only key ITS subsystems that are expected to support research objectives identified in Chapter 1 will be evaluated in this research;
- The selected ITS subsystems data, architecture flows, operations protocols and their operations context in providing incident detection, response and clearance functions will be fully evaluated as part of this research effort;
- Influence of system hardware, software, utilities accommodation such as power, earthwork, vegetation management, preventive, diagnostic, major parts replacement and system upgrades, retrofitting design changes and specifications accommodations on ITS operations are not considered as a part of this research scope. These will be assumed as out scope and data imputation methods will be used to eliminate such information from the database that

will be created for developing the ITS Operations Evaluation Models (ITSOEM); and

- The malfunctioning of ITS due to manual errors, system wide errors, misrepresentation of data, inaction from ergonomics factors such as fatigue, lack of performance and other man made and system-caused errors will be treated as out of scope.

These broad guiding principles form the basis of the research effort to develop ITSOEMs. In Chapter 4, a detailed discussion on the selection of Study Corridor, the pertinent ITS subsystems selected for developing ITSOEMs, and the Study Corridor ITS operations involving the selected ITS subsystems and their context in the development of ITSOEM is presented.

CHAPTER 4: STUDY CORRIDOR AND ITS OPERATIONS

4.1 Introduction

I-95 is selected as the Study Corridor for this research due to the importance the corridor has attained from the longstanding technology deployments that the Virginia State DOT has invested in it since 1975. The corridor is actively supported by 20 VDOT Regional Maintenance Area Head Quarters and a well-integrated Virginia State Police administered state of the art Computer Aided Dispatch system (VSPCAD). Additionally, the corridor is supported by a completely modernized 24 x 7 operating Public Safety Traffic Operations Center (called VDOT PSTOC). The PSTOC serves as a seamless, single stop, nucleus nerve center for all operations decision making. It also helps in managing a variety of field ITS operations, snow and ice response operations, incident and event management operations and houses all meta data and archive data bases that form the basis for this research. Amongst other ITS deployments, the corridor is equipped with 50 DMS, 50 CCTV surveillance units, a seamless VSPCAD system, and 36 Safety Service Patrol fleet. The DMSs are operated on the I-95 Study Corridor to support a variety of operational strategies to tackle recurring and non-recurring congestion events which include incident management, work zone operations, weather and other emergency management, variable speed limits, and commercial vehicle operations; and congestion management strategies including travel time and delay monitoring for general purpose and High Occupancy Vehicles (HOV) lane operations, diversion and alternate routing, and the recently initiated High Occupancy Toll lanes (HOT) lanes project which is under construction. This chapter is devoted to: a) an overview of operations features of the I-95 Study Corridor, b) ITS Deployments that are in place to date, their operations and relevance to this research, c) DMS Operations on I-95 and their inter-dependencies, and d) a suite of operations hypotheses that help define and pursue research objectives laid out in Chapter 1 of this dissertation.

4.2 I-95 as the Study Corridor

Interstate 95 (I-95) is a major thoroughfare corridor for the state of Virginia. The north-south I-95 corridor stretches for 179 miles in Virginia beginning with the milepost at the border of Virginia and North Carolina and ending at the Woodrow Wilson Bridge across the Potomac River near Maryland State border. The corridor meets vital mobility needs at regional as well as national levels and serves both freight and passenger transportation sectors.

Generally, the corridor consists of 3 travel lanes each in the northbound and the southbound direction and widens to accommodate 4 lanes upstream and downstream of a major system to system interchange, such as at I-295 in Richmond and at I-495 in Springfield. The I-95 corridor is generally supported by 10-foot shoulder lanes and a wide median. The northern segments of the I-95 corridor heavily caters to the urban commuter needs and serves as a vital connector for the National Capital Region, thus allowing commerce, business and recreation travelers to enter and exit the Washington D.C. region. The northern 14-mile portion of the I-95 Corridor is expanded to accommodate two reversible High Occupancy Lanes.

The 179 mile span of the I-95 corridor in Virginia passes through a range of varied and mixed area types that include completely rural regions, such as Henrico County, and jogs in and out of transitional urban areas, such as Spotsylvania County, and consistently travels through urban regions, such as Prince William and Fairfax Counties (Figure 4.1).

Based on discussions with VDOT operations officials, for this research, the I-95 Corridor from Mile Marker 120 through Mile Marker 179 is deemed as the I-95 Study Corridor, of which the portion of the I-95 corridor from Mile Marker 120 in Spotsylvania County through Mile Marker 155 in Stafford County is considered as “Transitional” segment, and from Mile Marker 155 in Prince William County to 179 in Fair Fax County is considered as “Urban Segment”. Rest of this research focuses primarily on the “Urban” and “Transition” segments of the I-95 Study Corridor.

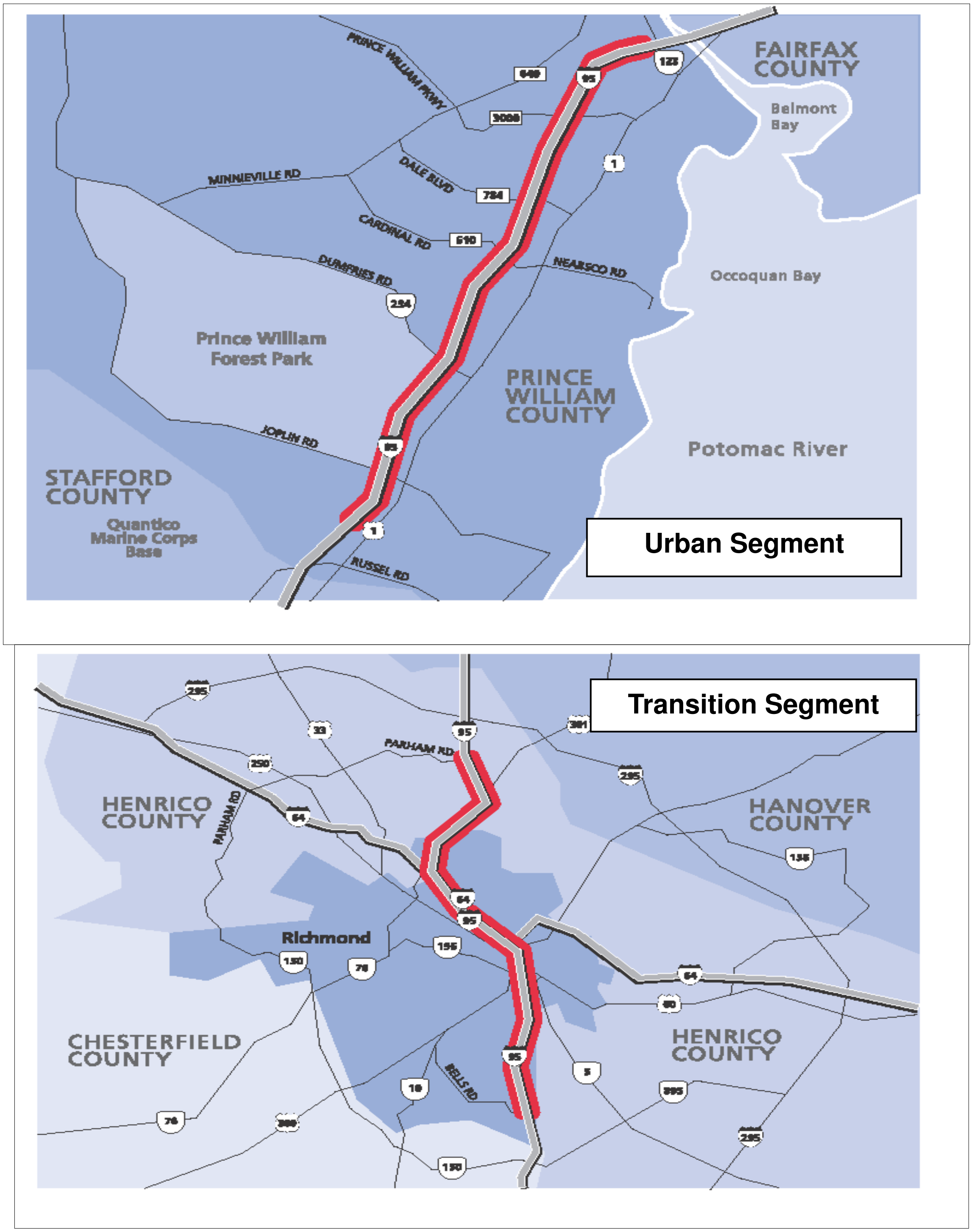


Figure 4.1 I-95 Study Corridor

4.3 Intelligent Transportation System (ITS) on I-95 Study Corridor

VDOT has expended significant resources to deploy ITS infrastructure which include Dynamic Message Signs (DMS), Closed Circuit Television (CCTV), state of the art Safety Service Patrol equipment, and an integrated network of Traffic Operations Centers that are interconnected with Virginia State Police Computer Aided Dispatch system. These four primary ITS components are ably supported by a state of the art relational database, namely “VA (Virginia) Traffic”. Following is a brief description of each of these ITS components and their role in supporting the I-95 Study Corridor operations.

4.3.1 Dynamic Message Signs (DMS)

In Virginia, currently there are 600 DMS statewide of which 50 DMS are deployed and in operation on the north and southbound I-95 Study Corridor segments spanning from Spotsylvania County line to Maryland State border. These DMS on the I-95 Study Corridor, Figure 4.2, provide real time information to the motorists on a variety of activities which include incident management, congestion, work zones, planned events and other specific motorist information events (e.g. Amber Alerts, senior alerts inclement weather, special events etc.).

DMSs play a critical role on this busy corridor and transmit information about prevailing traffic conditions and are considered to influence driver behavior, route choice decisions and enhance overall efficiency of the I-95 corridor. The DMS on the Study Corridor are also extensively used during inclement weather conditions and other emergency situations. By virtue of their placement on the I-95 Corridor, the DMSs provide actionable information (e.g., early warning, delay information, and alternative routing recommendations) to travelers, while supporting emergency response/incident clearance.

Figure 4.2 Dynamic Message Sign

4.3.2 Closed Circuit Television (CCTV)

Approximately 485 cameras are installed and operated on roadways in Virginia of which 25 are located on north and southbound direction segments of the I-95 Study Corridor. CCTV plays a significant role in DMS operations. The CCTVs, Figure 4.3, provide real time status updates on roadway and traffic conditions to the operators in the Traffic Operations Centers who in turn will be able to use the updates and disseminate messages and alerts on roadway conditions to the motorists. The CCTVs enable the TOC operators to carry out video surveillance, monitoring, detection and verification of roadway conditions, and as the roadway conditions warrant, they are able to successfully disseminate messages on DMSs.

Figure 4.3 Closed Circuit Television Camera

4.3.3 Safety Service Patrol (SSP)

Safety Service Patrols travel the I-95 Study Corridor and render assistance to motorists where needed. Assistance may include relocating disabled vehicles off the road, providing gasoline, changing flat tires, or providing minor repairs to allow the motorist to safely drive the vehicle from the highway. The mission of the SSP program is to improve safety and enhance efficient flow of traffic on Virginia’s highway system. It is an essential part of the overall incident management program. VDOT currently employs 26 Safety Service Patrollers in the I-95 Study Corridor. The SSP, Figure 4.4, besides providing basic assistance to the stranded motorist, offer services for all phases of incident management including incident detection, verification, notification, response/clearance, and dissemination of information.

Figure 4.4 Safety Service Patrol

4.3.4 VDOT Advanced Traffic Management System (ATMS) and Traffic Operations Center (TOC)

VDOT Field ITS devices, such as DMS, CCTV and Video Detection Systems, are remotely operated by VDOT's centrally administered Advanced Traffic Management Systems (109) called Open TMS (Traffic Management System – a software operating system built on Open Roads platform developed by a software consulting firm called Open Roads). These Open TMS driver modules are housed in a centralized operations center, namely the VDOT Traffic Operations Center (TOC), Figure 4.5. The TOC operates 24 x 7 and 365 days a year and provides a statewide, coordinated, real-time field and network operations services to VDOT's 57,000 lane miles of roadway network. Using the state of the art VA Traffic and Open TMS platforms, the TOC provides operational, logistic, and relational database, and physical and technical labor, material and equipment support to detect, verify, respond to and administer recovery operations for all recurring and non-recurring incident/events that take place on the VDOT roadways. Amongst several operating subsystem modules, the VDOT Open TMS has a DMS driver module that is designed and demarked to remotely activate DMS units and poll real-time and actionable information on the DMS devices to enable the motorists to have the up-to-date situational awareness on roadway conditions as they unfold in a real-time manner.

The I-95 corridor is considered to be one of the busiest corridor that caters to the regional passenger and freight mobility needs in the Washington D.C. National Capital Region and is equipped with DMS and other ITS infrastructure to support a variety of operations strategies to tackle recurring and non-recurring congestion events. The study corridor serves as an appropriate test bed for developing ITS operations models.

The reversible northbound and southbound HOV lane operations during peak hours and the density of ITS deployments offer prudent variability in operations characteristics that are of interest to this research and for developing the ITS Operations evaluation models. The corridor also experiences significant regional commuter patterns and exhibit strong driver familiarity with the I-95 corridor operations. This is expected to reflect in ITS operations models results particularly for assessing the influence of DMS operations on deterrence of secondary incidents.

4.4 VA Traffic Operating System and Virginia State Police Computer Aided Dispatch (VSP-CAD)

VDOT required an integrated solution for gathering, storing and disseminating relevant roadway information to field personnel, management and the traveling public, especially in the event of emergencies, such as severe weather. Data, related to both planned and unplanned events, had to be disseminated in an accurate and timely manner to benefit the public and internal customers. Planned events include lane closures for work zones, special events and bridge openings. Unplanned events include unforeseen occurrences such as traffic crashes and weather-related road conditions. Reporting and analysis tools were needed to support performance monitoring and planning activities. For this reason, a comprehensive solution, VA Traffic, was conceived, Figure 4.5, to improve the delivery of these capabilities. (110).

VA Traffic as shown in Figure 4.6 is designed to improve VDOT operations by providing a more efficient and advanced integrated data management platform for managing a variety of activities that affect the quality of travel experienced by motorists in the Commonwealth. VA Traffic provides VDOT operations staff with an integrated tool to collect, monitor, update, and disseminate roadway information more efficiently to the 511 Integrated Voice Recognition (IVR) system and Website, to provide pre-trip and en-route traveler information to the public and to other interested users. The schematic shows a high-level systems architecture for VA Traffic. The VA Traffic application collects and distributes critical operations data in real-time to and from a myriad of sources for consumers inside and outside the agency.

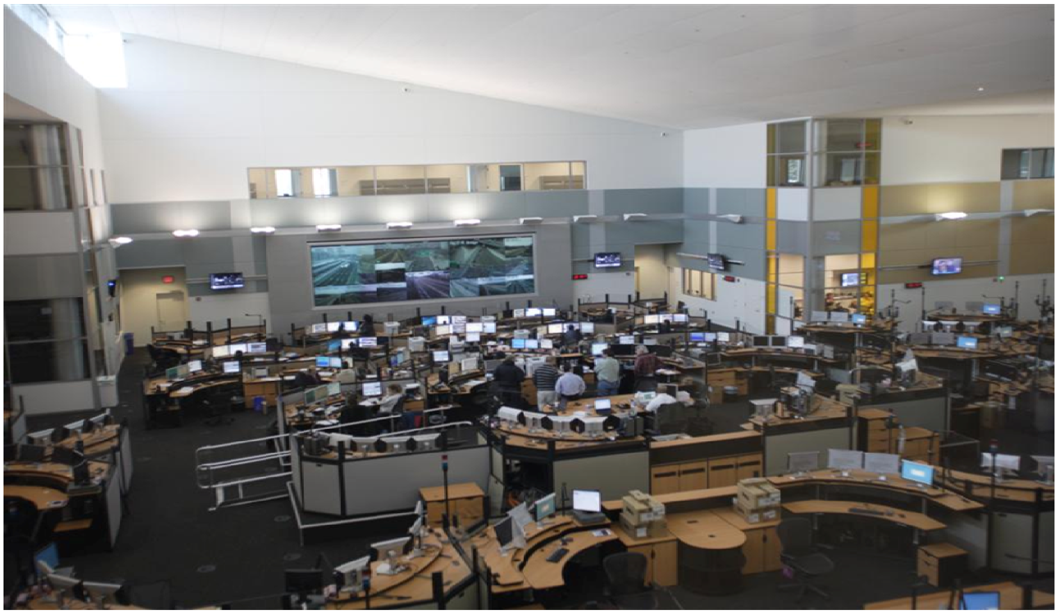


Figure 4.5 VDOT Traffic Operations Center

VDOT staff and contractors enter and maintain data and information about traffic incidents, weather events, security events, work zones, major events (i.e. NASCAR), fog and high wind advisories. More importantly, VA Traffic is the coordinating point for major emergencies including snow storms, flood and hurricanes. The information entered in VA Traffic comes from a variety of sources including sensors in the roadway, cameras monitoring traffic, data feeds from law enforcement partners and finally, direct coordination with VDOT staff “on the road” who help manage response to routine and major events.

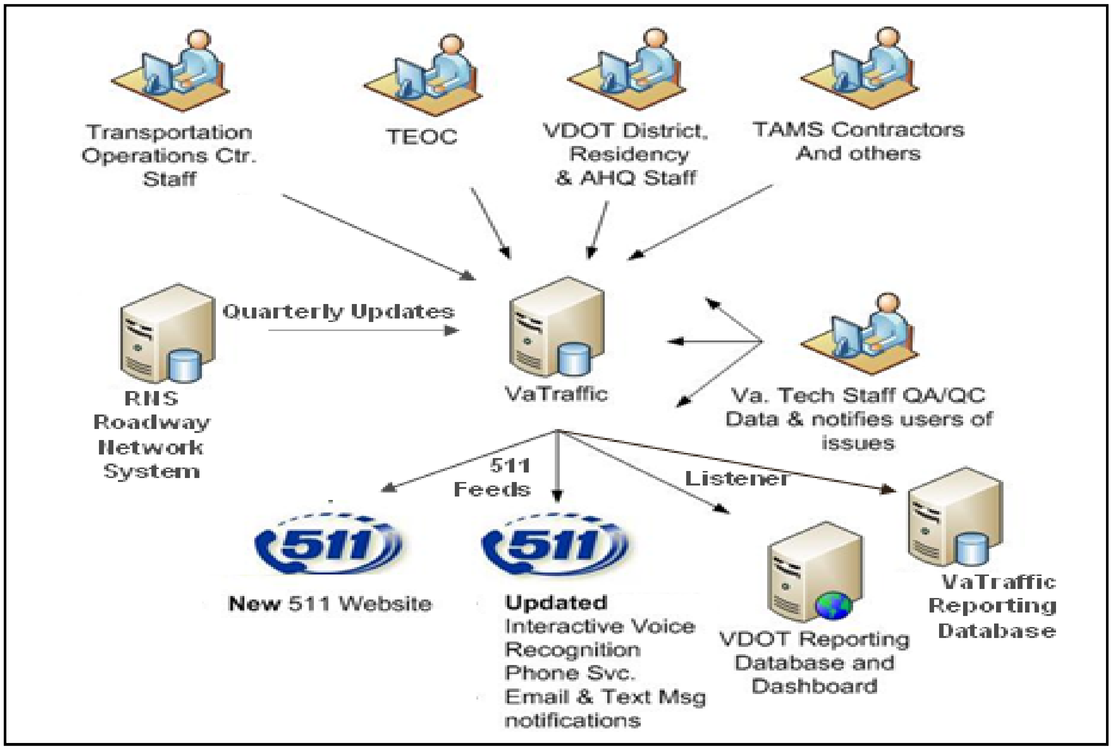


Figure 4.6 Virginia Traffic Operations Systems

VA Traffic provides the critical situational awareness function for VDOT decision-makers to assist them in VDOT's response to emergencies. Data managed in VA Traffic is also important in disaster recovery, providing the data necessary for FEMA reimbursement for activities in response to and the cleanup of disasters. VA Traffic data is also shared with outside partners, including motorists and media outlets via the 511 website, 511 phone service and 511 subscription emails. VDOT is also working with the Virginia Dept. of Emergency Management (VDEM) to provide VA Traffic's emergency data to state-wide emergency operations decision makers to enhance coordination and response among all agencies.

4.5 DMS Operations on I-95 Study Corridor

Integrated DMS operations scenarios, in conjunction with the existing and prevalent ITS systems on I-95 Study Corridor, are depicted in Figures 4.7 through 4.12. The scenario schematics attempt to capture the interdependencies amongst DMS and other ITS components on the I-95 Study Corridor.

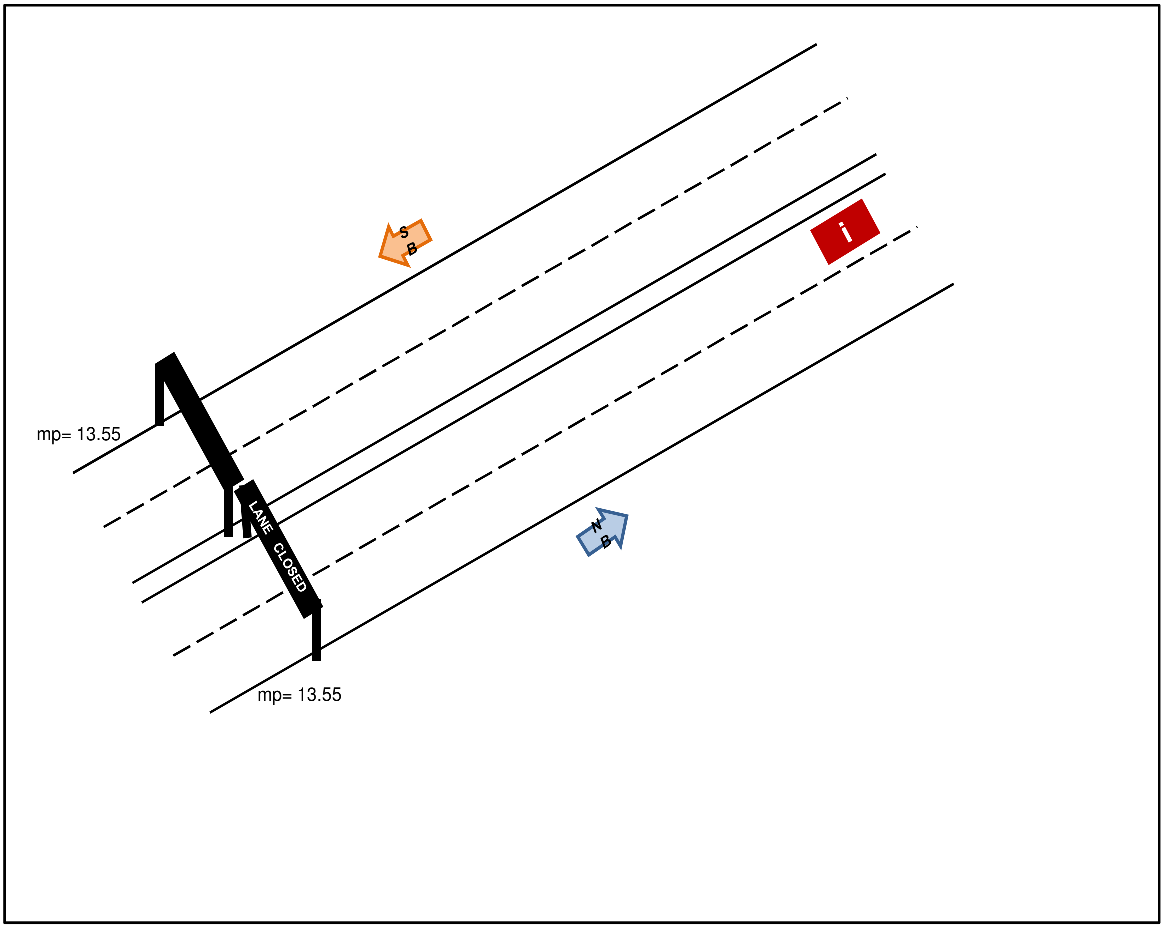


Figure 4.7 DMS Operations - 2 Lanes Operations

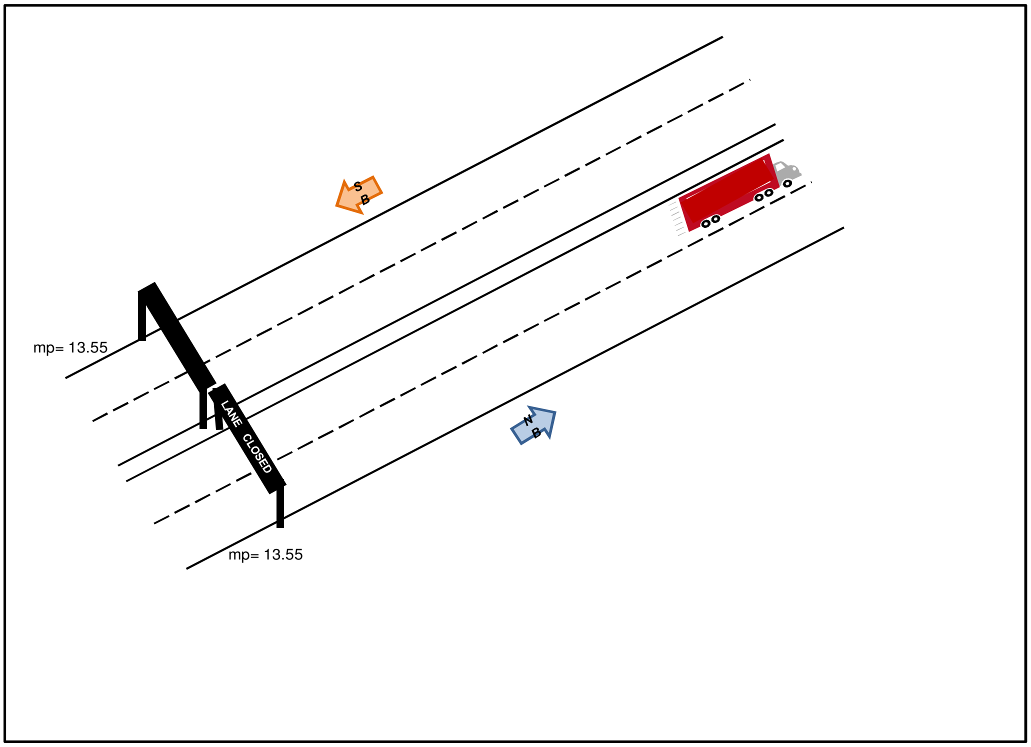


Figure 4.8 DMS Operations - Involving Trucks

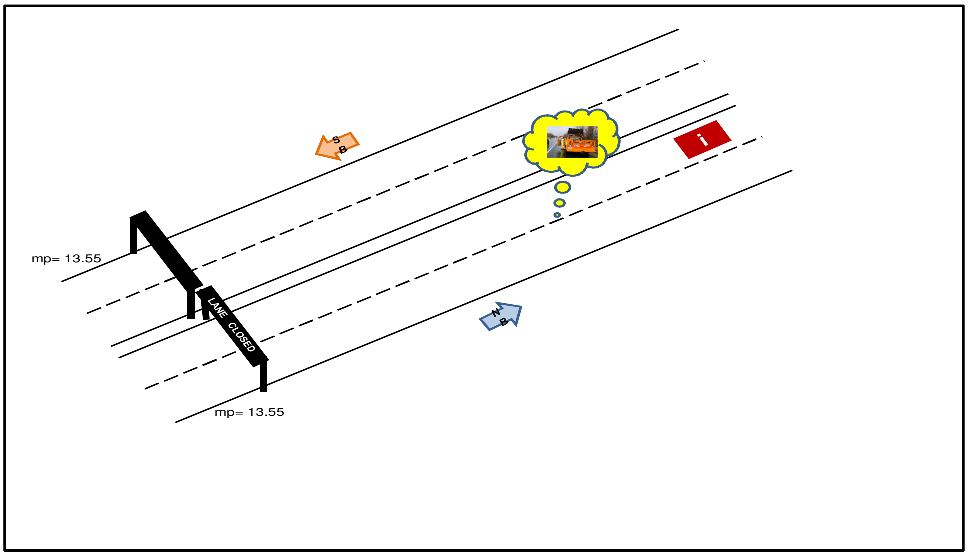


Figure 4.9 DMS Operations - SSP Detections

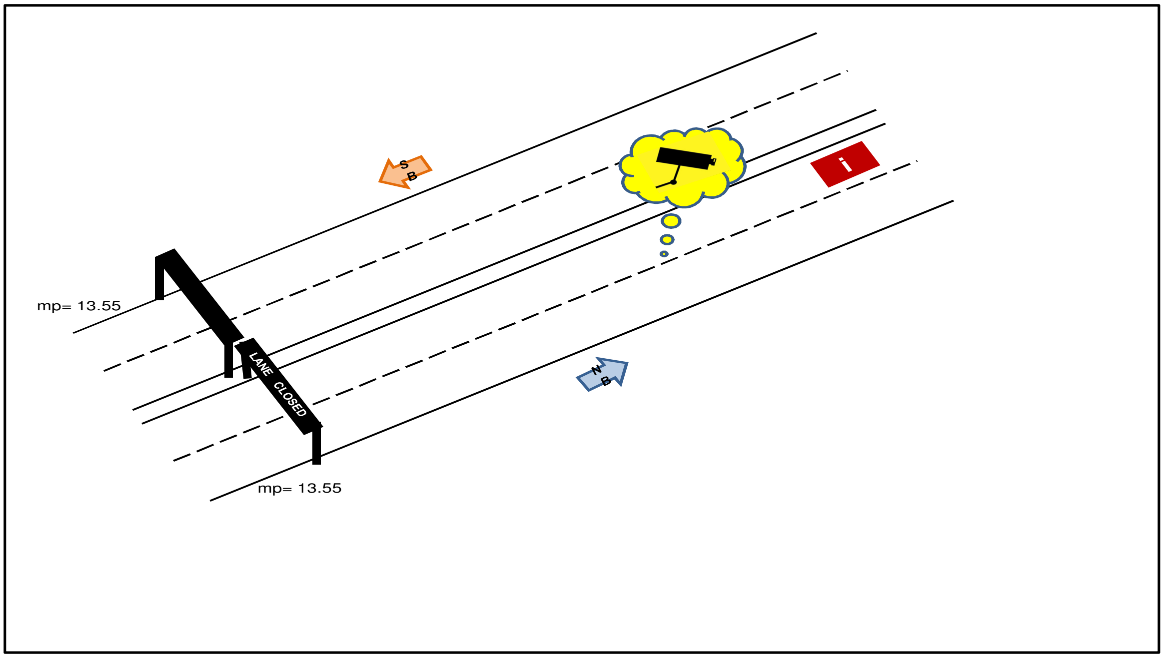


Figure 4.10 DMS Operations - CCTV Detections

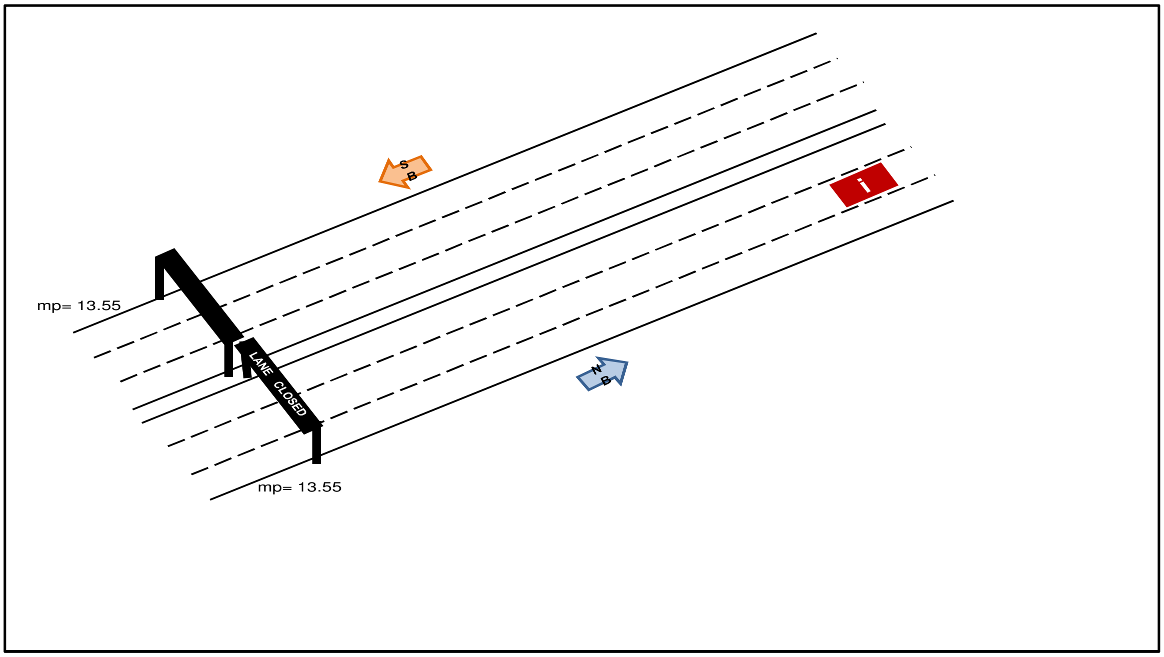


Figure 4.11 DMS Operations for Incident Impacting Multiple Lanes

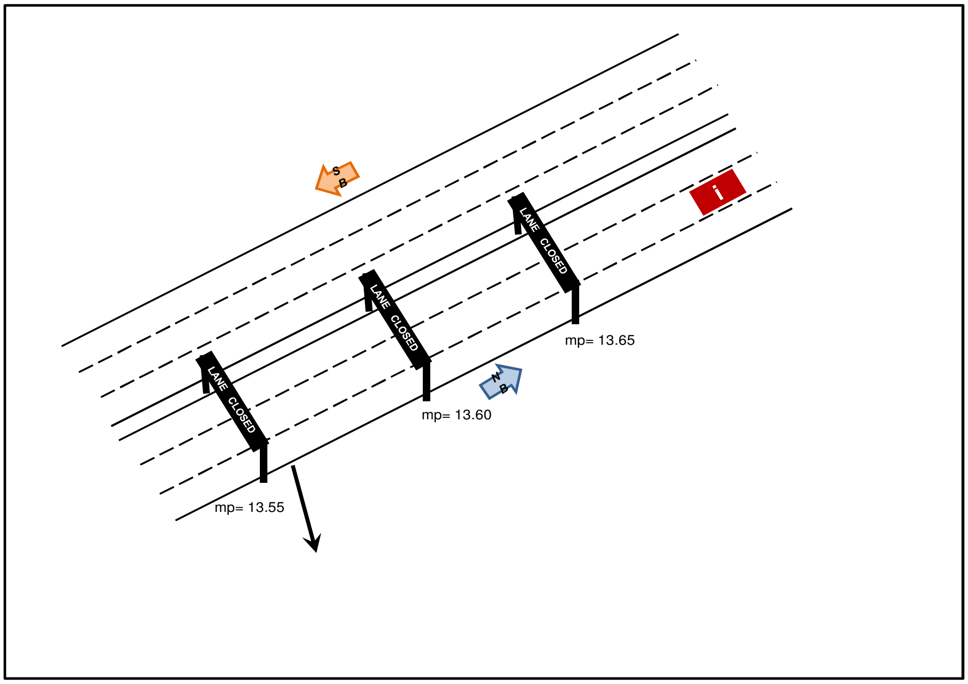


Figure 4.12 Multiple DMS Operations

From these scenarios, it is evident that the DMS message dissemination is highly subject to successful detection and verification of incidents, events and roadway situations as also summarized below:

- DMS messages resulting from incident and event detections from CCTV;
- DMS Messages resulting from incident and event detections from VSP CAD;
- DMS messages resulting from incident and event detections from Safety Service Patrol;
- DMS Operations indicating multiple lane closures; and
- Messages on multiple DMS locations.

4.6 DMS Operations and Research Hypothesis

The overview presented in the preceding sections provides an initial insight into DMS and ITS operations on the I-95 Study Corridor. It is evident from this discussion that the effectiveness of DMS operations for I-95 Study Corridor (and commonly for any corridor-based DMS operations) can be realized only when DMSs are activated to disseminate real-time, actionable information to motorists to enable them to take advantage of these alerts and updates and adjust their travel needs.

Thus, a series of expected outcomes or assessment criteria of these DMS operations scenarios or strategies can be hypothesized to assess DMS operations for the I-95 Study Corridor. For example, to evaluate the effectiveness of DMS operations during incident management, the corresponding hypothesis will be that the Detection Systems on the I-95 Study Corridor, such as CCTV, Safety Service Patrol and VSP-CAD, are successfully able to detect and relay the information to TOC and enable the operators to post the messages on the DMS.

To realize and achieve the objectives established for this research, and based on the prevalent DMS and ITS operations on I-95 Study Corridor, the research hypotheses and research objectives along with corresponding preliminary measures that will be explored as part of this research are presented in Table 4.1.

Table 4.1 Research Objectives and Research Hypothesis

Research Objective	Research Hypothesis Testing	Analyses Data
Research Objective 1 is to collect, extract and evaluate real time operations data from VDOT DMS and incident management operations programs and identify the factors contributing to the successful operation of DMS for the duration of incidents and events occurring on the I-95 Study Corridor.	The I-95 Study Corridor Detection Systems, such as CCTV, SSP and VSP CAD, detect, verify and provide accurate status updates during response, recovery and restoration phases of incidents leading to effective DMS Operations and dissemination of real time information during non-recurring congestion hours.	Operations data on High, Major and Minor profile incidents, such as incident location, incident duration, incident start time, incident end time, data on incident responders, number of lanes impacted, lane miles backed up etc., DMS operations data which includes DMS messages disseminated during High, Major and Low profile incidents, message duration, and message updates Incident detection system operations data including CCTV detections, Safety Service Patrol detections, Computer Aided Dispatch detections and Other data such as incidents in work zones, incidents under severe weather conditions and incidents during special events.

Table 4.1 (Continued)

Research Objective	Research Hypothesis Testing	Analyses Data
Research Objective 2 is to develop models and perform analytical assessment of incident detections and determine their measurable influence in successfully disseminating messages on DMS.	There is a cause and effect relationship between the I-95 Study Corridor detection systems and DMS operations. There is statistically significant correlation between number of messages posted on DMS with the number of incidents detected and assisted by CCTV, SSP, and VSP CAD systems for I-95 Study Corridor	The detection systems to be evaluated by the models include CCTV operations, Safety Service Patrols operations and Computer Aided Dispatch operations. The urban and transition operating conditions, the High, Major and Minor profile incidents and peak a.m. and p.m. hours and other analyses periods will be included in the model development scenarios.
Research Objective 3 is to develop models and quantitatively determine the measurable influence of DMS messages on operation of the I-95 Study Corridor during incidents and events.	DMS operation causes reduction in secondary crashes and influences incident duration.	The model variables to be analyzed to achieve this objective will be derived from data on High, Major and Minor profile incidents and include data on secondary incident, incident duration, and lane miles backed up due to incidents. Data on DMS operations include DMS messages and the message duration during the entire incident management operations.

Table 4.1 (Continued)

Research Objective	Research Hypothesis Testing	Analyses Data
Research Objective 4 is to develop guidelines on the application of these quantitative DMS evaluation models that transportation engineers can effectively use and perform DMS evaluations at other DMS locations.	The developed models are expected to be transferable for application and daily use by transportation engineers.	The developed DMS operations evaluation models will be subjected to validation and accuracy checks and the developed framework and guidelines are expected to enable practicing engineers to apply the models to evaluate DMS at locations outside Virginia.

The data collection and analyses methods for the I-95 Study Corridor, and the DMS and detection system factors identified in Table 4.1, are presented and discussed in detail in Chapter 5. In Chapter 5 the methods employed to collect/extract data on incident and event operations and incident management data from VA Traffic Operating System are described in detail. Chapter 5 also provides details on the methods used to extract DMS actuation data from ATMS located in VDOT Traffic Operations Centers that are used to remotely operate DMSs.

CHAPTER 5: DATA COLLECTION AND SYNTHESES

5.1 Data Needs

To quantitatively assess DMS operations, a suitable dataset containing the necessary variables has to be established. As described in the literature review, it is important that such a dataset has the required granularity in operational details for all phases of incident management, including detection, verification, response and recovery. This granularity in operations data includes details such as date and time of incident, incident duration, vehicle types involved in the incident – particularly incidents involving trucks, weather conditions, roadway conditions, work zones if any, number of lanes impacted, and incident clearance times. Similarly, the same level of granularity in DMS and ITS detection operations data is required; this includes messages disseminated during incidents, message duration, messages for work zones, messages with lane closure information, weather alerts, and work zone operations. It is critical to note here that a successful DMS operation can be defined in three fundamental ways:

- Ability to disseminate messages on DMS – Firstly, for successful and efficient dissemination of messages on DMS, it is imperative that all the software and hardware of DMS technical systems in the field and ATMS operating systems in TOC environments are in fully working condition. Additionally, the human error incurred through

TMC operators will also affect the ability to post messages on DMSs remotely from a TOC. In the scope of this research, these limitations are acknowledged but are not considered in the analyses methods since the focus of the research is to develop quantitative methods to measure the operations value of DMS based on the messages that are disseminated and not on the hardware, software and administrative limitations.

- Granular Operations Data - Secondly, besides the hardware, software and human interdependencies that define the successful dissemination of messages on DMS, it is imperative that granular operations data on the incident detection, verification and periodic updates on progress of incident response and recovery operations are available to TOC operators to use this real time information and disseminate messages on DMS. This is critical to this research and forms the foundation for achieving the research objectives. Extensive efforts are devoted to develop the granular operations data that is essential to develop ITS Operations Evaluation Models (ITSOEMs). It is also critical to note that there is a varying degree of granular operations data available from the ITS detection systems. For example data on ITS detections from CCTV are able to offer pictorial instantaneous granular details on incidents such as type of vehicle, length of the vehicle, extent and intensity of damage caused and the time for detection etc. Also the detections from CCTV provide quick verification and final confirmation needed to generate necessary response and message dissemination on DMS signs. On contrast, the other detections systems – Safety Service patrols and Computer Aided Dispatch – will not be able to offer such instantaneous data granularity. However, the data from Safety Service Patrol and VSPCAD detections are more robust in response and recovery operations and the field conditions that are otherwise very difficult to discern from video images. At night time the data from CCTV detection may not provide vivid details due to differing lighting conditions.

- Measurable Operations Benefits - Thirdly, the posted messages are actionable information for motorists and induce measurable operations benefits, such as possible reduction in incident duration and decline in secondary crashes, thereby enhancing safety and mobility on transportation corridors. This is also fundamental to achieving the research objective to quantitatively determine the tangible measure resulting from DMS operations, and is closely tied to the granular data requirements previously expressed.

This chapter is devoted to presenting the data collection processes and frameworks employed to carry out this research. As mentioned before, the data required for the I-95 Study Corridor for this research is obtained from VDOT administered VA Traffic Relational Database and ATMS software platforms that are housed in VDOT's Traffic Operations Center (TOC).

Field operations data pertinent to incident management, including the detection, verification, response and recovery phases that have taken place on I-95 Study Corridor and the corresponding DMS and ITS operations data, are being retrieved from the VDOT's VA Traffic and ATMS database for the 15 month period from September 2008 through December 2009. The data retrieved on DMS messages from VDOT ATMS is similar to a count data and the number of messages posted on the I-95 Study Corridor is counted over time, date and by place of occurrence.

5.2 VDOT VA Traffic Relational Database Operating System

VDOT's VA Traffic relational database maintains an event log of all incidents as they occur on all roadway corridors in the State of Virginia as shown in Table 5.1. From this relational database program, the following details of the incidents are available.

The information that arrives at TOC on all incidents is logged in VA Traffic Relational Database. Tables 5.2 and 5.3 show event log maintained in VDOT VA operating System.

Table 5.1 Incident Event Log

Incident Data	Incident Detection	Incident Verification	Incident Response	Incident Recovery
Date	Direction by CCTV	Verification by CCTV	Responding entry	Incident Scene command System
Time	Direction by SSP	Verification by SSP	VDOT	Operations
Direction	Detection by VSP/CAD	Verification by vsp-cad	Towing agency	Temporary and permanent lane controls
Route Number			EMS and Medivac	Lane closures
Location, mile post			HAZMAT	Lane restoration
Incident start time			Fire etc.	Return to normal traffic conditions/flow
Incident end time				
Incident duration				
Incident type				
Incident Management				

5.3 VDOT Advanced Travel Management System – DMS Operations Data

Similarly, VDOT's Advanced Travel Management System (ATMS) logs details of all DMS operations as shown in Table 5.4.

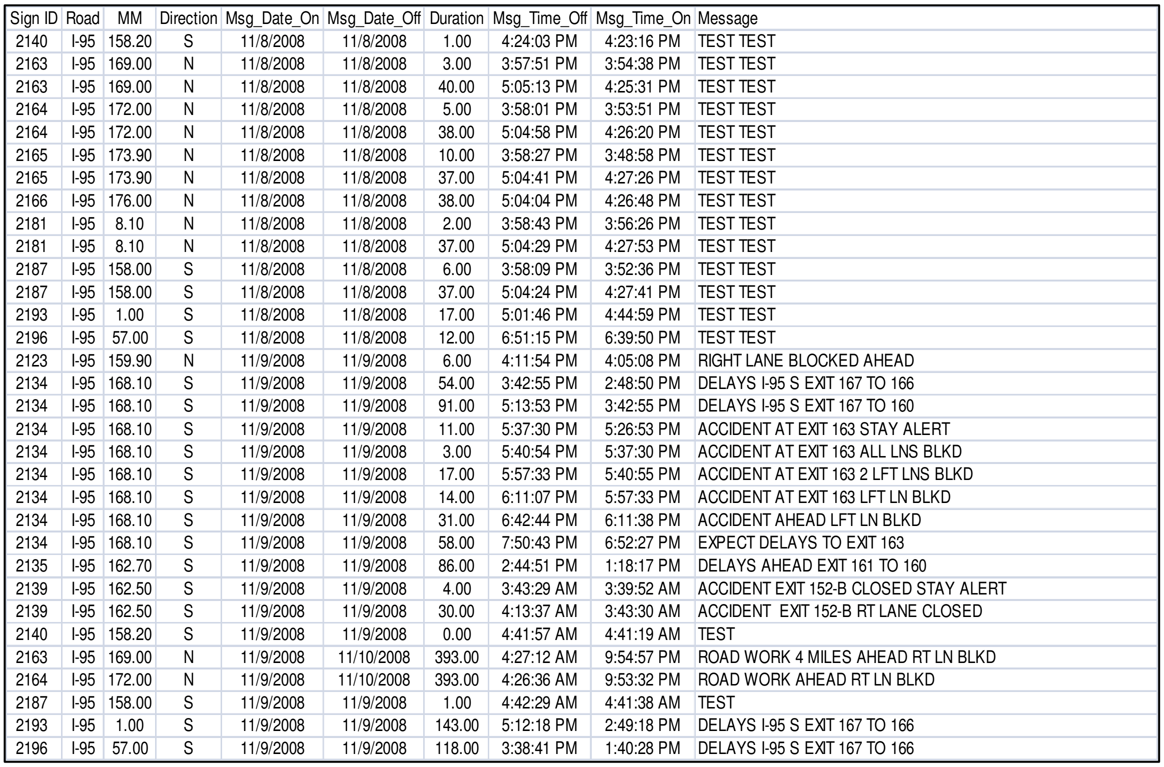
Table 5.2 VA Traffic Operating System Event Log – Part 1

Event ID	Region	District	Jurisdiction	Route Type	Road	Category	Priority
VaTraffic_INNO2003710-12022008	Northern Region	Northern Virginia	Fairfax (County)	Interstate	I-95N	Disabled Vehicle	High Profile
VaTraffic_INNO2008802-12312008	Northern Region	Fredericksburg	Stafford (County)	Interstate	I-95N	Disabled Vehicle	Major
VaTraffic_INNO2011851-01172009	Northern Region	Northern Virginia	Fairfax (County)	Interstate	I-95N	Disabled Vehicle	Major
VaTraffic_INNO2013453-01262009	Northern Region	Northern Virginia	Fairfax (County)	Interstate	I-95N	Disabled Vehicle	Major
VaTraffic_INNO2002130-11222008	Northern Region	Northern Virginia	Prince William (County)	Interstate	I-95N	Disabled Vehicle	Major
VaTraffic_INNO2011066-01142009	Northern Region	Northern Virginia	Fairfax (County)	Interstate	I-95N	Disabled Vehicle	High Profile
VaTraffic_INNO2009532-01062009	Northern Region	Northern Virginia	Fairfax (County)	Interstate	I-95N	Disabled Vehicle	Major
VaTraffic_INNO2010112-01092009	Northern Region	Fredericksburg	Stafford (County)	Interstate	I-95N	Disabled Vehicle	Minor
VaTraffic_INNO2010185-01092009	Northern Region	Fredericksburg	Spotsylvania (County)	Interstate	I-95N	Disabled Vehicle	Minor
VaTraffic_INNO2010323-01092009	Northern Region	Fredericksburg	Stafford (County)	Interstate	I-95N	Disabled Vehicle	Minor
VaTraffic_INNO2008559-12302008	Northern Region	Fredericksburg	Spotsylvania (County)	Interstate	I-95N	Disabled Vehicle	Minor
VaTraffic_INNO2008613-12302008	Northern Region	Fredericksburg	Spotsylvania (County)	Interstate	I-95N	Disabled Vehicle	Minor
VaTraffic_INNO2008796-12312008	Northern Region	Fredericksburg	Spotsylvania (County)	Interstate	I-95N	Disabled Vehicle	Minor
VaTraffic_INNO2008833-01012009	Northern Region	Fredericksburg	Stafford (County)	Interstate	I-95N	Disabled Vehicle	Minor
VaTraffic_INNO2012750-01222009	Northern Region	Fredericksburg	Spotsylvania (County)	Interstate	I-95N	Disabled Vehicle	Minor
VaTraffic_INNO2012953-01232009	Northern Region	Fredericksburg	Spotsylvania (County)	Interstate	I-95N	Disabled Vehicle	Minor
VaTraffic_INNO2012990-01232009	Northern Region	Fredericksburg	Stafford (County)	Interstate	I-95N	Disabled Vehicle	Minor
VaTraffic_INNO2011042-01142009	Northern Region	Northern Virginia	Fairfax (County)	Interstate	I-95N	Disabled Vehicle	Minor
VaTraffic_INNO2011206-01142009	Northern Region	Fredericksburg	Stafford (County)	Interstate	I-95N	Disabled Vehicle	Minor
VaTraffic_INNO2011515-01162009	Northern Region	Northern Virginia	Fairfax (County)	Interstate	I-95N	Disabled Vehicle	Minor

Table 5.3 VA Traffic Operating System Event Log – Part 2

Start	Closed	Duration	All Travel Lanes Clear	Scene Clear	# Veh.	Medflight	HazMat	Fatalities	Cont. Emp.	Cont. Equip.	State Emp.	State Prop.	State Veh.
12/2/2008 16:57	12/2/2008 18:36	1 hour 39 minutes			1	FALSE	FALSE	0	FALSE	FALSE	FALSE	FALSE	FALSE
12/31/2008 19:52	12/31/2008 20:06	14 minutes	12/31/2008 20:06		1	FALSE	FALSE	0	FALSE	FALSE	FALSE	FALSE	FALSE
1/17/2009 18:09	1/17/2009 18:26	17 minutes			1	FALSE	FALSE	0	FALSE	FALSE	FALSE	FALSE	FALSE
1/26/2009 15:07	1/26/2009 15:29	22 minutes			1	FALSE	FALSE	0	FALSE	FALSE	FALSE	FALSE	FALSE
11/22/2008 15:43	11/22/2008 16:00	17 minutes			2	FALSE	FALSE	0	FALSE	FALSE	FALSE	FALSE	FALSE
1/14/2009 7:00	1/14/2009 7:49	49 minutes			1	FALSE	FALSE	0	FALSE	FALSE	FALSE	FALSE	FALSE
1/6/2009 17:34	1/6/2009 18:02	28 minutes			1	FALSE	FALSE	0	FALSE	FALSE	FALSE	FALSE	FALSE
1/9/2009 6:49	1/9/2009 7:11	22 minutes	1/9/2009 7:11		1	FALSE	FALSE	0	FALSE	FALSE	FALSE	FALSE	FALSE
1/9/2009 10:33	1/9/2009 10:48	15 minutes	1/9/2009 10:48		1	FALSE	FALSE	0	FALSE	FALSE	FALSE	FALSE	FALSE
1/9/2009 18:00	1/9/2009 18:15	15 minutes	1/9/2009 18:15		1	FALSE	FALSE	0	FALSE	FALSE	FALSE	FALSE	FALSE
12/30/2008 13:53	12/30/2008 14:28	35 minutes	12/30/2008 14:28		1	FALSE	FALSE	0	FALSE	FALSE	FALSE	FALSE	FALSE
12/30/2008 17:48	12/30/2008 18:30	42 minutes	12/30/2008 18:30		1	FALSE	FALSE	0	FALSE	FALSE	FALSE	FALSE	FALSE
12/31/2008 19:09	12/31/2008 19:14	5 minutes	12/31/2008 19:14		1	FALSE	FALSE	0	FALSE	FALSE	FALSE	FALSE	FALSE
1/1/2009 12:49	1/1/2009 12:53	4 minutes	1/1/2009 12:53		1	FALSE	FALSE	0	FALSE	FALSE	FALSE	FALSE	FALSE
1/22/2009 13:12	1/22/2009 13:34	22 minutes	1/22/2009 13:34		1	FALSE	FALSE	0	FALSE	FALSE	FALSE	FALSE	FALSE

Table 5.4 VDOT ATMS DMS Message Log



Sign ID	Road	MM	Direction	Msg_Date_On	Msg_Date_Off	Duration	Msg_Time_Off	Msg_Time_On	Message
2140	I-95	158.20	S	11/8/2008	11/8/2008	1.00	4:24:03 PM	4:23:16 PM	TEST TEST
2163	I-95	169.00	N	11/8/2008	11/8/2008	3.00	3:57:51 PM	3:54:38 PM	TEST TEST
2163	I-95	169.00	N	11/8/2008	11/8/2008	40.00	5:05:13 PM	4:25:31 PM	TEST TEST
2164	I-95	172.00	N	11/8/2008	11/8/2008	5.00	3:58:01 PM	3:53:51 PM	TEST TEST
2164	I-95	172.00	N	11/8/2008	11/8/2008	38.00	5:04:58 PM	4:26:20 PM	TEST TEST
2165	I-95	173.90	N	11/8/2008	11/8/2008	10.00	3:58:27 PM	3:48:58 PM	TEST TEST
2165	I-95	173.90	N	11/8/2008	11/8/2008	37.00	5:04:41 PM	4:27:26 PM	TEST TEST
2166	I-95	176.00	N	11/8/2008	11/8/2008	38.00	5:04:04 PM	4:26:48 PM	TEST TEST
2181	I-95	8.10	N	11/8/2008	11/8/2008	2.00	3:58:43 PM	3:56:26 PM	TEST TEST
2181	I-95	8.10	N	11/8/2008	11/8/2008	37.00	5:04:29 PM	4:27:53 PM	TEST TEST
2187	I-95	158.00	S	11/8/2008	11/8/2008	6.00	3:58:09 PM	3:52:36 PM	TEST TEST
2187	I-95	158.00	S	11/8/2008	11/8/2008	37.00	5:04:24 PM	4:27:41 PM	TEST TEST
2193	I-95	1.00	S	11/8/2008	11/8/2008	17.00	5:01:46 PM	4:44:59 PM	TEST TEST
2196	I-95	57.00	S	11/8/2008	11/8/2008	12.00	6:51:15 PM	6:39:50 PM	TEST TEST
2123	I-95	159.90	N	11/9/2008	11/9/2008	6.00	4:11:54 PM	4:05:08 PM	RIGHT LANE BLOCKED AHEAD
2134	I-95	168.10	S	11/9/2008	11/9/2008	54.00	3:42:55 PM	2:48:50 PM	DELAYS I-95 S EXIT 167 TO 166
2134	I-95	168.10	S	11/9/2008	11/9/2008	91.00	5:13:53 PM	3:42:55 PM	DELAYS I-95 S EXIT 167 TO 160
2134	I-95	168.10	S	11/9/2008	11/9/2008	11.00	5:37:30 PM	5:26:53 PM	ACCIDENT AT EXIT 163 STAY ALERT
2134	I-95	168.10	S	11/9/2008	11/9/2008	3.00	5:40:54 PM	5:37:30 PM	ACCIDENT AT EXIT 163 ALL LNS BLKD
2134	I-95	168.10	S	11/9/2008	11/9/2008	17.00	5:57:33 PM	5:40:55 PM	ACCIDENT AT EXIT 163 2 LFT LNS BLKD
2134	I-95	168.10	S	11/9/2008	11/9/2008	14.00	6:11:07 PM	5:57:33 PM	ACCIDENT AT EXIT 163 LFT LN BLKD
2134	I-95	168.10	S	11/9/2008	11/9/2008	31.00	6:42:44 PM	6:11:38 PM	ACCIDENT AHEAD LFT LN BLKD
2134	I-95	168.10	S	11/9/2008	11/9/2008	58.00	7:50:43 PM	6:52:27 PM	EXPECT DELAYS TO EXIT 163
2135	I-95	162.70	S	11/9/2008	11/9/2008	86.00	2:44:51 PM	1:18:17 PM	DELAYS AHEAD EXIT 161 TO 160
2139	I-95	162.50	S	11/9/2008	11/9/2008	4.00	3:43:29 AM	3:39:52 AM	ACCIDENT EXIT 152-B CLOSED STAY ALERT
2139	I-95	162.50	S	11/9/2008	11/9/2008	30.00	4:13:37 AM	3:43:30 AM	ACCIDENT EXIT 152-B RT LANE CLOSED
2140	I-95	158.20	S	11/9/2008	11/9/2008	0.00	4:41:57 AM	4:41:19 AM	TEST
2163	I-95	169.00	N	11/9/2008	11/10/2008	393.00	4:27:12 AM	9:54:57 PM	ROAD WORK 4 MILES AHEAD RT LN BLKD
2164	I-95	172.00	N	11/9/2008	11/10/2008	393.00	4:26:36 AM	9:53:32 PM	ROAD WORK AHEAD RT LN BLKD
2187	I-95	158.00	S	11/9/2008	11/9/2008	1.00	4:42:29 AM	4:41:38 AM	TEST
2193	I-95	1.00	S	11/9/2008	11/9/2008	143.00	5:12:18 PM	2:49:18 PM	DELAYS I-95 S EXIT 167 TO 166
2196	I-95	57.00	S	11/9/2008	11/9/2008	118.00	3:38:41 PM	1:40:28 PM	DELAYS I-95 S EXIT 167 TO 166

From ATMS DMS log, the data on DMS messages posted include date and time the messages are posted, start time of the message, end time of the message and message type, such as messages posted for:

1. Congestion caused delays
2. Lanes blocked due to incidents
3. Situational awareness to motorists on types of incidents
    a. Fatalities
    b. Vehicle on fire
    c. Spill
4. RWIS Integrated - Weather warnings including:

a. High Wind warnings
b. Fog warnings
c. Icy conditions
d. Snow and ice
e. Bridge freezing etc.

5.4 DMS and VA Traffic Data Syntheses for the I-95 Study Corridor

Mining of Incident Management data from VA Traffic Relational Database and DMS, and operations data from VDOT ATMS are the critical and fundamental components of this research. Through a qualitative and quantitative assessment of data, each incident record in VA Traffic is combed through, and every incident and event actionable information recorded in VA Traffic is evaluated and compared with corresponding DMS activation data recorded and archived in the VDOT ATMS server. One of the fundamental outcomes of this research is to establish the data framework that transforms the VA Traffic actionable data and DMS activation data from VDOT ATMS into analyses Data Sets that can be used to develop ITSOEMs. The DMS messages data and incident management operations data from VA Traffic relational database operating system are corroborated by time and space and analyses data sets are prepared. The data synthesis approach is presented in Figure 5.1.

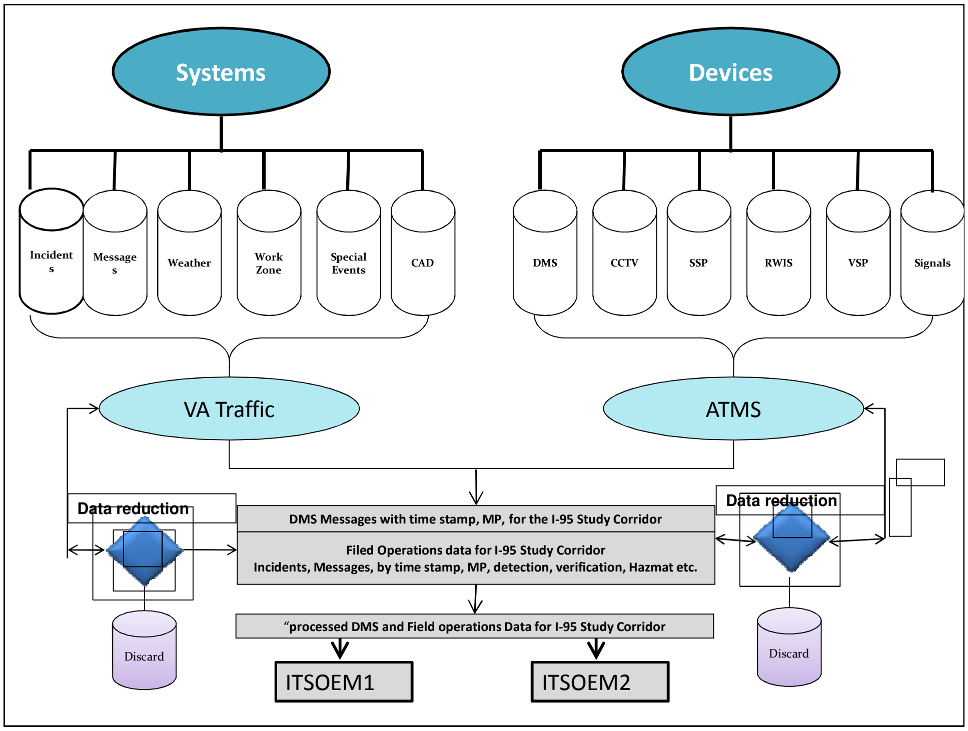


Figure 5.1 Data Synthesis Approach

The objective here is to determine whether (or not) an incident that occurred in the I-95 Study Corridor, that was logged in VA Traffic database, resulted in disseminating a message on the corresponding DMS. Furthermore, the aim of this research is also to establish the type of detection that resulted in enabling the TOC operators to disseminate such a message on the DMS sign. Additional details that are also critically pertinent to this research include the type of the incidents that occurred on the I-95 Study Corridor. From the VA Traffic Relational Database, and based on the VDOT adopted criteria the incidents are sorted into three categories: High Profile, Major Profile and Minor Profile. One of the High Profile incidents that occurred on I-95 study character is shown in Figure 5.2.

Figure 5.2 High Profile incidents

The VDOT specified criteria for High Profile Incidents are:

- All lanes on the Interstate are closed in one or both directions for 30 minutes;
- Do not wait 30 minutes to report the incident if it is obvious that the closure will exceed 30 minutes;
- All lanes on a Primary route are closed in one or both directions for 60 minutes;
- HAZMAT – dangerous materials of more than 25 gallons of diesel;
- HAZMAT evacuation of citizens from areas near the incident site;
- Multiple fatalities – two or more vehicles;
- A school bus crash with passenger injuries;
- A multi-vehicle crash – three or more vehicles;

- Any incident that occurs in a work zone with injuries or fatalities reported; and
- Any incident that results in:
    - VDOT or contract employee death;
    - 10-mile or greater backup;
    - The closure of all lanes in one or both directions for more than 30 minutes; and.
    - Major bridge or infrastructure damage.

The VDOT specified criteria for Major Profile Incidents as shown in Figure 5.3 are:

- One or more lanes are closed for 15 minutes or longer;
- Significant impact on travel;
- On or off ramp closed for 30 minutes or longer;
- One or more vehicles involved with serious or multiple injuries;
- Delays caused by bridge openings, etc.;
- Recurring congestion delays exceeding 45 minutes; and
- Lane miles back up exceeding 3 miles.

Figure 5.3 Major Profile incidents

Figure 5.4 Minor Profile incidents

The VDOT specified criteria for Minor Profile Incidents as shown in Figure 5.4 are:

- Minimum impact on travel and minimum notifications;
- No lane closures;
- Minor injuries;
- Minor HAZMAT that is contained;
- Rest Area closures due to mechanical problems;
- Recurring congestion delays exceeding 30 minutes; and
- Lane miles back up exceeding 2 miles.

5.5 Analyses Data Set for Development of ITSOEMs

The data reductions are performed with at most care to ensure that the pertinent granularity in the data is not compromised. Primarily the data reductions are applied to account for false alarm detection data that did not result in message disseminations, and to account for system outages that caused ATMS and VA Traffic servers to report and register test messages, and system upload and system booting messages.

Under no circumstances no data on incidents ITS detections is demarcated for data reductions. The VDOT specified incidents' profile criteria listed in Section 5.4 are used and the incident data from VA Traffic Database is matched with the DMS message data from VDOT ATMS using the date, time, and space attributes. The final matched and corroborated DMS and Incident management operations data sets are obtained to perform the analyses required for this research.

Through discussions with VDOT operations teams, suitable rules and logic were developed and adopted to match the incident and DMS data and to handle missing or erroneous data. For instance the 'test' messages recorded by ATMS and other such non-event or non-incident related messages were deleted from the final analyses data sets. Additionally, the following logic and rules were developed and adopted in matching the DMS and Incident management data:

- Logic 1: An incident logged in the VA Traffic database, that has a date, time and mile marker as the location stamp on the I-95 Study Corridor, is considered to have a match with the corresponding VDOT ATMS DMS message record only if: a) that message has the same date stamp, b) the message has approximately same time stamp (with details on detection and verification lag time), c) the location of DMS that has the message is situated downstream of the incident mile marker location, and finally, d) the DMS is facing the same cardinal direction of the I-95 Study Corridor where the incident occurred.

- Logic 2: The overall DMS message duration and Incident duration should be mostly equal.
- Logic 3: The DMS message content and context are clearly depicted and should match with the incident profile characteristics.
- Logic 4: Based on the incident severity the DMS messages could be posted on more than one DMS location within the incident influence area.

However for this research, once the date, time and space stamp is matched, the matched multiple DMS messages are considered as a single successful match for the subject incident. For example, a high profile incident that has a wide reaching impact on the I-95 Study Corridor results in successful ITS detection and enables the TOC operator to post DMS messages on several DMS locations downstream to the incident mile marker location.

Although disseminating messages on additional DMS is a positive operational attribute, for this research analyses purpose, that particular incident record is considered to have match with only a single successful DMS message dissemination event and no additional credit is given in the analyses. Thus, based on these DMS operations logic and guidelines as identified in discussions with VDOT DMS Operators, the following Data Synthesis Rules were developed and applied:

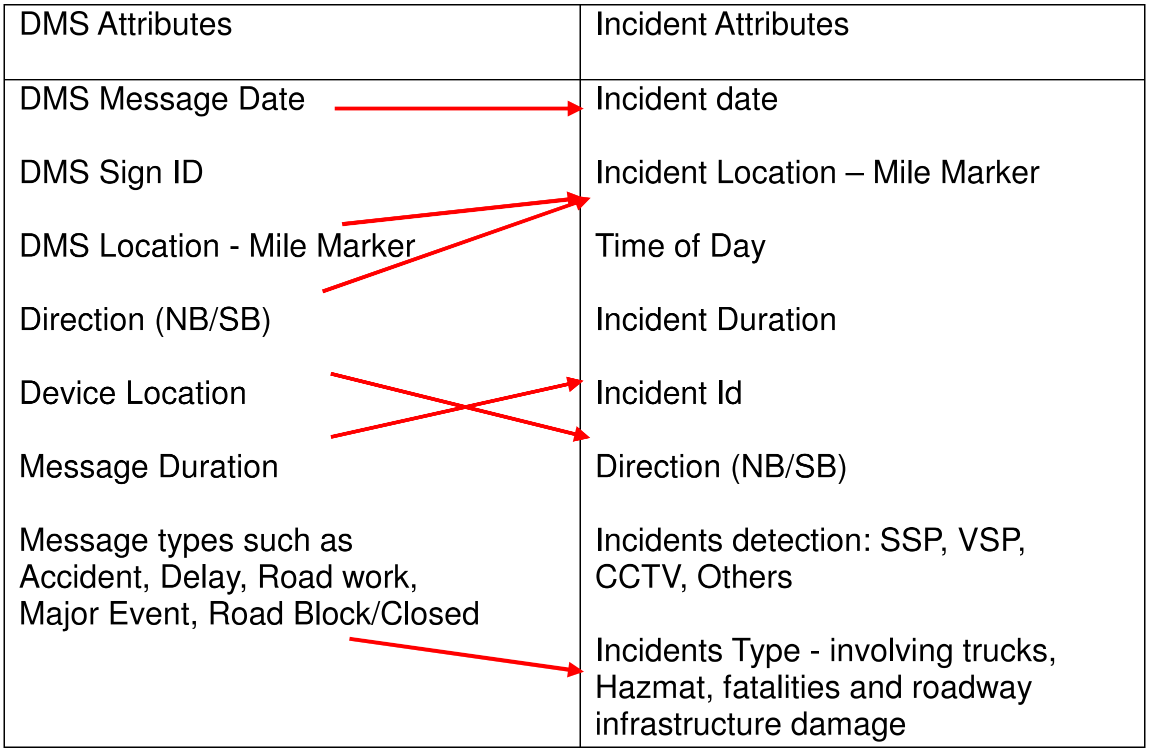
- Rule 1: DMS message and incident should have the same date stamp.
- Rule 2: The matched DMS location, where the posted message is considered a match, should be downstream to the incident location.
- Rule 3: The DMS message time stamp and incident time stamp should be within incident detection and verification time lag.
- Rule 4: Based on VDOT guidelines, if a DMS message is not matched within the 20 minutes from the start time of an incident, the Incident record in VA Traffic under consideration is considered to have zero matches with DMS message record in VDOT ATMS data.
- Rule 5: The maximum downstream distance is subjectively verified with reference to the incident severity and incident duration.

The DMS message and incident management data attributes are shown in Table 5.5 and the DMS and incident data used for data syntheses are shown in Figures 5.5 and 5.6. Similar data sets were developed for Mid-day, Peak PM and

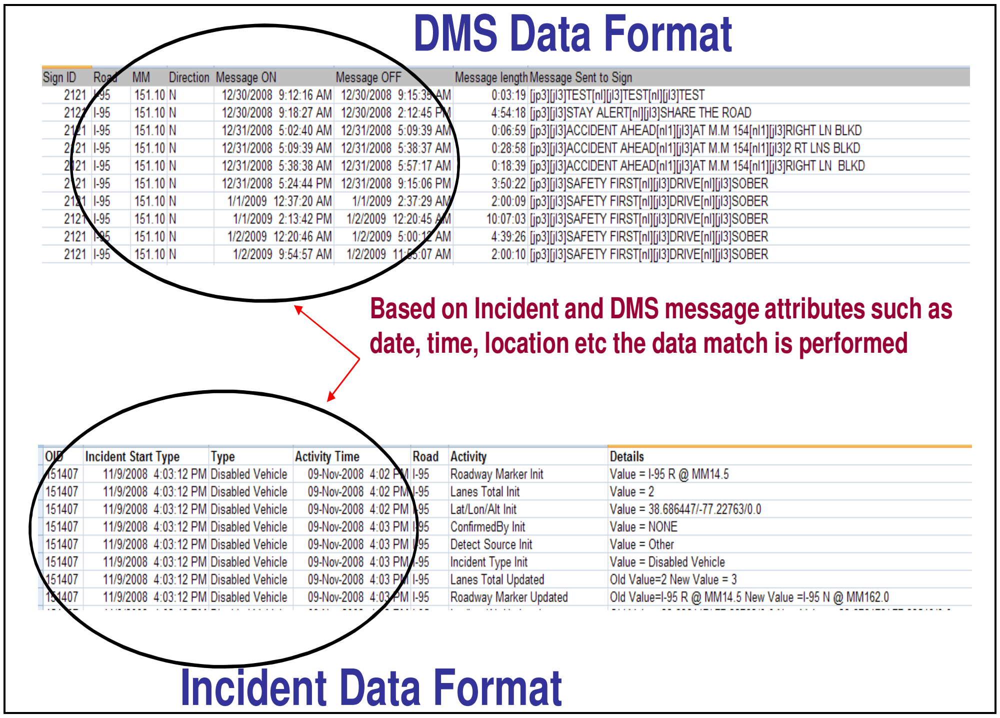
Night-Hours analyses periods. The final analyses data sets are used to develop ITS Operations Evaluation Models (ITSOEMs).

In Chapter 7, further processing and analyses of the final data sets is presented in detail along with model methodologies adopted for developing ITSOEMs. Chapter 7 also provides complete details on the model accuracy tests and validation methods, and presents the measures developed from ITSOEMs applications to determine DMS operations effectiveness.

Table 5.5 DMS and Incident Data Attributes



DMS Attributes	Incident Attributes
DMS Message Date	Incident date
DMS Sign ID	Incident Location – Mile Marker
DMS Location - Mile Marker	Time of Day
Direction (NB/SB)	Incident Duration
Device Location	Incident Id
Message Duration	Direction (NB/SB)
Message types such as Accident, Delay, Road work, Major Event, Road Block/Closed	Incidents detection: SSP, VSP, CCTV, Others
	Incidents Type - involving trucks, Hazmat, fatalities and roadway infrastructure damage



DMS Data Format

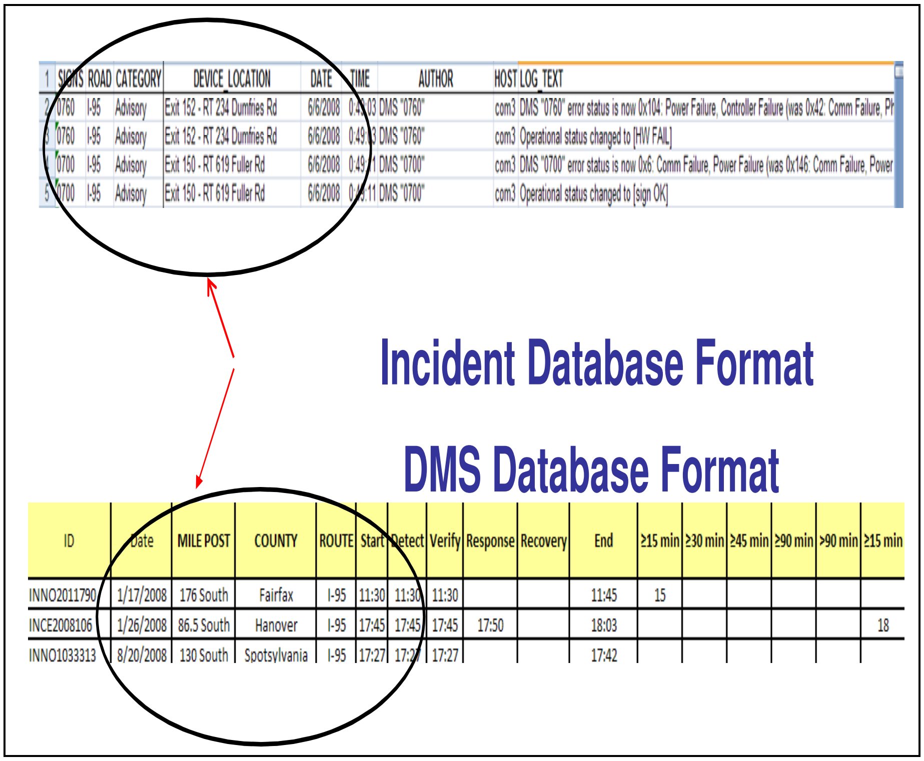
Sign ID	Road	MM	Direction	Message ON	Message OFF	Message length	Message Sent to Sign
2121	I-95	151.10	N	12/30/2008 9:12:16 AM	12/30/2008 9:15:35 AM	0:03:19	[jp3][jl3]TEST[nl][jl3]TEST[nl][jl3]TEST
2121	I-95	151.10	N	12/30/2008 9:18:27 AM	12/30/2008 2:12:45 PM	4:54:18	[jp3][jl3]STAY ALERT[nl][jl3]SHARE THE ROAD
2121	I-95	151.10	N	12/31/2008 5:02:40 AM	12/31/2008 5:09:39 AM	0:06:59	[jp3][jl3]ACCIDENT AHEAD[nl1][jl3]AT M.M 154[nl1][jl3]RIGHT LN BLKD
2121	I-95	151.10	N	12/31/2008 5:09:39 AM	12/31/2008 5:38:37 AM	0:28:58	[jp3][jl3]ACCIDENT AHEAD[nl1][jl3]AT M.M 154[nl1][jl3]2 RT LNS BLKD
2121	I-95	151.10	N	12/31/2008 5:38:38 AM	12/31/2008 5:57:17 AM	0:18:39	[jp3][jl3]ACCIDENT AHEAD[nl1][jl3]AT M.M 154[nl1][jl3]RIGHT LN BLKD
2121	I-95	151.10	N	12/31/2008 5:24:44 PM	12/31/2008 9:15:06 PM	3:50:22	[jp3][jl3]SAFETY FIRST[nl][jl3]DRIVE[nl][jl3]SOBER
2121	I-95	151.10	N	1/1/2009 12:37:20 AM	1/1/2009 2:37:29 AM	2:00:09	[jp3][jl3]SAFETY FIRST[nl][jl3]DRIVE[nl][jl3]SOBER
2121	I-95	151.10	N	1/1/2009 2:13:42 PM	1/2/2009 12:20:45 AM	10:07:03	[jp3][jl3]SAFETY FIRST[nl][jl3]DRIVE[nl][jl3]SOBER
2121	I-95	151.10	N	1/2/2009 12:20:46 AM	1/2/2009 5:00:12 AM	4:39:26	[jp3][jl3]SAFETY FIRST[nl][jl3]DRIVE[nl][jl3]SOBER
2121	I-95	151.10	N	1/2/2009 9:54:57 AM	1/2/2009 11:55:07 AM	2:00:10	[jp3][jl3]SAFETY FIRST[nl][jl3]DRIVE[nl][jl3]SOBER

Based on Incident and DMS message attributes such as date, time, location etc the data match is performed

OID	Incident Start Type	Type	Activity Time	Road	Activity	Details
151407	11/9/2008 4:03:12 PM	Disabled Vehicle	09-Nov-2008 4:02 PM	I-95	Roadway Marker Init	Value = I-95 R @ MM14.5
151407	11/9/2008 4:03:12 PM	Disabled Vehicle	09-Nov-2008 4:02 PM	I-95	Lanes Total Init	Value = 2
151407	11/9/2008 4:03:12 PM	Disabled Vehicle	09-Nov-2008 4:02 PM	I-95	Lat/Lon/Alt Init	Value = 38.686447/-77.22763/0.0
151407	11/9/2008 4:03:12 PM	Disabled Vehicle	09-Nov-2008 4:03 PM	I-95	ConfirmedBy Init	Value = NONE
151407	11/9/2008 4:03:12 PM	Disabled Vehicle	09-Nov-2008 4:03 PM	I-95	Detect Source Init	Value = Other
151407	11/9/2008 4:03:12 PM	Disabled Vehicle	09-Nov-2008 4:03 PM	I-95	Incident Type Init	Value = Disabled Vehicle
151407	11/9/2008 4:03:12 PM	Disabled Vehicle	09-Nov-2008 4:03 PM	I-95	Lanes Total Updated	Old Value=2 New Value = 3
151407	11/9/2008 4:03:12 PM	Disabled Vehicle	09-Nov-2008 4:03 PM	I-95	Roadway Marker Updated	Old Value=I-95 R @ MM14.5 New Value =I-95 N @ MM162.0

Incident Data Format

Figure 5.5 DMS Data Synthesis



1	SIGNS	ROAD	CATEGORY	DEVICE_LOCATION	DATE	TIME	AUTHOR	HOST	LOG_TEXT
2	0760	I-95	Advisory	Exit 152 - RT 234 Dumfries Rd	6/6/2008	0:49:03	DMS "0760"	com3	DMS "0760" error status is now 0x104: Power Failure, Controller Failure (was 0x42: Comm Failure, Ph
3	0760	I-95	Advisory	Exit 152 - RT 234 Dumfries Rd	6/6/2008	0:49:03	DMS "0760"	com3	Operational status changed to [HW FAIL]
4	0700	I-95	Advisory	Exit 150 - RT 619 Fuller Rd	6/6/2008	0:49:11	DMS "0700"	com3	DMS "0700" error status is now 0x6: Comm Failure, Power Failure (was 0x146: Comm Failure, Power
5	0700	I-95	Advisory	Exit 150 - RT 619 Fuller Rd	6/6/2008	0:49:11	DMS "0700"	com3	Operational status changed to [sign OK]

Incident Database Format

DMS Database Format

ID	Date	MILE POST	COUNTY	ROUTE	Start	Detect	Verify	Response	Recovery	End	≥15 min	≥30 min	≥45 min	≥90 min	>90 min	≥15 min
INNO2011790	1/17/2008	176 South	Fairfax	I-95	11:30	11:30	11:30			11:45	15					
INCE2008106	1/26/2008	86.5 South	Hanover	I-95	17:45	17:45	17:45	17:50		18:03						18
INNO1033313	8/20/2008	130 South	Spotsylvania	I-95	17:27	17:27	17:27			17:42						

Figure 5.6 Incident Data Synthesis

CHAPTER 6: MODELING METHODOLOGY

6.1 Introduction

As described in Chapter 1 of this dissertation, the focus of this research is to develop ITS Operations Evaluation Models (ITSOEMs) that fulfill the following two key research objectives:

- To develop analytical models to determine the measurable influence of incident detections in successfully disseminating messages on DMS, and
- To develop ITS Operations Evaluation Models to determine the effectiveness of DMS messages during incidents by quantifying the influence of DMS messages in the deterrence of secondary incidents.

The focus of this chapter is to present the details of the analyses of data sets developed in Chapter 5, and determine and develop suitable modeling methods that can appropriately employ the DMS operations data, ITS detection data and incident management data assembled for the I-95 Study Corridor. Furthermore, a detailed assessment of the data sets developed in Chapter 5 indicate that the DMS operations data from VDOT ATMS and Incident data from VA Traffic Database are a mix of continuous non-negative integer data and discontinuous data. For instance, the DMS message data and ITS detection data from CCTV, VSP-CAD and SSP activations are non-negative integer data; they primarily denote the presence or absence of the DMS and detection system activations during the occurrence of High Profile, Major Profile and Minor Profile incidents on the I-95 Study Corridor.

Also, from the incident data from VA Traffic database, the occurrence of High profile, Major Profile and Minor Profile incidents on the I-95 Study Corridor can also be coded as integer non- negative data. The other variables for consideration in this research, for the development of ITS Operations Evaluation Models (ITSOEMs), are incident duration (in minutes) and distance from incident location to DMS location (in miles) are clearly continuous data. Therefore, in order to achieve the desired modeling structure to develop ITSOEMs, it is evident from the I-95 analyses data that the response or dependent variable and the causal variable are in the discrete form and need modeling methods that can handle discrete data.

6.2 Model Selection for ITSOEM Development

The data and modeling methods observations were further clearly postulated and described by Washington et al (2); their book on “Statistics and Econometrics Methods for Transportation Data Analyses” emphasizes that in order to evaluate the effectiveness of ITS, it is critical to understand the nature of the ITS operations data. The authors explain that the nature of ITS operations data is generally similar to the count data which is non-negative integer data. This means that ITS data have a fixed number, such as number of activations of an ITS device, or if the ITS device is present or not, or the frequency of use of ITS deployed to achieve the desired results from ITS operations. Further, the authors confirm that “a common mistake is to model count data as continuous data and employ standard analytical methods such as regression techniques, and this is not correct as these methods yield predicted values that are not integers and these methods predict values that are negative which are inconsistent with the count data. These limitations make the application of the standard regression analyses inappropriate for modeling count data without modifying dependent variables.

In the same manner, additional assessment of analyses data sets developed in Chapter 5 indicated that the potential analyses data are binary or dichotomous and categorical in format and clearly point to the exploration and adoption of logistic regression methods as the most appropriate and suitable modeling technique to develop ITSOEMs. For example, the DMS message data can be further reduced as a dichotomous discrete variable and take the value 1 or 0, with a value 1 representing successful message data match with the incident data (indicating that the DMS was able to meet the initial success of displaying the message for the incident in question) and take the value of 0 when there is no message match with the incident (indicating a lack of DMS operational success). Similarly the incident detection systems data, CCTV, SSP and VSP-CAD and incident data, and High, Major and Minor profile data, can be converted to dichotomous binary analyses data. The remaining sections of this chapter are devoted to detailed discussion on: a) the appropriateness of Logistic Regression as the preferred modeling technique for this research, b) description of Logistic Regression modeling methodology, c) an Overview of Logistic Regression Applications, and d) Logistic Regression Models of ‘goodness-of-fit measures’ that are employed in assessing the modeling results.

6.3 Aptness of Logistic Regression Modeling Methods

Regression methods are very widely used as preliminary foundation efforts for developing predictive models and have become central to data analyses. For employing correct regression methods, a good understanding of the response or dependent variable is essential to achieve the desired results from such predictive models. In the usual regression methods, the dependent variable is assumed continuous and many a times such an assumption is not true. The usual regression methods are not appropriate when the response variable is not continuous and rather discrete.

Logistic regression is a statistical modeling method that is used for categorical response variables. It describes the relationship between the categorical response variable and one or more continuous and/or categorical explanatory variables. Logistic regression is used when explanatory variables are either continuous or categorical, and response variables are only categorical. For instance, consider the research objective to establish the relationship between pre-treatment of pavements with de-icing chemicals during snow and ice conditions, and the effectiveness of RWIS (Road Weather Information System) and road closure duration due to pavement freeze warnings. The objective is to quantify the extent of influence the RWIS has on the outcome of de-icing of the pavements through chemical treatments. In this example, the response or dependent variable is pre-treatment of the pavement (either pre-treated or not, with pre-treated as 1 and not pre-treated as 0), and the independent or explanatory variable is whether the RWIS was able to detect accurate pavement temperature and generate alerts in advance for the maintenance crew to initiate de-icing operations. In this case, we have the 2 x 2 case-control design because we have two levels in response variables (pre-treated pavement / not pre-treated pavement) and two responses in explanatory variables (RWIS effective/ RWIS not effective). If the research is also interested in the role of additional causal variables, such as lane closure duration, delays incurred due to pavement freeze etc., one can add "lane closure duration” and “delays incurred" as continuous variables. The logistic regression model tests whether the RWIS has an effect on the outcome “of pavement treatment” and whether the delays further influenced the ability to initiate pavement treatments. The variables, pavement treatment, RWIS operations, lane closure duration and delays incurred, try to find the best model which can predict the success of pavement de-icing operations.

The logistic regression model is useful when the focus of the research is to examine and develop analytical models based on the relationship between the categorical response variable and the categorical and/or continuous explanatory variables. Munley et al (112) have further specified in their research that, “the choice of categorical response variable precluded the use of other analytical methods that require the dependent variable be continuous and able to assume any value between - ∞ to + ∞.”

6.4 Logistic Regression Modeling Methodology

The Logistic Regression model, which is based on the cumulative logistic probability function ‘$F(Z_i)$’, is specified as follows Sinha et al (21), Munley (112) and Hosmer et al (113).

$$P_{(i)} = F(Z_i) = F\,(\beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \beta_pX_p\,) \quad (6.1)$$

where, F(Zi) is the Cumulative logistic probability function, β represents the coefficients of the explanatory variable X and ‘P (i)’ is the probability value of the cumulative probability and is defined as:

$$P_{(i)} = \frac{1}{1+e^{-z}} \quad (6.2)$$

Thus using (5.1) and (5.2) the cumulative logistic probability function further specified as follows:

$$P_{(i)} = \frac{1}{1+e^{-(\beta 0 + \beta 1 X1 + \beta 2 X2 + \ \beta 3 X3 + \beta 4 X4 + \beta 5 X5 + \beta 6 X6 \ \ldots\ldots + \beta p X p)}} \quad (6.3)$$

By rearranging the equations 6.2 and 6.3 we get the following equations:

$$P_{(i)} (1 + e^{-z}) = \frac{1}{1+e^{-z}} (1 + e^{-z}) \quad (6.4)$$

$$P_{(i)} + P_{(i)}\, e^{-z} = 1 \quad (6.5)$$

Multiplying both sides of the equation (6.5) by $1+e^{-Zi}$, we get

$$e^{-Zi} = \frac{1-Pi}{Pi} \quad (6.6)$$

Inverting the above equation we have

$$e^{zi} = \frac{Pi}{1-Pi} \quad (6.7)$$

By taking logarithm on both sides equation 6.7 becomes

$$Z_i = \log \left(\frac{Pi}{1-Pi}\right) = (\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ \beta_3 X_3 + \beta_4 X_4 .. + \beta_p X_p) \quad (6.8)$$

In the above equation (6.8) the $\beta_{1,}$ β_2 etc are the model coefficients representing the numeric weight or influence of independent variable on the dependent variable. Further the exponent of the coefficients $\beta_{1,}$ $\beta_{2,}$ called Odds ratio,, is critical for the analyses to be performed in this research. The odds ratio of each explanatory variable $X_{1,}$ $X_{2....}X_p$ is a measure of association and is used to interpret the estimated coefficients.

The odds ratio approximates how much more likely it is for the outcome to be present given the presence of the independent variable in the logistic regression. Therefore the logistic model transforms the focus of predicting probabilities within a (0/1) range to the objective of predicting the odds of an event occurring within the range.

This estimation of odds ratio for each of the independent variable becomes the fundamental crux of this research work and in the development of ITSOEMs. As one of the primary research objectives is to "develop ITS Operations Evaluation Models and perform analytical assessment of incident detections and determine their measurable influence in successfully disseminating messages on DMS"- the measurable influence of the ITS detection system is determined by predicting the odds of a particular detection system to detect the incident and successfully result in the dissemination of the message on DMS.

In the same manner for the other principal research objective which is aimed to “develop ITSOEMs and quantitatively determine the measurable influence of DMS messages on operations of the I-95 Study Corridor during incidents and events” the measurable influence of DMS messages on operations of the I-95 Study Corridor is determined by predicting the odds of disseminated messages on DMS that can result in the reduction of secondary incidents on I-95 Study Corridor.

6.5 Logistic Regression Models Validation and Goodness-of-Fit Estimates

The following key standard statistical significance tests and model estimates are used to evaluate the logistic regression models goodness-of-fit:

- -2 Log Likelihood
- Overall model Chi-Square Significance test
- Hosmer and Lemeshow Significance Test
- Wald Significance test
- Odds ratios and Class Interval

6.5.1 The -2 Log Likelihood

The “-2 Log likelihood" is the log likelihood statistic used in estimation of chi-square statistics. The -2 log-likelihood serves as a "baseline" value by which we can compare other models (e.g., between constant only versus with all predictors etc).

The goodness-of-fit indicator states that by introducing the independent variables the -2 Log likelihood value should decrease when compared to the constant only model – indicating that the addition of independent variables is improving the model performance.

6.5.2 Overall Model Significance Test-Chi Square Significance

The overall chi-square value is computed by taking a difference between the log likelihood at constant only and the log-likelihood for final model estimation run and compared for significance (and considered statistically significant at $p < .005$).

6.5.3 Hosmer and Lemeshow Test

The "Hosmer and Lemeshow Test" is a measure of fit which evaluates the goodness-of-fit between predicted and observed probabilities. Similar to the -2 log likelihood test, we want this chi-square value to be low and non-statistically significant if the predicted and observed probabilities match up nicely.

6.5.4 Model Coefficients Estimation and Wald Significance Test

The models coefficients are a major part of the logistic regression output and in addition to interpreting previous goodness-of-fit statistics, the interpretation of these coefficients is critical to this research. The Wald statistics is similar to the t-statistic conceptually, and is a test of the null hypothesis that the model coefficient is equal to 0. The null hypotheses is rejected at a specified significance level usually at $p<0.005$. Research citations and review guidance allows research discretion to include the variables in the final model (or increase the significance acceptance level) based on the independent variable’s prominence and significance to research objectives.

6.5.5 Odds Ratio and Class Interval

The Exponential value of the coefficient is called an "odds ratio" and is interpreted differently for continuous variable and categorical variables. For continuous variables, the odds ratio is interpreted as: an increase of 1 unit of the independent variable increases the odds of the occurrence of the dependent variable.

For categorical variable, the odds ratio indicates the scalar or magnitude of odds in percentage that the independent variable causes the occurrence of the dependent variable. The 95% confidence interval for the exponential value is used to determine if the value of the coefficient lies between the lower and upper limits of the class interval.

6.6 Logistic Regression Models Odds Ratios Applications

In the last 15 years, the logistic regression has become the most prominent and accepted method of analyses of binary outcome variables. This is attributed to “the ease of interpretation of results from logistic regression fitted models and the power of estimated odds ratios in explaining the influence of independent variables on the dependent variables", Hosmer D.W. et al (113). To this effect logistic regression methods are widely used in transportation research. Munley et al (112) successfully used logistic regression methods to determine the safety ratings for urban bicycle routes and used the odds ratios to determine the influence of independent variables such as "pavement width, traffic volume, traffic density, one-way operations, pavement riding surface, route choice, truck composition, time of day (day light vs. night time)" on the dependent variable "the propensity of selection of the bicycle route". Sinha et al (21) estimated odds ratios using logistic regression methods to determine ITS benefits for Indiana's Borman Expressway. The authors estimated odds of secondary incidents occurrence by developing predictive logistic regression models that consist of secondary incidents as binary outcome or dependent variable (i.e., takes the value of 0 for primary incidents that are not followed by secondary incidents and 1 for primary incidents followed by secondary incidents) and incident duration, incident clearance time, trucks presence in vehicle composition and winter weather conditions as independent variables. After fitting the models, the odds ratios for each of the independent variable were used to interpret their individual influence in causing the occurrence of secondary crashes. Similar applications by Pandey et al (114) and Cottrell (115) have confirmed that the logistic regression methods are the preferred analytical frameworks to research and develop evaluation frameworks when the analyses data sets consist of both continuous and dichotomous variables.

In Chapter 7 details of the dependent and response variables selection to develop the ITSOEMs are presented. The final analyses data sets developed in Chapter 5 are further synthesized to prepare the input data files consisting of the selected dependent and independent variables. Using the Logistic Regression methods the ITSOEMs are constructed and model assessments and results are presented.

CHAPTER 7: DEVELOPMENT OF ITS OPERATIONS EVALUATION MODELS (ITSOEMS)

7.1 Introduction

This chapter is devoted to the development of ITSOEMs that are expected to quantitatively evaluate ITS operations. To achieve this core research objective two sets of models are developed. The ITSOEM1 are expected to measure or quantify the success of DMS operations based on DMS message dissemination as outcomes resulting from detection and verification of incidents on the I-95 Study Corridor. The ITSOEM2 are intended to quantify the tangible influence of DMS messages on the occurrence of secondary incidents and the influence of incident duration on the I-95 Study Corridor. Both sets of models, ITSOEM1 and ITSOEM2, are developed for urban and transition I-95 Study Corridor segments. Two principal foundation underpinnings form the basis for developing the ITSOEM1 and ITSOEM2:

- For developing ITSOEM1 the dependent variable “DMS Messages” is in binary (0/1) form. It takes the value of 0 for incident detections that are not followed by message dissemination on DMS and 1 when detections are followed by message dissemination on DMS. Based on this the modeling’s sole purpose is designed to determine the probability that a DMS message occurs given the descriptors of the detections and incidents. Figure 7.1 shows the ITSOEM1 binary structure of the dependent variable.

- In the same manner the dependent variable for ITSOEM2 “secondary incidents” once again takes binary (0/1) form. It takes the value 0 for incidents that are not followed by secondary incidents and takes the value of 1 when primary incidents are followed by secondary incidents.

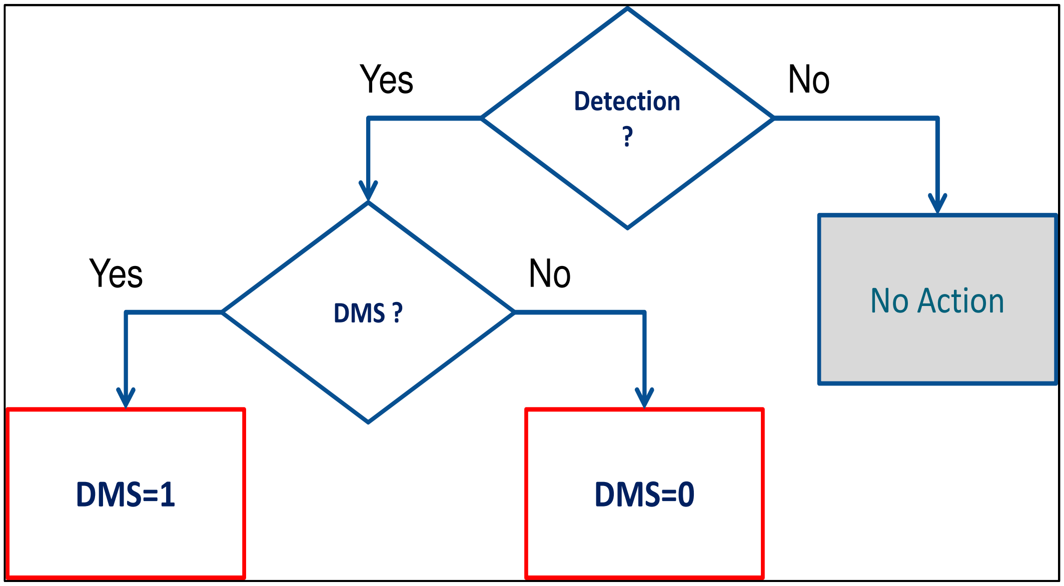


Figure 7.1 ITSOEM1 Binary Data Structure

Figure 7.2 shows the ITSOEM2 binary structure of the dependent variable.

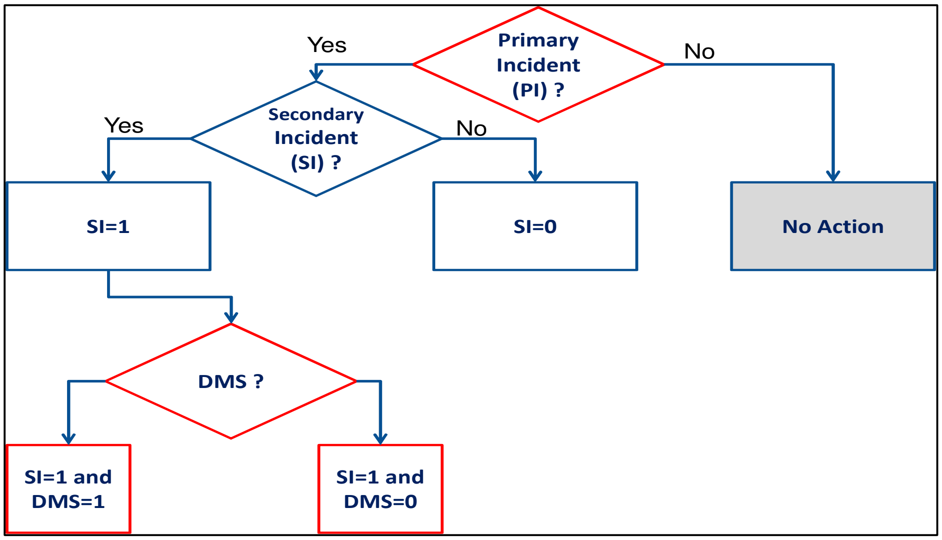


Figure 7.2 ITSOEM2 Binary Data Structure

Further in discussions with VDOT operations staff the following I-95 Corridor’s incident operations criteria were used to denote secondary incidents:

- All incident records in the final data sets prepared for the OEM development were initially considered as Primary Incidents;
- The demarcated secondary incident occur within 4.5 miles from the primary incident;
- The demarcated secondary incident occur within 30 minutes from the end time of the primary incident;
- The secondary incident was at a downstream location to the primary incident; and
- The secondary incident was in the same cardinal direction of the primary incident.

7.2 Selection of ITSOEM Variables

In order to determine and quantify the success and effectiveness of DMS operations and link the likelihood of dissemination of messages on DMS with the detection operations and incidents occurrence, a series of explanatory variables were considered for possible inclusion into the logistic regression models ITSOEM1 and ITSOEM2. For ITSOEM1, the variables selected were expected to provide quantifying results that help determine which incident detection system enhances the likelihood of dissemination messages on the DMS. For ITSOEM2, the variables are expected to provide quantifying results that determine the measurable influence of disseminated messages on traffic conditions on I-95 Study Corridor. Following a full scale evaluation of DMS operations data, incident management and operations data, and detection system operations data, the variables described in the following sections were expected to influence the likelihood of message dissemination and their concurrent influence on the I-95 Study Corridor operations and were considered for inclusion into the logistic regression models ITSOEM1 and ITSOEM2.

7.2.1 CCTV Detections (D_{CCTV})

CCTV Detections are Incident detection resulting from Closed Circuit Television (CCTV) camera surveillance operations – It is assumed that the likelihood of dissemination of message on DMS signs is influenced by the CCTV traffic surveillance operations. The 24 x 7 live streaming video data into Traffic Operations Center provides seamless real time information on roadway conditions. The incidents occurring on roadways are detected by CCTV units and instantly provide live updates on incident management in progress, thereby enhancing the likelihood of posting messages on DMS signs. This is a dichotomous variable coded as 0/1. (A value of 0 indicates that the incident is not detected by CCTV and a value of 1 denotes that the incident is detected by CCTV).

7.2.2 Virginia State Police Computer Aided Dispatch Detections (D_{VSPCAD})

Virginia State Police Computer Aided Detections are Incident detections resulting from the 24 x7 State Emergency Operations 911 VSP Computer Aided Dispatch (CAD) operations – by far the most authentic incident detections and verifications are considered to occur once the alerts come from 911 VSP-CAD operations. The likelihood of disseminating a message on DMS is expected to be very high for incidents that are detected and verified by VSP-CAD operations. This is a dichotomous variable coded as 0/1. (A value of 0 indicates that the incident is not detected by VSP-CAD and a value of 1 denotes that the incident is detected by VSP-CAD).

7.2.3 Safety Service Patrol Detections (D_{SSP})

Safety Service Patrol Detections are the only incident detections that involve human interface with incident management and operations in a real time manner. By virtue of their constant roving operations amidst traffic streams, it is often the SSP operator who will be the first to know the incidents as they occur on roadways and who provides the quickest alerts and updates to Traffic Operations Centers resulting in a high likelihood of message dissemination on DMS. This is also a dichotomous variable coded as 0/1 (A value of 0 indicates that the incident is not detected by SSP and a value of 1 denotes that the incident is detected by SSP).

7.2.4 High Profile Incidents (I_{HIGH})

High Profile Incident are the severe type incidents that are complex and cause intense long-duration incident impacts such as crashes involving tanker trailer over turns, multiple vehicle crashes, and Hazmat spills leading to a minimum of 90 minutes and extending to several hours lane closures. These High Profile Incidents involve specialized towing and MediEvac operations and at times lead to the complete shutdown of roadways in both travel directions. Such severe incidents are certain to get all the attention from first responders, law enforcement operations and Traffic Operations Centers causing major mobility disruptions at a regional scale and have the largest likelihood of incident detection and message dissemination on DMS. This is a dichotomous variable coded as 0/1. (A value of 0 indicates that the incident is not a high profile incident and a value of 1 denotes that the incident is a high profile incident).

7.2.5 Major Profile Incidents (I_{MAJOR})

Major Profile Incidents are the incidents that are severe enough to block one or more lanes for a considerable duration, and may involve two or more vehicles. They also may involve severe injuries and road closures lasting anywhere from 30 to 60 minutes, causing significant traffic disruptions during all hours and having a good likelihood of being detected by the detection systems and resulting in message dissemination. This is a categorical variable coded as 0/1. (A value of 0 indicates that the incident is not a Major Profile Incident and a value of 1 denotes that the incident is a Major Profile Incident).

7.2.6 Minor Profile Incidents (I_{MINOR})

Minor Profile Incidents are the incidents that result from fender bender type crashes, disabled vehicles, and debris spills leading to temporary lane closures lasting anywhere from 15 minutes to 45 minutes. They are still capable of causing severe backups and traffic hindrances particularly during AM and PM hours and have a reasonably significant likelihood of being detected and causing message dissemination on DMS signs. This is also a categorical dichotomous variable coded as 0/1. (A value of 0 indicates that the incident is not a Minor Profile Incident and a value of 1 denotes that the incident is a Minor Profile Incident).

7.2.7 Incident Duration ($I_{DURATION}$)

Several research studies have confirmed that incident duration is one of the strong indicators of impacts resulting from any type of incident. It is also expected that by providing real time and accurate updates on incidents to motorists through message dissemination on DMS. There is a likelihood of reduction in incident duration. This is one of the continuous variables used in this research.

7.2.8 Distance to DMS Location (D_{DMS})

It is anticipated that in spite of successful detection of incidents, the proximity of DMS location to the incident location will define the prudency of message dissemination. The farther the distance of DMS location from the incident location, the lesser the likelihood a message will be disseminated on the DMS.

7.2.9 Approach Volume ($V_{App.Vol}$)

This is defined as the downstream approach volume to the incident location. This variable is meant to provide insightful inferences such as the greater the volume the greater the propensity of secondary incident occurrence and/or the greater the chance of message dissemination, the lesser the propensity of secondary incident occurrence.

7.2.10 Secondary Incidents ($SecInc_{=1/0}$)

Secondary incidents are expected to occur when incident duration increases. Studies confirmed that there is a strong likelihood of secondary crash occurrence when there is increased incident duration. This variable is used as a dependent or response variable to determine the impacts resulting from disseminating messages on DMS and their effectiveness in the deterrence of secondary incidents on the I-95 Study Corridor. This is a dichotomous categorical variable bearing the value of 0 for no secondary incidents following the primary incident and 1 when a secondary incident is found to occur following the primary incident.

7.2.11 DMS Messages ($DMS_{MESSAGES=0/1}$)

DMS message is the dichotomous dependent variable bearing the value of 0 when no message is disseminated for an incident in consideration and 1 when the message is disseminated.

7.3 Development of Design Variables for ITSOEM1 and ITSOEM2

The analyses data sets developed in Chapter 5 are further refined and the data inputs for analyses variables and analyses scenarios are assembled to develop ITSOEM1 and ITSOEM2. As it can be observed from the analyses data sets, the detection system has three sub-categories, namely CCTV, VSP-CAD and SSP, and the incident profile also consists of High, Major and Minor sub-categories. In order to account for the comparative characteristics of which of the three detection system are relatively effective in the detection of incidents followed by dissemination of messages on DMS signs, the three detection system independent variables are further formatted to fit into the logistic regression procedures by designating one of the detection systems as the reference variable and the ITSOEM1 models are developed to quantify the relative influence of the other two detection variables. After specifying the reference variable within the analyses data, the other two analyses variables used for ITSOEM1 and ITSOEM2 are recognized as Design Variables. A summary of the employed design variables and reference variables matrix used for developing ITSOEM1 and ITSOEM2 models and the detailed procedures employed to create design and reference variables are presented in Appendix A. The selection of the reference variable is usually based on the research and analyses objectives. For instance, the ITSOEMS1 and ITSOEM2 models that consist of SSP detections and Minor Profile Incidents as reference variables are considered to portray the real time ITS operations that are prevalent on the urban and transition segments of I-95 Study Corridor. This is primarily owing to the VDOT operations program administration protocols that constituted CCTV and VSP-CAD detection systems as automated and integrated incident management components into VDOT's Advanced Traffic Management Systems (ATMS) and VDOT VA Traffic database operations system. The SSP detection systems are considered operational primarily as a demand-response operations protocol systems and are frequently subjected to severe budget severances.

7.4 Analyses Scenarios

The analyses scenarios considered for ITSOEM model building were established in such a manner that the passenger, freight and high occupancy lanes operations that define the traffic and regional mobility attributes for I-95 Study Corridor are captured by ITSOEMs. The ITSOEM models are developed for 5 analyses scenarios for NB and SB urban and transition segments of I-95

Study Corridor and include: a) 5 AM – 1 PM b) 1 PM – 9 PM and c) 9 PM – 1PM for urban segments and d) 6 AM – 6 PM and e) 6 PM – 6 AM for transition segments.

7.5 ITSOEM1 and ITSOEM2 Model Building Process

Hosmer and Lemeshow (113) and Harrel (116) and Greenland (117) cautioned that the acceptance of logistic regression models is not solely based on statistical significance and goodness-of-fit criteria. Greenland (117) noted that mere selection of model variables based on statistical significance values and not taking into account the effect of individual variables as they enter into model runs will lead to rejection of certain variables that may be critical for achieving the research objectives. This may end up producing a final effects model that is statistically competent but may not produce results that can be put into application framework. Following these guidelines, a model development framework is developed that can construct statistically viable ITSOEMs that use as many analyses variables that are identified as essential for the development of ITSOEM1 and ITSOEM2 models. To achieve this, block-wise logistic regression modeling framework method is adopted to identify a set of model variables that individually and collectively improve the overall ITSOEM performance.

In the block-wise logistic regression model, the independent variables are grouped into distinct sets, and each set is entered into the model as series of blocks. The 1st step in the block-wise ITSOEM building process denoted as $Block_0$ is a 'null model' meaning the ITSOEM $Block_0$ model is built up of constant only model and no other independent variables are entered. Figures 7.3 and 7.4 show the ITSOEM1 and ITSOEM2 block-wise model building frameworks.

For ITSOEM1 the incident profile independent variables I_{HIGH}, I_{MAJOR}, I_{MINOR} are entered as Block 1, followed by detection system variables D_{CCTV}, $D_{VSP,}$ D_{SSP} as Block 2, and d_{DMS} and $DMS_{APP\ VOL}$ as Block 3. Similarly, for ITSOEM2, the incident profile variable are entered as Block 1, $DMS_{=0,1}$ as Block 2, $I_{DURATION}$ as Block 3 and d_{DMS} and $DMS_{APP\ VOL}$ as Block 4.

Following the 'null model' successive sequential block-wise logistic regression models are developed. The following goodness-of-fit statistical measures as described below are comparatively assessed to determine how the ITSOEM variables have performed, both within the block and from one block to another block, as compared to statistical outcomes recorded for the 'null model'.

- The -2 Log Likelihood Ratio test – The likelihood ratio is defined as the ratio of likelihood of an event occurring determined from using the 'null model' to that of the likelihood of the same event determined using an alternative model. The logarithm of this likelihood ratio is called -2Log Likelihood Ratio and is used to compute a p-value or compared to a critical value to decide whether to reject the null model in favor of the alternative model. As the logarithm of the likelihood ratio is used, the statistic is known as a log-likelihood ratio statistic and denoted as -2LL.

- Chi-Square Significance Test – The difference between the two -2LL ratios is called the deviance and is used to perform the Chi-Square significance test. The deviance value computed between successive block-wise models is used to signify and validate which block of variables, by adding to the model, is enhancing model performance to accurately predict the dependent variable. The deviance value at any given model building stage is a comparative indicator with the 'null model' – and provides how the overall model performance is better (or not) with any number of variables entered as compared to the 'null' model (i.e., null model with constant only and with zero variables). The acceptable chi-square significance for deviance is 0.05.
- Hosmer and Lemeshow Significance Test – this is used to evaluate the goodness-of-fit between predicted and observed probabilities. Here the null hypotheses is set to examine if the model can effectively predict the dependent variable which is $\text{DMS}_{=0/1}$ for ITSOEM1 and $\text{SecInc}_{=0/1}$ for ITSOEM2. The hypothesis is rejected if the results are not significant at 0.05.

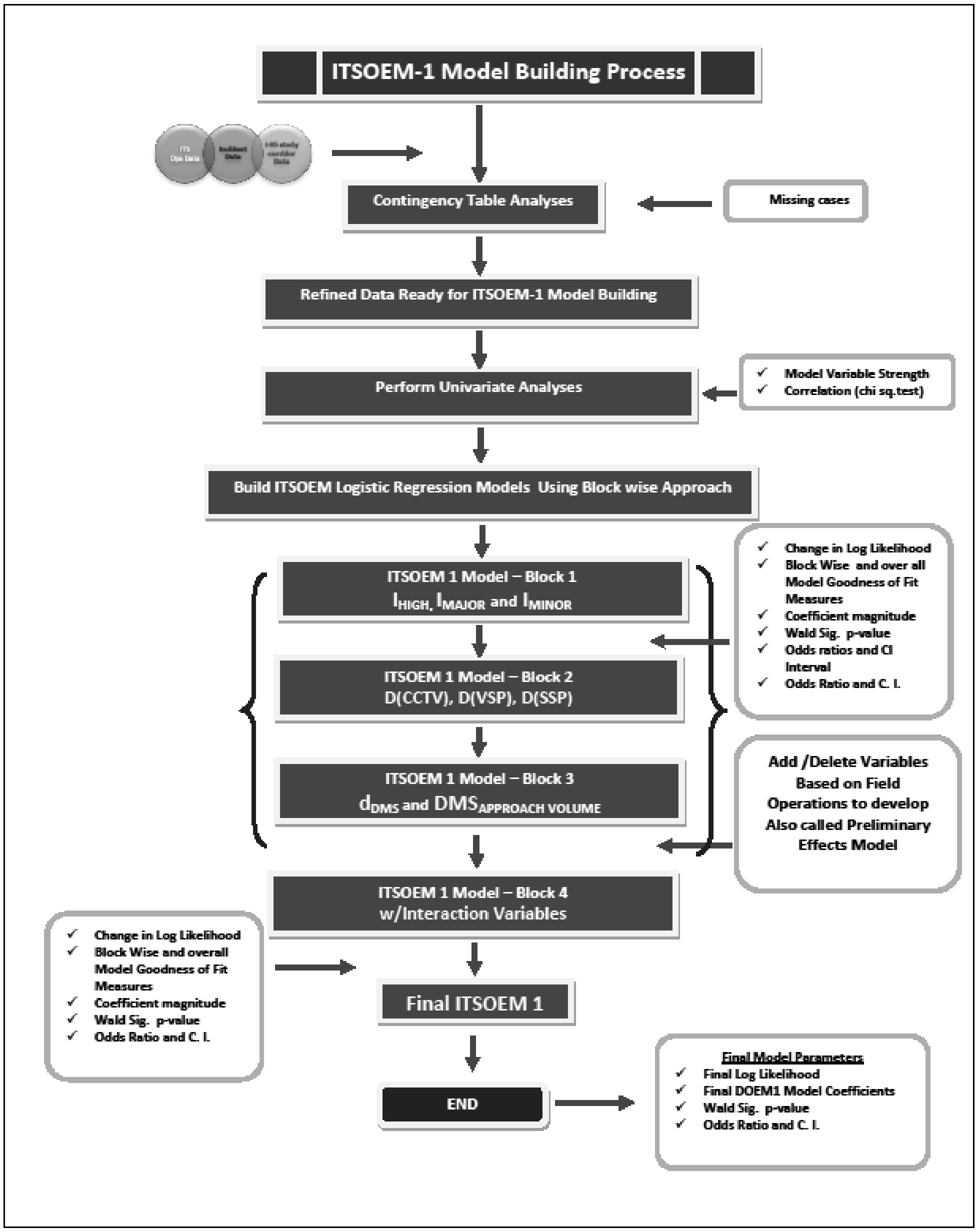


Figure 7.3 ITSOEM1 Model Building Process

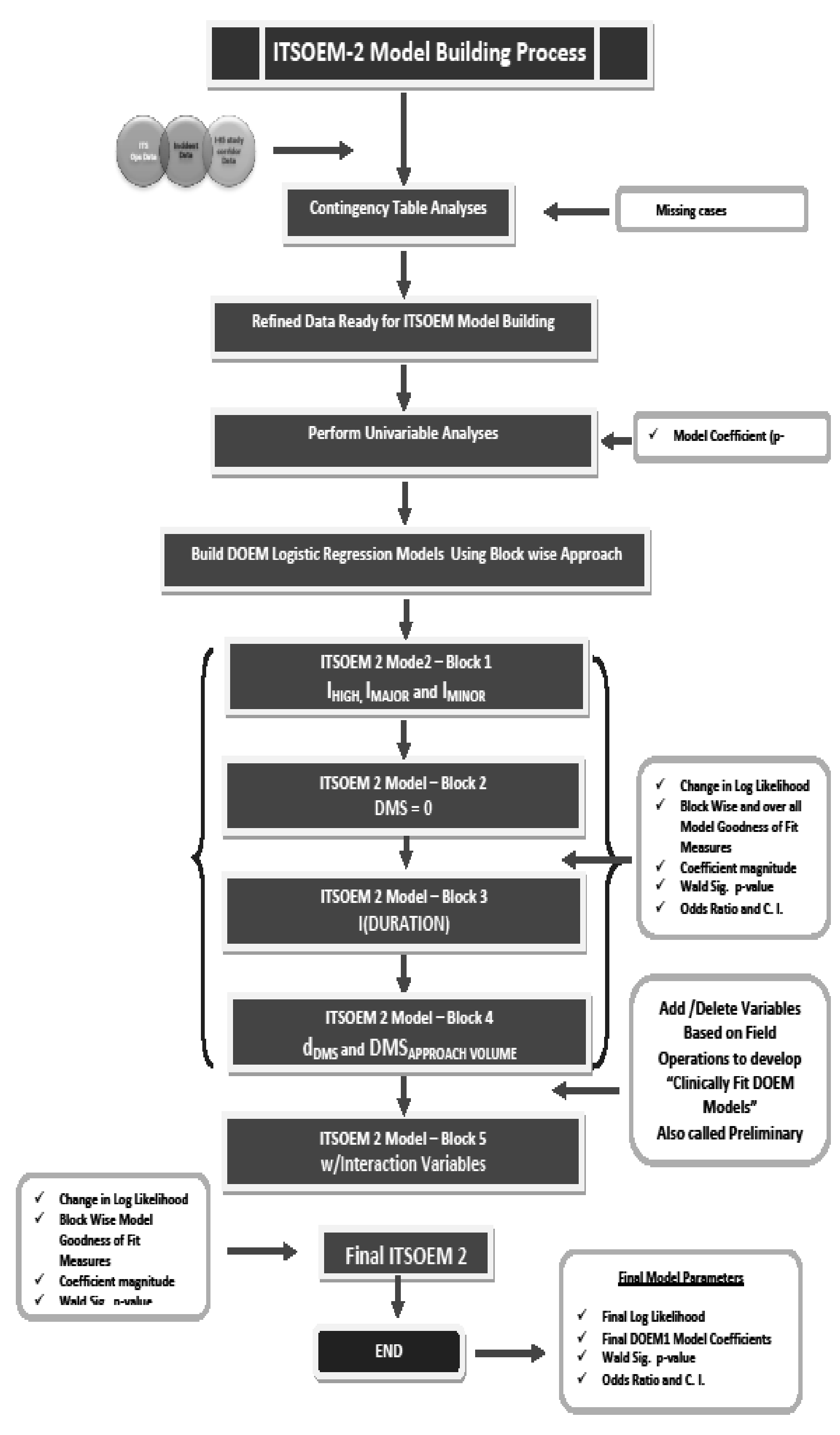


Figure 7.4 ITSOEM2 Model Building Process

- Wald Significance Test - is conceptually similar to the t-statistic and is a test of the null hypothesis that the model coefficient is equal to 0. This test primarily provides validation of the statistical soundness of the inclusion of individual variables in the model.
- Odds ratios and Class Interval – The exponential of the ITSOEMs coefficient, also known as Odds ratio, is one of the critical determining outcomes that quantifies ITS operations during incidents. It is essential to statistically validate the odd ratio. The 95% confidence interval for the exponential value is used to determine if the value of the coefficient lies between the lower and upper limits of the class interval.

7.6 ITSOEM1 and ITSOEM2 Model Development

Using SPSS 19 software, the block-wise logistic regression model runs are performed, the model parameters are summarized to assess the goodness-of-fit measures, and the final effects model is selected. The developed ITSOEM1 and ITSOEM2 models take the following generic functional form:

$$\text{ITSOEM1}_{(\text{DMS}=1/0)} = f(D_{\text{CCTV}}, D_{\text{SSP}}, D_{\text{VSPCAD}}, I_{\text{HIGH}}, I_{\text{MAJOR}}, I_{\text{MINOR}}, d_{\text{DMS}}, V_{\text{AppVol}})$$

$$\text{ITSOEM2}_{(\text{Sec Inc}=1/0)} = f(I_{\text{HIGH}}, I_{\text{MAJOR}}, I_{\text{MINOR}}, D_{\text{DMS}=0/1}, I_{\text{DURATION}}, d_{\text{DMS}}, V_{\text{AppVol}})$$

where, for ITSOEM1 models, DDMS = 1/0 is the dependent variable and DCCTV, DSSP, DVSPCAD, IHIGH, IMAJOR, IMINOR, ddms, VApp Vol are independent variables and for ITSOEM2 models, Sec Inc = 0/1 is the dependent variable and IHIGH, IMAJOR, IMINOR, DDMS=0/1, IDURATION, dDMS, and VApp Vol are the independent variables.

For the analyses scenarios described earlier (in section 7.3) and based on the design variables selection criteria (as described in appendix A), the ITSOEM building process is implemented using SPSS Version 19 and 180 ITSOEM1 models and 60 ITSOEM2 models (a total of 240 models) are developed. To demonstrate the application potential of ITSOEMs, the ITSOEM1 and ITSOEM2 models are also developed for High Profile only, Major Profile only and Minor Profile only incidents. The analyses scenarios along with design variables options are presented in Appendix B. As evident from the discussions in Appendix B the 240 ITSOEMs are developed using all design variable and reference variable matrix options feasible within this research scope and for all the five analyses time periods identified in section 7.3.

7.7 ITSOEM1 and ITSOEM2 Model Presentation

To illustrate the application of ITSOEM building process, to describe the application of goodness-of-fit measures employed and to present the ITSOEM modeling results in a meaningful and comprehensive manner, a set of key analyses scenarios are selected that encompass and portray ITS operations during all critical operating conditions of the I-95 Study Corridor. Further, as discussed in an earlier section (section 7.2), these selected ITSOEM models are built using SSP detections and Minor Profile Incidents as reference variables and CCTV, VSP-CAD and High Profile and Major profile as design variables. The selected analyses scenarios for presentation of ITSOEM model estimates include:

- For I-95 northbound urban segments the ITSOEM1 and ITSOEM2 Models are presented for 5am-1pm and 9pm-5am analyses scenarios.
- For I-95 southbound urban segments the ITSOEM1 and ITSOEM2 Models are presented for 1pm-9pm and 9pm-5am analyses scenarios.
- For I-95 northbound and southbound transition segments the ITSOEM1 and ITSOEM2 Models are presented for 6am-6pm and 6pm-6am analyses scenarios.

The above specified ITSOEMs are selected for presentation such that the analyses scenarios will depict the full 24-hour operations conditions for the I-95 Study Corridor which include: a) the I-95 urban segment’s northbound peak AM duration traffic flows that typically occur during 5 AM – 1 PM, b) the I-95 urban segments southbound peak PM duration traffic that typically occur during 1PM – 9 PM on SB, c) I-95 urban corridor segments’ both northbound and southbound off-peak directions that exhibit similar traffic flow and non-recurring congestion characteristics and that occur during 9 PM – 9 AM hours, and finally c) the I-95 Study Corridor's north and southbound transition segments typical traffic flows analyzed as two distinct analyses scenarios covering 6am – 6pm and 6pm- 6am.

The primary objective in the presentation of the ITS model goodness-of-fit estimates is to highlight how the model estimates are used to screen and select model variables for the ITSOEM block-wise models building stage and also serve as the basis for the selection of final effects ITSOEMs. Therefore, to illustrate the prudent use of ITSOEM goodness-of-fit measures at block-wise and final effects ITSOEM building stages the complete suite of goodness-of-fit measures estimated for ITSOEM1 and ITSOEM 2 models including: a) – 2 Log Likelihood Ratio, b) Model Chi Square Significance, c) Block-wise Chi Square – Deviance, d) Hosmer Lemeshow Significance e) model coefficient estimate, f) Wald Significance test – p value, g) Odds ratio and h) Odds ratio Class Interval are discussed in detail only for the I-95 NB Urban segment's 5am – 1pm analyses scenario. However, for the remaining analyses scenarios selected for presentation in this section, although the complete suite of model goodness-of-fit measures are applied at the block- wise modeling and final effects model selection stages, only the final effects model estimates including: a) model coefficient estimate, b) Wald Significance test – p value, c) Odds ratio, and d) Odds ratio Class Interval estimate are presented.

A complete output for all models and the pertinent goodness-of-fit measures and model estimates for 240 ITSOEM model are summarized in Tables B3-B20 in Appendix B.

7.7.1 I-95 NB Urban Segment 5am-1pm Analyses Scenario ITSOEM1 Model Estimates

The ITSOEM1 model block-wise goodness-of-fit measures estimated for I-95 Urban NB segments during 5am to 1pm hours of operations indicated that the inclusion of incident profile and ITS detection variables into ITSOEM1 models consistently improved the performance of ITSOEM1 models. Figure 7.5 shows the block-wise -2 Log Likelihood (-2LL) ratio and model deviance values for ITSOM1 models; the consistent decline of -2LL ratios with 568.381 for Block 0 - which is constant only ITSOM1 model to 552.100 for Block 1 (ITSOEM1 Model consisting of Incident Profile variables only), and to 532.209 to Block 2 (consisting of Incident Profile and Incident Detection variables) confirm that - incident profile variables and detection variables have contributed significant predictability strength to the ITSOEM1 model. However, a reduced -2LL value for Block 3 indicates that the addition of ‘Approach Volume’ and ‘distance to DMS location’ as independent variables did not add any significant strength to the ITSOEM1 model. Additional Chi-square significance tests at a ‘p’ value of 0.05 are shown in Figures 7.5 and Figures 7.6. The ‘p’ values for Block 1 and Block 2 variables remain significant at 0.000 confirming that the incident profile and detection variables continue to prove as candidate final variables for ITSOEM1 model, while at a ‘p’ value of 0.226, the Block 3 variables do not meet the significance test for further consideration. The Hosmer and Lemeshow significance test as presented in Figure 7.7 confirmed that the ITSOEM1 model variables exhibited good predictability hence rejecting the null hypotheses for this test that the model is not capable of predicting the dependent variable. Additional model runs were performed to develop final effect ITSOEM1 model that also included verification of any possible interaction between the selected independent variables. The detection system independent variable 'D_{CCTV}' and distance to DMS location variable 'd_{DMS}' variables exhibited interaction and met the significance test. The final effects ITSOEM1 model coefficient estimates, Wald Significance test 'p' values, odds ratios and class interval for Odds ratios are summarized in Table 7.1. The 'p' values for the ITSOEM1 model coefficients with the exception of D_{VSPCAD} variable, confirm that the model coefficients are significant at 0.05 'p' value and can predict the model outcomes effectively. The Confidence Interval for the Odds ratios estimated for these model coefficients are also observed to be within the acceptable limits.

The $D_{VSP\text{-}CAD}$' variable at a 'p' value of 0.304 (an acceptable value is at or below 0.05) with Odds ratio of 0.687 and at a Class Interval of 0.336-1.406 (with a value of 1.00 being in the range) is the only variable that has exhibited poor significance. However, due to the D_{VSPCAD} variable significance to the research and its contribution to overall ITSOEM1 explanatory strength as confirmed in block-wise model building significance tests, this variable is included in the final effects ITSOEM1 model.

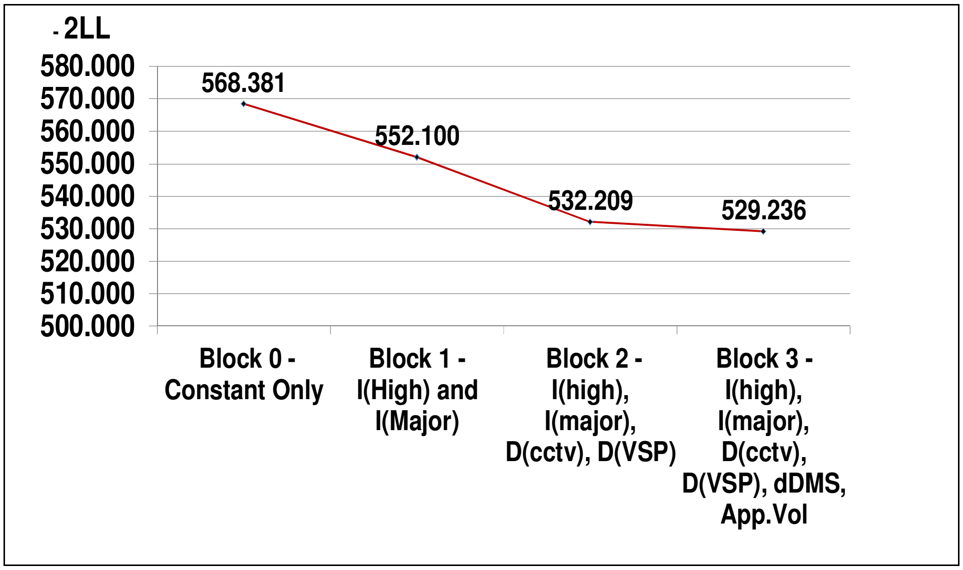


Figure 7.5 ITSOEM1 Goodness-of-Fit Measures – The -2 Log Likelihood for I-95 NB Urban Segment (5am-1pm)

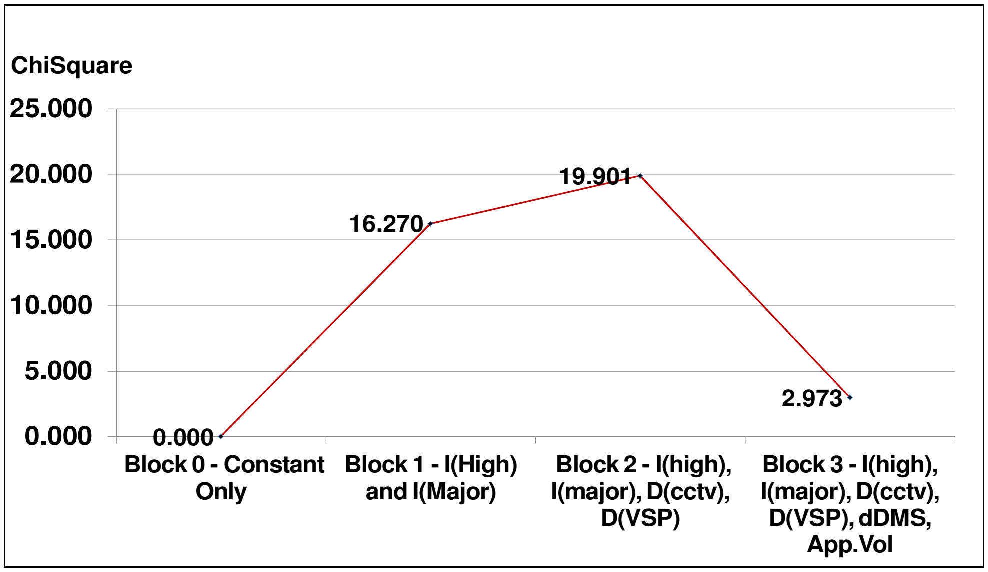


Figure 7.6 ITSOEM1 Goodness-of-Fit Measures - Block Wise Chi Square Deviance for I-95 NB Urban Segment (5am-1pm)

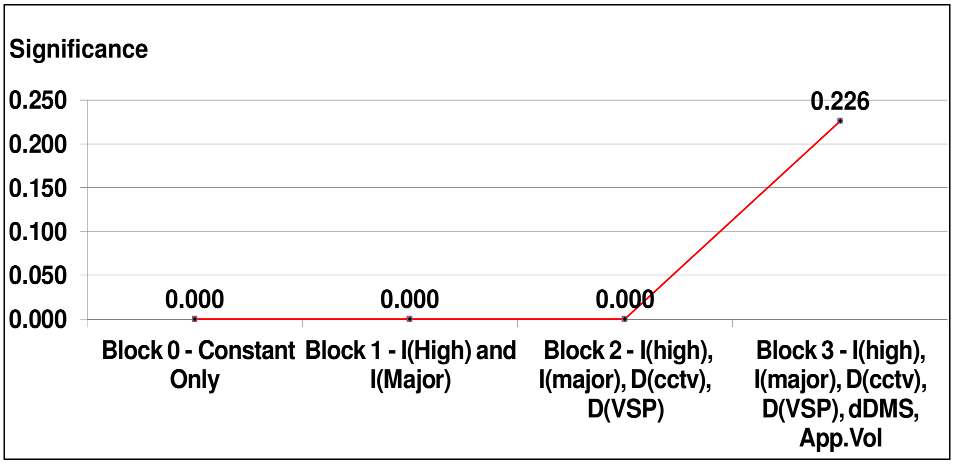


Figure 7.7 ITSOEM1 Goodness-of-Fit Measures - Block Wise Chi Square Significance (p-value) for I-95 NB Urban Segment (5am-1pm)

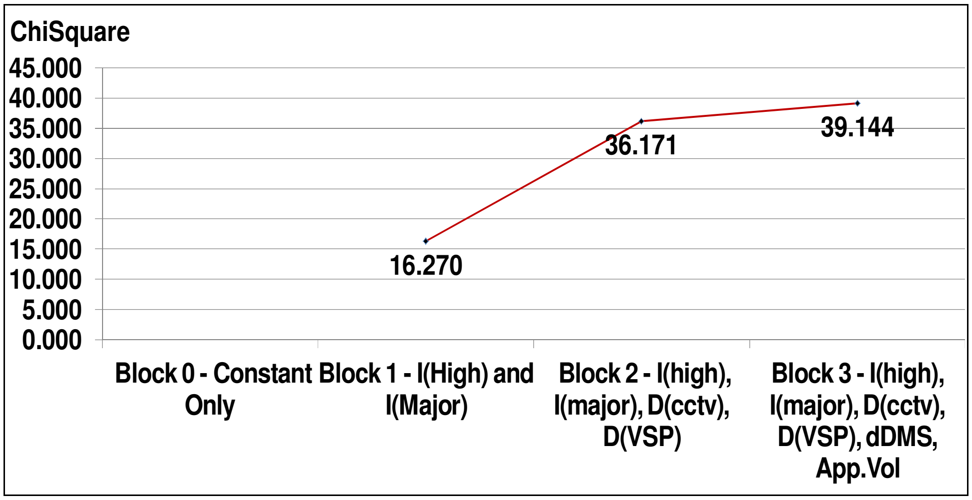


Figure 7.8 ITSOEM1 Goodness-of-Fit Measures – Model Chi Square Deviance for I-95 NB Urban Segment (5am-1pm)

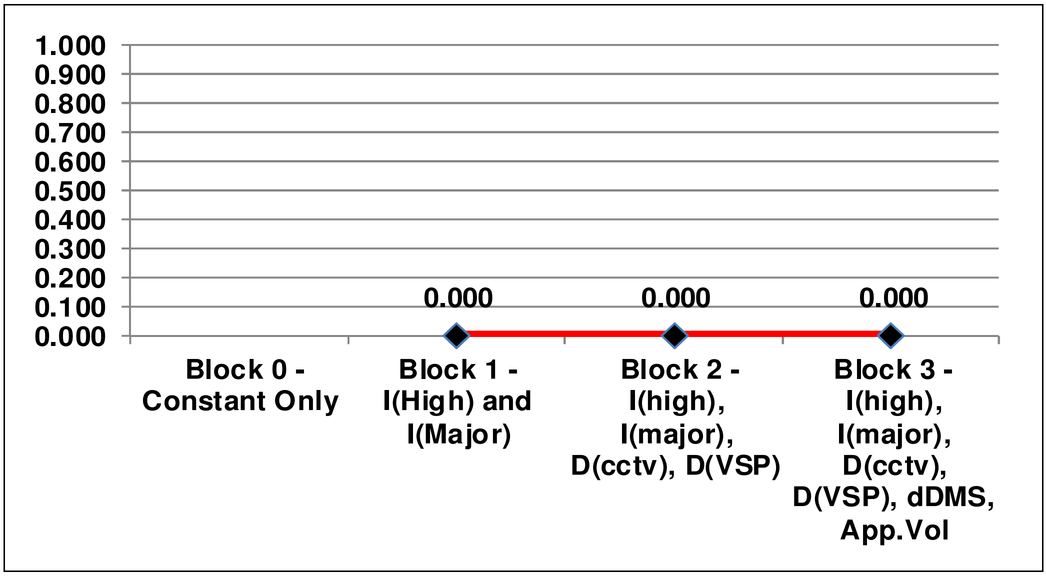


Figure 7.9 ITSOEM1 Goodness-of-Fit Measures – Model Chi Square Significance (p-value) for I-95 NB Urban Segment (5am-1pm)

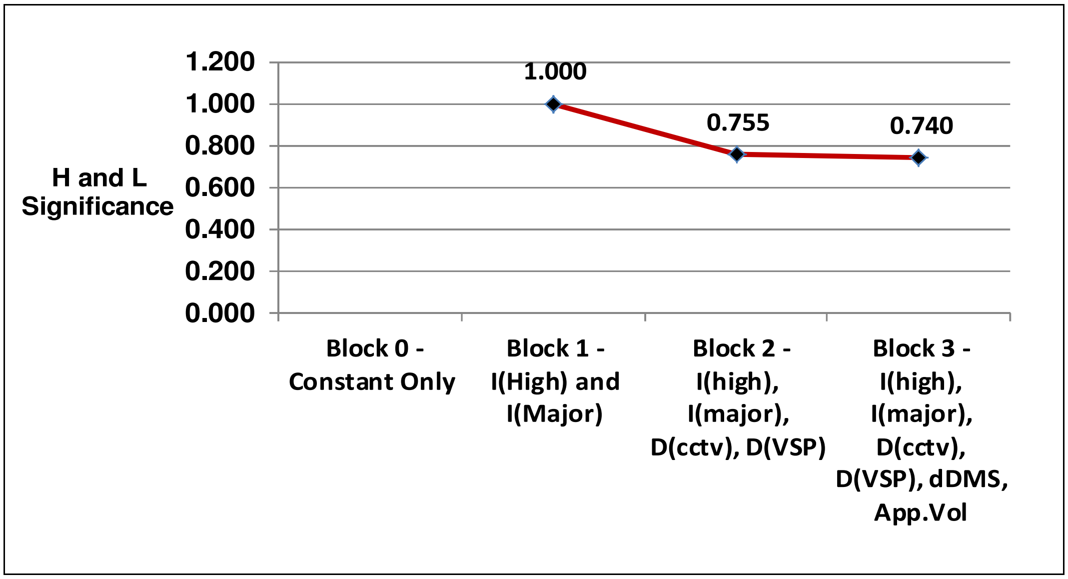


Figure 7.10 ITSOEM1 Goodness-of-Fit Measures - Hosmer and Lemeshow Significance (p-value) for I-95 NB Urban Segment (5am-1pm)

Table 7.1 ITSOEM1 Final Effects Model Estimates for I-95 NB Urban 5am-1pm Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
D_{CCTV}	1.534	0.004	4.639	1.650-13.039
$D_{VSP\text{-}CAD}$	-0.375	0.304	0.687	0.336-1.406
$I_{HIGH\ PROFILE}$	1.154	0.000	3.170	1.775-5.659
$I_{MAJOR\ PROFILE}$	0.522	0.026	1.686	1.065-2.671
d_{DMS}	0.255	0.032	1.290	1.023-1.627
D_{CCTV}*d_{DMS}	-0.412	0.012	0.662	0.480-0.913
Constant	-1.524	0.000	0.218	

Based on the above goodness-of-fit analyses, the final effects ITSOEM1 model for I-95 NB Urban Segment and for 5am – 1pm analyses scenario is:

$$\log\left(\frac{Pi}{1-Pi}\right)_{DMS=0/1} = -1.524 + 1.534\, D_{CCTV} - 0.375\, D_{VSPCAD} + 1.154\, I_{HIGH} + 0.522 I_{MAJOR} + 0.255\, d_{DMS} - 0.412 * D_{CCTV} * d_{DMS}$$

7.7.2 I-95 NB Urban Segment 5am-1pm Analyses Scenario ITSOEM2 Model Estimates

The ITSOEM2 model block-wise goodness-of-fit measures estimated for I-95 Urban NB segments during 5am to 1pm hours of operations indicated that the inclusion of incident profile variables, $DMS_{=0,1}$, and $I_{DURATION}$ variables into the model building process consistently improved the performance of ITSOEM2 models. Figure 7.9 shows the block-wise -2 Log Likelihood (-2LL) ratio and model Deviance values for ITSOM2 models; the consistent decline of -2LL ratios with 486.927 for Block 0 - which is constant only ITSOEM2 model to 479.662 for Block 1 (ITSOEM2 Model consisting of Incident Profile variables only), to 468.390 for Block 2 (ITSOEM2 model consisting of Incident profile and $DMS_{=0,1}$ variable) and to 458.551 for Block 3 (ITSOEM2 model that now includes $I_{DURATION}$ variable) confirm that incident profile variables, $DMS_{0,1}$ variable and $I_{DURATION}$ variable have contributed significant predictability strength to the ITSOEM2 model. However, similar to the ITSOEM1 Models, with a reduced -2LL value for Block 4 indicated that the addition of 'Approach Volume' and 'distance to DMS location' as independent variables did not add any significant strength to the ITSOEM2 model. Additional Chi-square significance tests at a 'p' value of 0.05 are shown in Figures 7.10 and Figures 7.11. The 'p' values for Block1, Block 2 and Block 3 variables remain significant at 0.000 confirming that the incident profile, $DMS_{=0,1}$ and $I_{DURATION}$ variables continue to prove as final variable candidates for ITSOEM2 model. At a 'p' value of 0.972, the Block 4 variables do not meet the significance test for further consideration. The Hosmer and Lemeshow significance test, as presented in Figure 7.11, confirmed that the ITSOEM2 model variables exhibited good predictability, hence rejecting the null hypotheses for this test that the model descriptors are not capable of predicting the dependent variable. Additional model runs were performed to develop final effects ITSOEM2 model to verify for any possible interaction between the selected independent variables and found no interaction amongst the ITSOEM2 variables.

For ITSOEM2, the model runs were performed for two distinct DMS conditions: a) DMS = 0 condition, when the incident detection was not followed by message dissemination on DMS and b) DMS = 1 condition – when the incident detection was followed by message dissemination on DMS. The ITSOEM2 model coefficient estimates, Wald Significance test 'p' values, odds ratios and class interval for Odds ratios for ITSOEM2 are summarized in Tables 7.2 and 7.3.

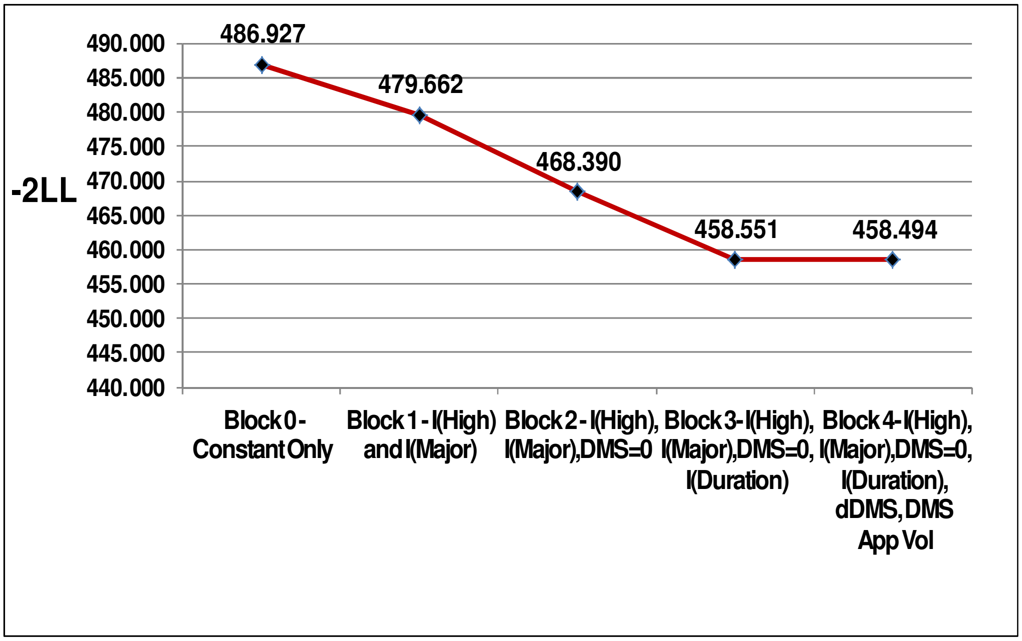


Figure 7.11 ITSOEM2 Goodness-of-Fit Measures – The -2 Log Likelihood for I-95 NB Urban Segment (5am-1pm)

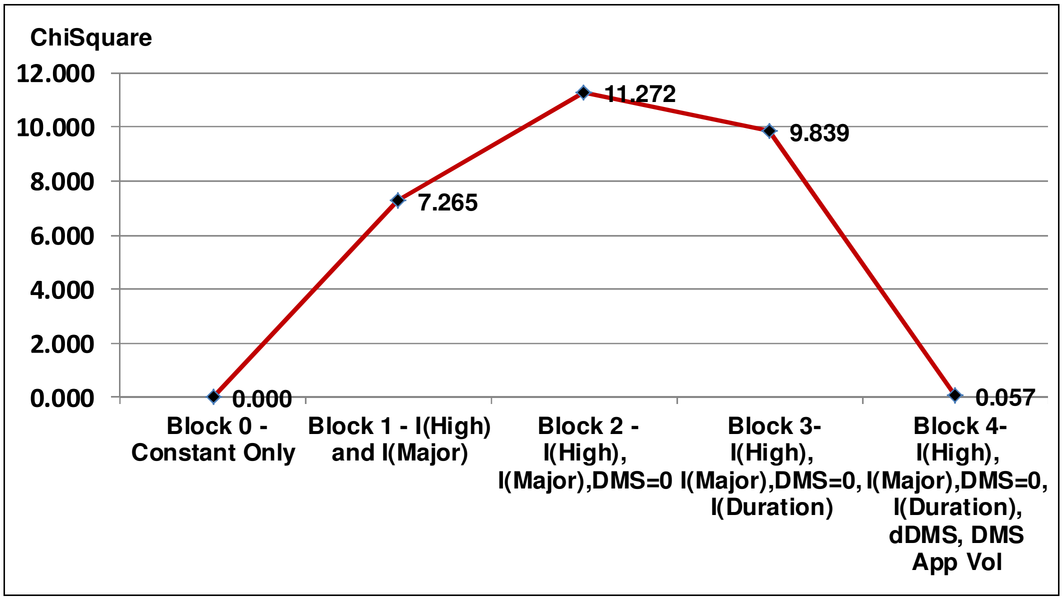


Figure 7.12 ITSOEM2 Goodness-of-Fit Measures – Block Wise Chi Square Deviance for I-95 NB Urban Segment (5am-1pm)

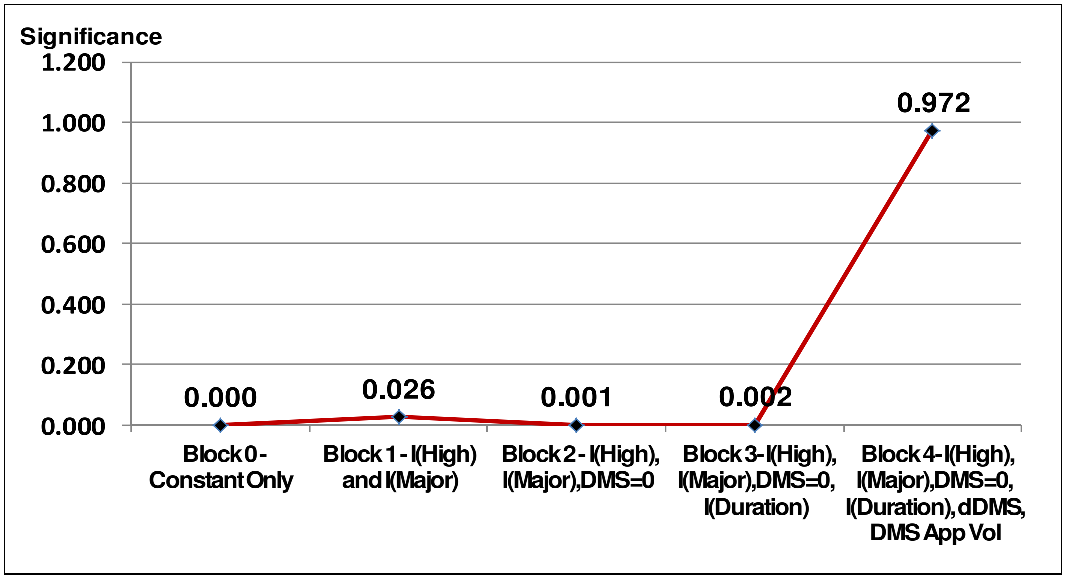


Figure 7.13 ITSOEM2 Goodness-of-Fit Measures – Block Wise Chi Square Significance (p-value) for I-95 NB Urban Segment (5am-1pm)

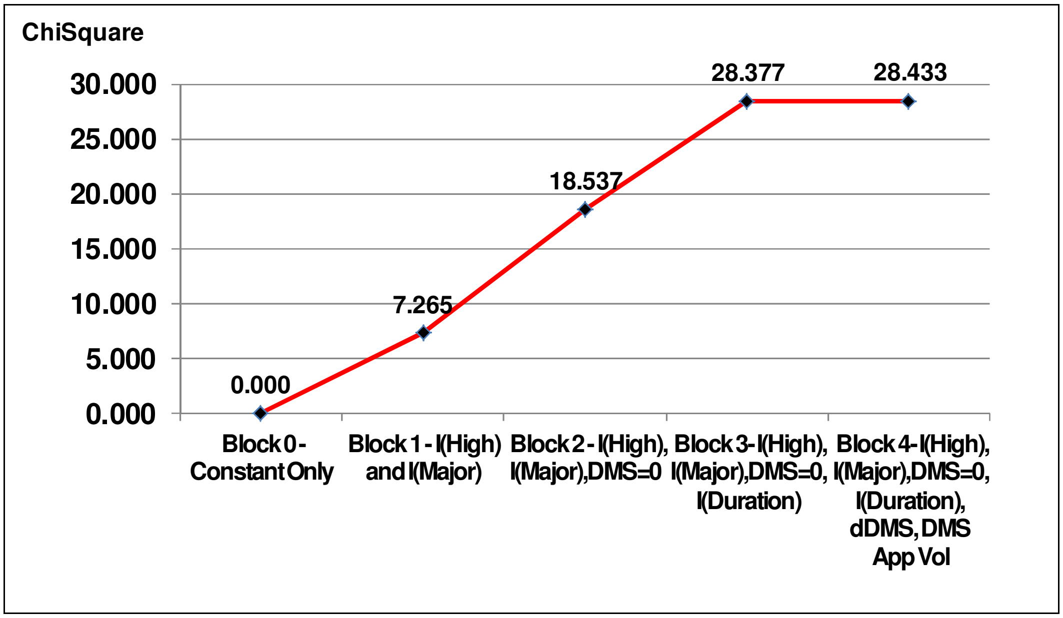


Figure 7.14 ITSOEM2 Goodness-of-Fit Measures – Model Chi Square Deviance I-95 NB Urban Segment (5am-1pm)

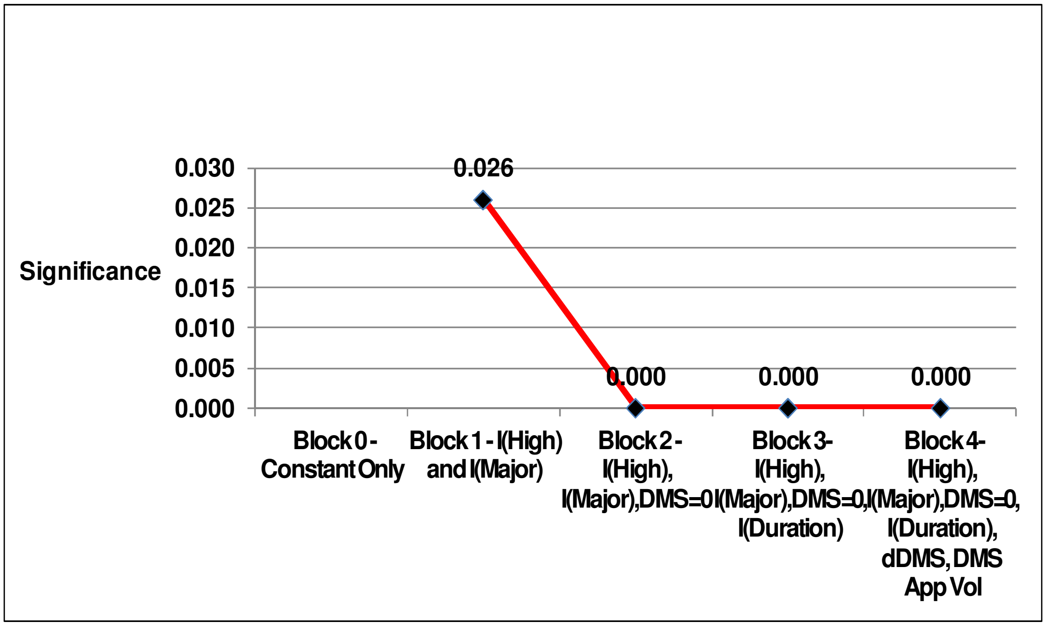


Figure 7.15 ITSOEM2 Goodness-of-Fit Measures - Model Chi Square Significance (p-value) for I-95 NB Urban Segment (5am-1pm)

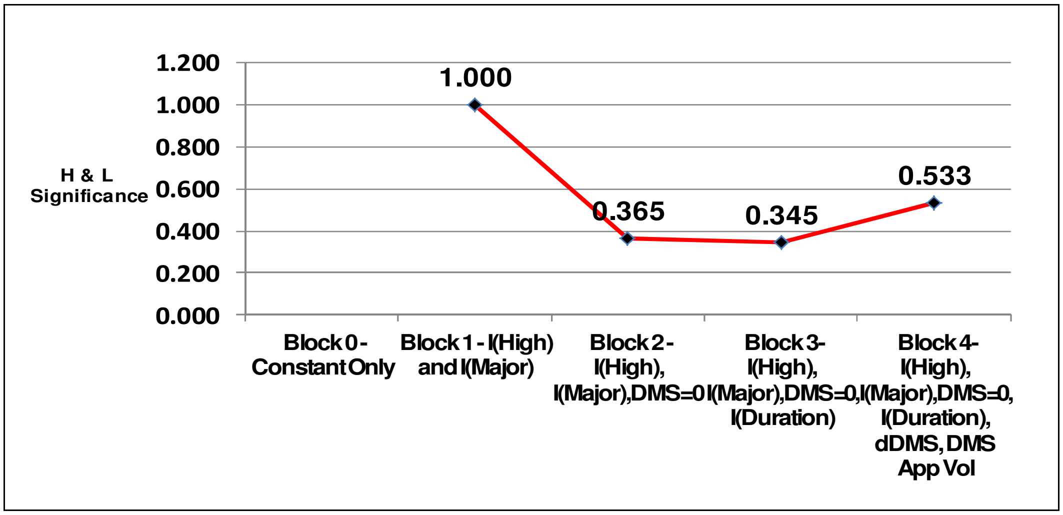


Figure 7.16 ITSOEM2 Goodness-of-Fit Measures - Hosmer and Lemeshow Significance (p-value) for I-95 NB Urban Segment (5am-1pm)

Table 7.2 ITSOEM2 Model Coefficient for DMS = 0 Condition for I-95 NB Urban 5am-1pm Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
$DMS_{=0}$ condition	0.849	0.001	2.338	1.422-3.844
$I_{DURATION}$	0.009	0.004	1.009	1.003-1.016
$I_{HIGH\ PROFILE}$	0.920	0.004	2.509	1.330-4.731
$I_{MAJOR\ PROFILE}$	0.557	0.031	1.745	1.053-2.893
Constant	-2.504	0.000	0.082	

The ‘p’ values for the ITSOEM2 model coefficients confirm that the model coefficients are significant at 0.05 ‘p’ value and are capable of predicting the model outcomes effectively. The Confidence Interval for the Odds ratios estimated for these model coefficients are also observed to be within the acceptable limits.

Table 7.3 ITSOEM2 Model Coefficient for DMS = 1 Condition for I-95 NB Urban 5am-1pm Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
$DMS_{=1\ condition}$	-0.849	0.001	0.428	0.260-0.703
$I_{DURATION}$	0.009	0.004	1.009	1.003-1.016
$I_{HIGH\ PROFILE}$	0.920	0.004	2.509	1.330-4.731
$I_{MAJOR\ PROFILE}$	0.557	0.031	1.745	1.053-2.893
Constant	-1.654	0.000	0.191	

Based on the above goodness-of-fit analyses, the final effects of the ITSOEM2 model for I-95 NB Urban Segment and for 5am – 1pm analyses scenario and for DMS=0 condition the following ITSOEM2 Model is developed.

$$\log\left(\frac{Pi}{1-Pi}\right)_{SecInc=0/1} = -2.504 + 0.849\ DMS_{=0} + 0.009\ I_{DURATION} + 0.920 I_{HIGH} + 0.557\ I_{MAJOR}$$

Also, for DMS = 1 condition the following ITSOEM2 model is obtained.

$$\log\left(\frac{Pi}{1-Pi}\right)_{SecInc=0/1} = -1.654 - 0.849\ DMS_{=1} + 0.009\ I_{DURATION} + 0.920\ I_{HIGH} + 0.557\ I_{MAJOR}$$

As mentioned earlier, in the following sections, for the remaining ITSOEM models selected for presentation, only model coefficient estimates that lead to the selection of final effects ITSOEM1 and ITSOEM2 models are discussed. For these models, block-wise goodness-of-fit measures are not presented and the full details of goodness-of-fit measures are summarized in Appendix B.

7.7.3 I-95 SB Urban Segment 1pm-9pm Analyses Scenario ITSOEM1 Model Estimates

The ITSOEM1 model coefficient estimates, Wald Significance test ‘p’ values, odds ratios and class interval for Odds ratios are summarized in Table 7.4. The ‘p’ values for all coefficients confirm that the model coefficients can predict the model outcomes effectively. The Class Interval confirms that the estimated odds ratios are within the acceptable limits.

Table 7.4 ITSOEM1 Model Coefficient for I-95 SB Urban 1pm-9pm Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
D_{CCTV}	-0.698	0.035	0.498	0.260-0.951
$D_{VSP-CAD}$	-0..678	0.035	0.508	0.270-0.954
$I_{HIGH\ PROFILE}$	1.037	0.000	2.820	1.669-4.765
$I_{MAJOR\ PROFILE}$	0.773	0.000	2.167	1.412-3.325
Constant	-0.031	0.919	0.969	

Based on the above goodness-of-fit analyses, the final effects for the ITSOEM1 model for I-95 NB Urban Segment and for 5am – 1pm analyses scenario is:

$$\log \left(\frac{Pi}{1-Pi}\right)_{DMS=0/1} = -0.031 - 0.698\ D_{CCTV} - 0.678\ D_{VSPCAD} + 1.037\ I_{HIGH} + 0.773\ I_{MAJOR}$$

7.7.4 I-95 SB Urban Segment 1pm-9pm Analyses Scenario ITSOEM2 Model Estimates

The ITSOEM2 model coefficient estimates, Wald Significance test ‘p’ values, odds ratios and class interval for Odds ratios for ITSOEM2 are summarized in Table 7.5 and 7.6.

Table 7.5 ITSOEM2 Model Coefficient for DMS = 0 Condition for I-95 SB Urban 1pm-9pm Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
$DMS_{=0\ condition}$	0.838	0.000	2.312	1.445-3.699
$I_{DURATION}$	0.012	0.000	1.012	1.005-1.018
$I_{HIGH\ PROFILE}$	1.462	0.000	4.313	2.291-8.121
$I_{MAJOR\ PROFILE}$	1.084	0.000	2.955	1.701-5.135
Constant	-3.054	0.000	0.047	

The ‘p’ values for all coefficients confirm that the model coefficients are capable of predicting the model outcomes effectively. The Confidence Interval (CI) confirms that the Odds ratios are within the acceptable limits.

Table 7.6 ITSOEM2 Model Coefficient for DMS = 1 Condition for I-95 SB Urban 1pm-9pm Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
$DMS_{=1 \text{ condition}}$	-0.838	0.000	0.432	0.270-0.692
$I_{DURATION}$	0.012	0.000	1.012	1.005-1.018
$I_{HIGH\ PROFILE}$	1.462	0.000	4.313	2.291-8.121
$I_{MAJOR\ PROFILE}$	1.084	0.000	2.955	1.701-5.135
Constant	-2.216	0.000	0.109	

Based on the above goodness-of-fit analyses, the final effects for the ITSOEM2 model for I-95 SB Urban Segment and for 1pm – 9 pm analyses scenario is for DMS = 0 Condition, the developed ITSOEM2 model is:

$$\log \left(\frac{Pi}{1-Pi}\right)_{SecInc=0/1} = -3.054 + 0.838\ DMS_{=0} + 0.012\ I_{DURATION} + 1.462\ I_{HIGH} + 1.084\ I_{MAJOR}$$

and following is the ITSOEM2 model for DMS = 1 condition

$$\log\left(\frac{Pi}{1-Pi}\right)_{SecInc=0/1} = -2.216 - 0.838\ DMS_{=1} + 0.012\ I_{DURATION} + 1.462\ I_{HIGH} + 1.084\ I_{MAJOR}$$

7.7.5 I-95 NB Urban Segment 9pm-5am Analyses Scenario ITSOEM1 Model Estimates

The ITSOEM1 model coefficient estimates, Wald Significance test ‘p’ values, odds ratios and class interval for Odds ratios are summarized in Table 7.7. The ‘p’ values for all coefficients confirm that the model coefficients exhibit a poor significance. The odds ratios Class Interval has the value 1.0, confirming that the estimated odds ratios are not within the acceptable limits.

Table 7.7 ITSOEM1 Model Coefficient for I-95 NB Urban 9pm-5am Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
D_{CCTV}	-0.142	0.788	0.868	0.308-2.441
$D_{VSP\text{-}CAD}$	-0.263	0.600	0.769	0.288-2.054
$I_{HIGH\ PROFILE}$	0.760	0.082	2.139	0.909-5.037
$I_{MAJOR\ PROFILE}$	0.353	0.394	1.424	0.632-3.205
Constant	-0.081	0.862	0.922	

Based on the above, the ITSOEM1 model for I-95 NB Urban Segment and for 5am – 1pm analyses scenario takes the following form:

$$\log\left(\frac{Pi}{1-Pi}\right)_{DMS=0/1} = -0.081- 0.142\ D_{CCTV} - 0.\ 263\ D_{VSPCAD} + 0760\ I_{HIGH}+$$

$$0.353\ I_{MAJOR}$$

The 9pm – 5am analyses scenario is one of the significant analyses scenarios for the I-95 northbound urban segments. Hence the above model construct is pursued in spite of obtaining inadequate model significance estimates. As can be seen in the above presented ITSOEM1 model, the model coefficient estimate for D_{CCTV} variable only has a better Wald significance 'p' value approaching 0.082.

For this scenario, additional understanding of contributing factors that define the ITS operations needs to be explored to improve the model performance. For now, the model coefficient estimates are to be used with caution and for accurate model results interpretation, additional engineering and field operations judgment is warranted.

7.7.6 I-95 NB Urban Segment 9pm-5am Analyses Scenario ITSOEM2 Model Estimates

The ITSOEM2 model coefficient estimates, Wald Significance test 'p' values, odds ratios and class interval for Odds ratios are summarized in Table 7.8 and 7.9.

With the exception of the DMS_0 and $DMS_{=1}$ variables, the ‘p’ values for all other model coefficients confirm that the model coefficients exhibit a poor Wald significance. For these variables the odds ratios Class Interval has the value 1.0., confirming that the estimated odds ratios are not within the acceptable limits.

Table 7.8 ITSOEM2 Model Coefficient for DMS = 0 Condition for I-95 NB Urban 9pm-5am Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
$DMS_{=0\ condition}$	0.982	0.043	2.670	1.033-6.904
$I_{DURATION}$	0.047	0.882	1.048	0.568-1.931
$I_{HIGH\ PROFILE}$	0.514	0.381	1.673	0.529-5.291
$I_{MAJOR\ PROFILE}$	0.095	0.867	1.099	0.362-3.341
Constant	-2.304	0.000	0.100	

Table 7.9 ITSOEM2 Model Coefficient for DMS = 1 Condition for I-95 NB Urban 9pm-5am Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
$DMS_{=1\ condition}$	-0.982	0.043	0.375	0.145-0.968
$I_{DURATION}$	0.047	0.882	1.048	0.568-1.931
$I_{HIGH\ PROFILE}$	0.514	0.381	1.673	0.529-5.291
$I_{MAJOR\ PROFILE}$	0.095	0.867	1.099	0.362-3.341
Constant	-1.322	0.007	0.267	

The resulting possible ITSOEM2 model for I-95 NB Urban Segment and for 9pm – 5 am analyses scenario for DMS=0 condition is as follows:

$$\log\left(\frac{Pi}{1-Pi}\right)_{\mathrm{SecInc}=0/1} = -2.304 + 0.982\ \mathrm{DMS}_{=0} + 0.047\ I_{\mathrm{DURATION}} + 0.514 I_{\mathrm{HIGH}} + 0.095\ I_{\mathrm{MAJOR}}$$

and the resulting ITSOEM2 model for DMS = 1 condition is:

$$\log\left(\frac{Pi}{1-Pi}\right)_{\mathrm{SecInc}=0/1} = -1.322 - 0.982\ \mathrm{DMS}_{=0} + 0.047\ I_{\mathrm{DURATION}} + 0.514\ I_{\mathrm{HIGH}} + 0.095\ I_{\mathrm{MAJOR}}$$

For ITSOEM2, the 9pm – 5am analyses scenario is also one of the significant analyses scenarios for the I-95 northbound urban segments. Hence, the above model construct is pursued in spite of obtaining inadequate model significance estimates. As can be seen in the above presented ITSOEM2 model coefficient estimates, $\mathrm{DMS}_{=0}$ and $\mathrm{DMS}_{=1}$ are the only variables that have passed the Wald significance test at ‘p’ values approaching 0.042, which is lower than the acceptable 0.05 significance level.

For this scenario, additional understanding of contributing factors that define the ITS operations for I-95 Study Corridor needs to be explored to improve the model performance. For now, the model coefficient estimates are to be used as preliminary guidance. Further, the model building should be undertaken only after full evaluation of additional engineering and field conditions and complete assessment of all variables that influence the 9pm – 5am analyses scenario.

7.7.7 I-95 SB Urban Segment 9pm-5am Analyses Scenario ITSOEM1 Model Estimates

The ITSOEM1 model coefficient estimates, Wald Significance test ‘p’ values, odds ratios and class interval for Odds ratios are summarized in Table 7.10. The ‘p’ values for most of the coefficients confirm that the model coefficients exhibit good Wald significance. The odds ratios class interval also confirms that several estimated odds ratios are within the acceptable limits.

Table 7.10 ITSOEM1 Model Coefficient for I-95 SB Urban 9pm-5am Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
D_{CCTV}	0.033	0.947	1.034	0.391-2.731
$D_{VSP\text{-}CAD}$	-1.386	0.004	0.250	0.099-0.635
$I_{HIGH\ PROFILE}$	-0.897	0.060	0.408	0.160-1.038
$I_{MAJOR\ PROFILE}$	-0.827	0.033	0.437	0.204-0.936
Constant	1.005	0.030	2.733	

Based on the above, the ITSOEM1 model for I-95 NB Urban Segment and for 5am – 1pm analyses scenario takes the following form:

$$\log\left(\frac{Pi}{1-Pi}\right)_{DMS=0/1} = 1.005 + 0.033\ D_{CCTV} - 1.386\ D_{VSPCAD} - 0.897\ I_{HIGH} - 0.827\ I_{MAJOR}$$

The 9pm – 5am analyses scenario is also one of the significant analyses scenarios for the I-95 southbound urban segments. The ITSOEM1 model construct above consists of several model variables that exhibit acceptable or border line acceptable model significance estimates. As seen in the ITSOEM1 model presented above, the model coefficient estimate for D_{CCTV} variable has failed significantly with a high Wald significance ‘p’ value of 0.947. Overall as observed for the ITSOEM1 models for I-95 north and southbound urban segments for 9pm – 5am analyses scenario, additional understanding of contributing factors that define the ITS operations need to be explored to improve the model performance. For now, the model coefficient estimates are to be used with caution and for accurate model results interpretation additional engineering and field operations judgment is warranted.

7.7.8 I-95 SB Urban Segment 9pm – 5am Analyses Scenario ITSOEM2 Model Estimates

The ITSOEM2 model coefficient estimates, Wald Significance test ‘p’ values, odds ratios and class interval for odds ratios are summarized in Table 7.11 and 7.12. As evident from the table, ‘p’ values for all other model coefficients confirm that the model coefficients exhibit a poor Wald significance and the odds ratios class interval contains the value 1.0 confirming that the estimated odds ratios are not within the acceptable limits. The potential ITSOEM2 model for I-95 NB Urban Segment and for 9pm – 5 am analyses scenario and for DMS = 0 condition is:

$$\log\left(\frac{Pi}{1-Pi}\right)_{\text{SecInc}=0/1} = -2.030 + 0.257\ DMS_{=0} + 0.365\ I_{DURATION} - 0.881 I_{HIGH} + 0.110\ I_{MAJOR}$$

and for DMS=1 condition the ITSOEM2 model is:

$$\log\left(\frac{Pi}{1-Pi}\right)_{\text{SecInc}=0/1} = -1.722 - 0.257\ DMS_{=1} + 0.365\ I_{DURATION} - 0.881\ I_{HIGH} + 0.110\ I_{MAJOR}$$

Table 7.11 ITSOEM2 Model Coefficient for DMS = 0 Condition for I-95 SB Urban 9pm-5am Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
$DMS_{=0\ condition}$	0.257	0.558	1.293	0.546-3.061
$I_{DURATION}$	0.365	0.289	1.441	0.734-2.831
$I_{HIGH\ PROFILE}$	-0.881	0.223	0.414	0.100-1.711
$I_{MAJOR\ PROFILE}$	0.110	0.814	1.117	0.445-2.799
Constant	-2.030	0.000	0.131	

Table 7.12 ITSOEM2 Model Coefficient for DMS = 1 Condition for I-95 SB Urban 9pm-5am Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
$DMS_{=1\ condition}$	- 0.257	0.558	0.773	0.327-1.830
$I_{DURATION}$	0.365	0.289	1.441	0.734-2.831
$I_{HIGH\ PROFILE}$	-0.881	0.223	0.414	0.100-1.711
$I_{MAJOR\ PROFILE}$	0.110	0.814	1.117	0.445-2.799
Constant	-1.772	0.000	0.170	

The ITSOEM2 model construct above is pursued in spite of inadequate model significance estimates to develop preliminary insights on ITS operations during 9pm – 5am analyses scenario for I-95 southbound urban segment. As for other models identified for northbound segments, for this scenario additional understanding of contributing factors that define the ITS operations for I-95 Study Corridor needs to be explored to improve the model performance. The model coefficient estimates as presented here need to be used with caution. For accurate model results' interpretation, additional engineering and field operations judgment is warranted.

7.7.9 I-95 NB Transition Segment 6am-6pm Analyses Scenario ITSOEM1 Model Estimates

The ITSOEM1 model coefficient estimates, Wald Significance test 'p' values, odds ratios and class interval for odds ratios are summarized in Table 7.13.

Table 7.13 ITSOEM1 Model Coefficient for I-95 NB Transition 6am-6pm Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
D_{CCTV}	0.034	0.907	1.034	0.587-1.822
$D_{VSP\text{-}CAD}$	0.182	0.504	1.199	0.704-2.041
$I_{HIGH\ PROFILE}$	0.228	0.442	1.256	0.702-2.248
$I_{MAJOR\ PROFILE}$	0.349	0.135	1.418	0.897-2.242
Constant	-0.630	0.009	0.532	

The ‘p’ values for all coefficients confirm that the model coefficients exhibit a poor significance. The odds ratios class interval possesses the value 1.0 confirming that the estimated odds ratios are not within the acceptable limits.

Based on the above the ITSOEM1 model for I-95 NB transition segment and for 6am – 6pm analyses scenario takes the following form:

$$\log\left(\frac{Pi}{1-Pi}\right)_{DMS=0/1} = -0.630 - 0.034\ D_{CCTV} - 0.\ 182\ D_{VSPCAD} + \ 0228\ I_{HIGH} + 0.349\ I_{MAJOR}$$

The ITSOEM1 model construct above is pursued in spite of inadequate model significance estimates to develop preliminary insights on ITS operations during 6am – 6pm analyses scenario for the I-95 northbound transition segment. Additional understanding of contributing factors that define the ITS operations during 6am – 6pm duration for I-95 Study Corridor needs to be explored to improve the model performance. The model coefficient estimates as presented here need to be used with caution and for accurate model results' interpretation additional engineering and field operations judgment is warranted.

7.7.10 I-95 NB Transition Segment 6am-6pm Analyses Scenario ITSOEM2 Model Estimates

The ITSOEM2 model coefficient estimates, Wald Significance test 'p' values, odds ratios and class interval for Odds ratios are summarized in Table 7.14 and 7.15.

All ITSOEM2 model coefficients exhibit good Wald significance. The odds ratios class intervals determined for these coefficients confirm that the estimated odds ratios are well within the acceptable limits.

Table 7.14 ITSOEM2 Model Coefficient for DMS = 0 Condition for I -95 NB Transition 6am-6pm Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
$DMS_{=0 \text{ condition}}$	1.092	0.000	2.979	1.730-5.131
$I_{DURATION}$	0.012	0.001	1.013	1.005-1.020
$I_{HIGH\ PROFILE}$	1.478	0.000	4.386	2.242-8.582
$I_{MAJOR\ PROFILE}$	1.050	0.000	2.859	1.638-4.988
Constant	-3.153	0.000	0.043	

Table 7.15 ITSOEM2 Model Coefficient for DMS = 1 Condition for I-95 NB Transition 6am-6pm Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
$DMS_{=1\ condition}$	-1.092	0.000	0.336	0.195-0.578
$I_{DURATION}$	0.012	0.001	1.013	1.005-1.020
$I_{HIGH\ PROFILE}$	1.478	0.000	4.386	2.242-8.582
$I_{MAJOR\ PROFILE}$	1.050	0.000	2.859	1.638-4.988
Constant	-2.062	0.000	0.127	

The ITSOEM2 model for I-95 NB transition segment for 6am – 6pm analyses scenario for DMS = 0 condition is

$$\log\left(\frac{Pi}{1-Pi}\right)_{SecInc=0/1} = -3.153 + 1.092\ DMS_{=0} + 0.012\ I_{DURATION} + 1.478\ I_{HIGH} + 1.050\ I_{MAJOR}$$

and ITSOEM2 model for DMS = 1 condition is

$$\log\left(\frac{Pi}{1-Pi}\right)_{SecInc=0/1} = -2.062 - 1.092\ DMS_{=1} + 0.012\ I_{DURATION} + 1.478\ I_{HIGH} + 1.050\ I_{MAJOR}$$

7.7.11 I-95 SB Transition Segment 6am – 6pm Analyses Scenario ITSOEM1 Model Estimates

The ITSOEM1 model coefficient estimates, Wald Significance test ‘p’ values, odds ratios and class interval for Odds ratios are summarized in Table 7.16.

Table 7.16 ITSOEM1 Model Coefficient Estimates for I-95 SB Transition 6am-6pm Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
D_{CCTV}	0.303	0.293	1.353	0.770-2.377
$D_{VSP\text{-}CAD}$	-0.111	0.684	0.895	0.525-1.526
$I_{HIGH\ PROFILE}$	0.864	0.005	2.372	1.296-4.339
$I_{MAJOR\ PROFILE}$	-0.112	0.622	0.894	0.572-1.396
Constant	-0.186	0.439	0.830	

With the exception of the $I_{HIGH\ Profile}$ variable, the ‘p’ values for all other ITSOEM1 model coefficients exhibit poor Wald significance values. The odds ratios class interval possesses the value 1.0 confirming that the estimated odds ratios are not within the acceptable limits.

Based on the model estimates presented above, the potential ITSOEM1 model for I-95 SB transition segment for 6am – 6pm analyses scenario takes the following form:

$$\log\left(\frac{Pi}{1-Pi}\right)_{DMS=0/1} = -0.186 + 0.303\ D_{CCTV} - 0.111\ D_{VSPCAD} + 0.864\ I_{HIGH} - 0.112\ I_{MAJOR}$$

The ITSOEM1 model construct above is pursued in spite of inadequate model significance estimates to develop preliminary insights on ITS operations during 6am – 6pm analyses scenario for the I-95 southbound transition segment.

Additional understanding of contributing factors that define the ITS operations during 6am – 6pm duration for the I-95 Study Corridor need to be explored to improve the model performance.

The model coefficient estimates as presented here need to be used with caution and for accurate model results' interpretation additional engineering and field operations judgment is warranted.

7.7.12 I-95 SB Transition Segment 6am-6pm Analyses Scenario ITSOEM2 Model Estimates

The ITSOEM2 model coefficient estimates, Wald Significance test 'p' values, odds ratios and class interval for Odds ratios are summarized in Table 7.17 and 7.18.

Table 7.17 ITSOEM2 Model Coefficient for DMS = 0 Condition for I-95 SB Transition 6am-6pm Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
$DMS_{=0\ condition}$	0.437	0.072	1.549	0.962-2.493
$I_{DURATION}$	0.007	0.048	1.007	1.000-1.014
$I_{HIGH\ PROFILE}$	0.420	0.225	1.523	0.772-3.005
$I_{MAJOR\ PROFILE}$	0.243	0.372	1.275	0.747-2.176
Constant	-2.034	0.000	0.131	

Table 7.18 ITSOEM2 Model Coefficient for DMS = 1 Condition for I-95 SB Transition 6am-6pm Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
$DMS_{=1\ condition}$	-0.437	0.072	0.646	0.401-1.039
$I_{DURATION}$	0.007	0.048	1.007	1.000-1.014
$I_{HIGH\ PROFILE}$	0.420	0.225	0.131	0.772-3.005
$I_{MAJOR\ PROFILE}$	0.243	0.372	1.523	0.747-2.176
Constant	-1.597	0.000	0.202	

All ITSOEM2 model coefficients exhibit reasonably well to moderately approaching the acceptable ‘p’ value for passing Wald significance test. The odds ratios class intervals determined for these coefficients also appear to confirm that the estimated odds ratios are approaching acceptable limits.

The potential and plausible ITSOEM2 model for I-95 SB transition segment for 6am – 6pm analyses scenario and for DMS = 0 condition is

$$\log\left(\frac{Pi}{1-Pi}\right)_{\mathrm{SecInc=0/1}} = -2.034 + 0.437\ \mathrm{DMS}_{=0} + 0.007\ \mathrm{I}_{\mathrm{DURATION}} + 0.420\ \mathrm{I}_{\mathrm{HIGH}} + 0.243\ \mathrm{I}_{\mathrm{MAJOR}}$$

and for DMS = 1 condition the ITSOEM2 model is

$$\log\left(\frac{Pi}{1-Pi}\right)_{\mathrm{SecInc=0/1}} = -1.597 - 0.437\ \mathrm{DMS}_{=1} + 0.007\ \mathrm{I}_{\mathrm{DURATION}} + 0.420\ \mathrm{I}_{\mathrm{HIGH}} + 0.243\ \mathrm{I}_{\mathrm{MAJOR}}$$

The above ITSOEM12 model construct above is pursued in spite of moderate to acceptable model significance estimates, and is primarily used to develop preliminary insights on ITS operations during the 6 AM – 6 PM analyses scenario for the I-95 southbound transition segment. Additional understanding of the ITS operations during the 6 AM – 6 PM duration for the I-95 Study Corridor need to be explored to improve the model performance.

The model coefficient estimates as presented here need to be used with caution and for accurate model results' interpretation, additional engineering and field operations judgment is warranted.

7.7.13 I-95 NB Transition Segment 6pm-6am Analyses Scenario ITSOEM1 Model Estimates

The ITSOEM2 model coefficient estimates, Wald Significance test ‘p’ values, odds ratios and class interval for Odds ratios are summarized in Table 7.19. With the exception of D_{CCTV} variable, the ITSOEM2 model coefficients exhibit reasonably well to moderately approaching acceptable ‘p’ value for passing the Wald significance test. The odds ratios Class Intervals determined for these coefficients also appear to confirm that the estimated odds ratios are approaching to the acceptable limits.

Table 7.19 ITSOEM1 Model Coefficient Estimates for I-95 NB Transition 6pm-6am Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
D_{CCTV}	0.102	0.811	1.107	0.480-2.554
$D_{VSP\text{-}CAD}$	0.811	0.054	2.250	0.985-5.139
$I_{HIGH\ PROFILE}$	1.072	0.044	2.922	1.028-8.300
$I_{MAJOR\ PROFILE}$	1.134	0.004	3.109	1.433-6.744
Constant	-0.905	0.015	0.405	

Based on the above model estimates, the plausible ITSOEM1 for the I-95 NB transition segment and for the 6 PM – 6 AM analyses scenario takes the following form:

$$\log\left(\frac{Pi}{1-Pi}\right)_{DMS=0/1} = -0.905 - 0.102\ D_{CCTV} + 0.811\ D_{VSPCAD} + 1.072\ I_{HIGH} + 1.134\ I_{MAJOR}$$

The ITSOEM1 model construct above is pursued in spite of moderate to acceptable model significance estimates is primarily to develop preliminary insights on ITS operations during the 6 PM – 6 AM analyses scenario for the I-95 northbound transition segment. Additional understanding of contributing factors that define the ITS operations during the 6 AM – 6 PM duration for the I-95 Study Corridor need to be explored to improve the model performance. The model coefficient estimates as presented here need to be used with caution and for accurate model results' interpretation additional engineering and field operations judgment is warranted.

7.7.14 I-95 NB Transition Segment 6pm-6am Analyses Scenario ITSOEM2 Model Estimates

The ITSOEM1 model coefficient estimates, Wald Significance test 'p' values, odds ratios and class interval for Odds ratios are summarized in Table 7.20 and 7.21.

The 'p' values for all coefficients confirm that the model coefficients exhibit a poor significance. The odds ratios class interval has the value 1.0., confirming that the estimated odds ratios are not within the acceptable limits.

Table 7.20 ITSOEM2 Model Coefficient for DMS = 0 Condition for I-95 NB Transition 6pm-6am Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
$DMS_{=0\ condition}$	0.198	0.660	1.219	0.505-2.947
$I_{DURATION}$	-0.005	0.978	0.995	0.705-1.406
$I_{HIGH\ PROFILE}$	-0.493	0.535	0.611	0.129-2.893
$I_{MAJOR\ PROFILE}$	-0.541	0.362	0.582	0.182-1.863
Constant	-1.729	0.000	0.178	

Table 7.21 ITSOEM2 Model Coefficient for DMS = 1 Condition for I-95 NB Transition 6pm-6am Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
$DMS_{=1\ condition}$	-0.198	0.660	0.820	0.339-1.982
$I_{DURATION}$	-0.005	0.978	0.995	0.705-1.406
$I_{HIGH\ PROFILE}$	-0.493	0.535	0.611	0.129-2.893
$I_{MAJOR\ PROFILE}$	-0.541	0.362	0.582	0.182-1.863
Constant	-1.530	0.000	0.216	

The ITSOEM2 model for I-95 NB transition segment for 6pm – 6am analyses scenario For DMS = 0 condition is

$$\log\left(\frac{Pi}{1-Pi}\right)_{SecInc=0/1} = -1.729 + 0.198\ DMS_{=0} - 0.005\ I_{DURATION} - 0.493\ I_{HIGH} + 0.541\ I_{MAJOR}$$

and for DMS = 1 condition the ITSOEM2 Model is:

$$\log\left(\frac{Pi}{1-Pi}\right)_{\text{SecInc=0/1}} = -1.530 - 0.198\ \text{DMS}_{=1} - 0.005\ I_{\text{DURATION}} - 0.493\ I_{\text{HIGH}} + 0.541\ I_{\text{MAJOR}}$$

The ITSOEM1 model construct above is pursued in spite of inadequate model significance estimates to develop preliminary insights on ITS operations during the 6 AM – 6 PM analyses scenario for I-95 southbound transition segment. Further, the algebraic sign of the coefficient such as I_{DURATION} is found to be inconsistent with the research hypothesis and with model estimates obtained for this variable for other scenarios discussed earlier.

Additional understanding of contributing factors that define the ITS operations during the 6 AM – 6 PM duration for the I-95 Study Corridor need to be explored to improve the model performance. The model coefficient estimates as presented here need to be used with caution and for accurate model results' interpretation additional engineering and field operations judgment is warranted.

7.7.15 I-95 SB Transition Segment 6pm – 6am Analyses Scenario ITSOEM1 Model Estimates

The ITSOEM1 model coefficient estimates, Wald Significance test 'p' values, odds ratios and class interval for Odds ratios are summarized in Table 7.22. With the exception of the $D_{\text{VSP-CAD}}$ variable, all other ITSOEM1 model coefficients exhibit reasonably well to moderately approaching acceptable ‘p’ value for passing Wald significance test. The odds ratios Class Intervals determined for these coefficients also appear to confirm that the estimated odds ratios are approaching the acceptable limits.

Table 7.22 ITSOEM1 Model Coefficient Estimates for I-95 SB Transition 6pm-6am Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
D_{CCTV}	0.767	0.052	2.153	0.993-4.670
$D_{VSP-CAD}$	0.052	0.895	1.053	0.486-2.281
$I_{HIGH\ PROFILE}$	0.556	0.297	1.744	0.614-4.956
$I_{MAJOR\ PROFILE}$	0.705	0.036	2.023	1.049-3.904
Constant	-0.876	0.009	0.417	

Based on the model estimates presented above, the plausible ITSOEM1 model for I-95 SB transition segment for the 6 AM – 6 PM analyses scenario takes the following form:

$$\log \left(\frac{Pi}{1-Pi}\right)_{DMS=0/1} = -0.876 + 0.767\ D_{CCTV} + 0.052\ D_{VSPCAD} + 0.556\ I_{HIGH} + 0.705\ I_{MAJOR}$$

The model construct ITSOEM1 above is primarily pursued in spite of moderate to well model significance estimates to develop preliminary insights on

ITS operations during the 6 PM – 6 AM analyses scenario for the I-95 southbound transition segment.

Additional understanding of contributing factors that define the ITS operations during the 6 PM – 6 AM duration for I-95 Study Corridor needs to be explored to improve the model performance.

The model coefficient estimates as presented here need to be used with caution and for accurate interpretation of the model results, additional engineering and field operations judgment is warranted.

7.7.16 I-95 SB Transition Segment 6pm-6am Analyses Scenario ITSOEM2 Model Estimates

The ITSOEM1 model coefficient estimates, Wald Significance test ‘p’ values, odds ratios and class interval for Odds ratios are summarized in Table 7.23 and 7.24.

The ‘p’ values for all coefficients confirm that the model coefficients exhibit a poor significance. The odds ratios Class Interval possesses the value 1.0 confirming that the estimated odds ratios are not within the acceptable limits.

Table 7.23 ITSOEM2 Model Coefficient for DMS = 0 Condition for I-95 SB Transition 6pm-6am Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
$DMS_{=0 \text{ condition}}$	0.279	0.453	1.322	0.638-2.737
$I_{DURATION}$	-0.002	0.996	0.998	0.534-1.867
$I_{HIGH\ PROFILE}$	-1.761	0.094	0.172	0.022-1.354
$I_{MAJOR\ PROFILE}$	-0.513	0.213	0.598	0.267-1.343
Constant	-1.166	0.011	0.312	

Table 7.24 ITSOEM2 Model Coefficient for DMS = 1 Condition for I-95 SB Transition 6pm-6am Analyses Scenario

Explanatory Variable	Coefficient Estimate	Wald Significance (p-value)	Odds ratio	Class Interval
$DMS_{=1 \text{ condition}}$	-0.279	0453	0.757	0.365-1.567
$I_{DURATION}$	-0.002	0.996	0.998	0.534-1.867
$I_{HIGH\ PROFILE}$	-1.761	0.094	0.172	0.022-1.354
$I_{MAJOR\ PROFILE}$	-0.513	0.213	0.598	0.267-1.343
Constant	-0.887	0.011	0.412	

The potential and plausible ITSOEM2 model for I-95 SB transition segment for 6am – 6pm analyses scenario and for DMS=0 condition the ITSOEM2 models is:

$$\log \left(\frac{Pi}{1-Pi}\right)_{SecInc=0/1} = -1.166 + 0.279\ DMS_{=0} - 0.002\ I_{DURATION} - 1.761\ I_{HIGH}$$

$$+- 0.513\ I_{MAJOR}$$

and for DMS = 1 condition the ITSOEM2 mode is

$$\log\left(\frac{Pi}{1-Pi}\right)_{SecInc=0/1} = -0.0887 - 0.279\ DMS_{=1} - 0.002\ I_{DURATION} - 1.761\ I_{HIGH} - 0.513\ I_{MAJOR}$$

The ITSOEM2 model construct above is pursued in spite of inadequate model significance estimates to develop preliminary insights on ITS operations during 6am – 6pm analyses scenario for I-95 southbound transition segment. Further, the algebraic sign of the coefficient such as $I_{DURATION}$ is found to be inconsistent with the research hypothesis and with model estimates obtained for this variable in the scenarios discussed earlier. Additional understanding of contributing factors that define the ITS operations during the 6 AM – 6 PM duration for the I-95 Study Corridor need to be explored to improve the model performance. The model coefficient estimates as presented here need to be used with caution and for accurate interpretation of model results, additional engineering and field operations judgment is warranted.

Based on the detailed discussions on model goodness-of-fit measures and model estimates of ITSOEM1 and ITSOEM2 models developed for the I-95 Study Corridor and presented for the selected key analyses scenarios, it is apparent that for several critical analyses scenarios, the ITSOEM1 and ITSOEM2 models developed satisfied the specified and targeted block-wise model goodness-of-fit measures. The selected overall model coefficient of estimates also proved significant at Wald significance levels. However, for some of the key analyses scenarios and most specifically for the 9 PM – 5 AM analyses scenarios for urban segments and for the 6 AM – 6 PM analyses scenarios for transition segments of the I-95 corridor, the model estimates did not meet the specified model goodness-of-fit measures. For these scenarios, the ITSOEM1 and ITSOEM2 models presented here are for conceptual understanding of the power the application of such models to perform ITS operations assessment. Additional research of ITS and field operations parameters, that are deemed beyond the scope of this effort, is needed.

In Chapter 8, a detailed step by step interpretation of the ITSOEM1 and ITSOEM2 model coefficients estimates is presented. The model results are interpreted to quantitatively assess the effectiveness of ITS operations on the I-95 Study Corridor.

CHAPTER 8: ITSOEM RESULTS INTERPRETATION

8.1 Introduction

This chapter is dedicated to discussing ITSOEM results. After ITSOEM model development the emphasis shifts from the computation and assessment of goodness-of-fit measures and significance of estimated ITSOEM1 and ITSOEM2 model coefficients to interpretation of their values. The interpretation of fitted ITSOEM1 and ITSOEM2 model coefficients leads to the realization of this research's core research objectives and to the quantitative determination of the effectiveness of ITS operations on the I-95 Study Corridor.

8.2 ITSOEM Model Results Interpretation

The estimation of odds ratio for each of the independent variables of ITSOEM1 and ITSOEM2 models become the fundamental crux of this research work and form the basis to interpret ITSOEM results. The interpretation of ITSOEM1 and ITSOEM2 involves understanding and appropriately defining the unit of change for the independent variable. The estimated coefficients for ITSOEM1 and ITSOEM2 models independent variables ($D_{CCTV,}$ D_{VSPCAD}, D_{SSP}, I_{HIGH}, I_{MAJOR}, $I_{MINOR,}$ $I_{DURATION}$ etc.) represent the slope (rate of change) of a function of the dependent variable per unit of change in the independent variable, Hosmer and Lemeshow (113). Mathematically, the odds ratio is the exponential value of the model coefficient and approximates how much more likely (or unlikely) the outcome is present given the existence of the independent variable. The Odds ratios determined for the ITSOEM1 and ITSOEM2 models are used to measure the strength of the association between the independent and dependent variables.

The modeling methods used to develop logistic regression ITSOEM transform the focus of predicting probabilities within a 0/1 range to the objective of predicting the odds ratio of an event occurring in that range. In The event for ITSOEM1 models is the ‘message dissemination (or not) on DMS signs’ and for ITSOEM2 models the event is ‘occurrence (or not) of secondary incidents’ on the I-95 Study Corridor. The Odds ratios developed in Chapter 7 are used to measure the strength of the association between the ITSOEM1 and ITSOEM2 models independent and dependent variables. The odds ratio is the exponential value of the model coefficient and approximates how much more likely (or unlikely) the outcome is present given the existence of the independent variable. ITSOEM models’ coefficients with odds ratio values greater than 1 indicate the greater extent of the influence of that particular variable on the outcome of the dependent variable, and vice versa for the coefficients with the odds ratio equal to or lower than 1.0. If the coefficient has an odds ratio approaching or equal to 1.0., this indicates that particular coefficient has no effect on the outcome of the dependent variable. Thus the interpretation of odds ratios resulting from ITSOEM1 and ITSOEM2 is critical to achieve the core research objectives.

8.3 ITSOEM1 Model Results Interpretation

One of the primary objectives of the ITSOEM1 models is to determine the measurable influence of the detection system in successfully disseminating messages on DMS. The odds ratios from the ITSOEM1 model developed for the I-95 NB 5am – 1pm analyses scenario with SSP detections (D_{SSP}) as a reference variable are presented in Figure 8.1; the odds ratio for D_{CCTV} is 4.639.

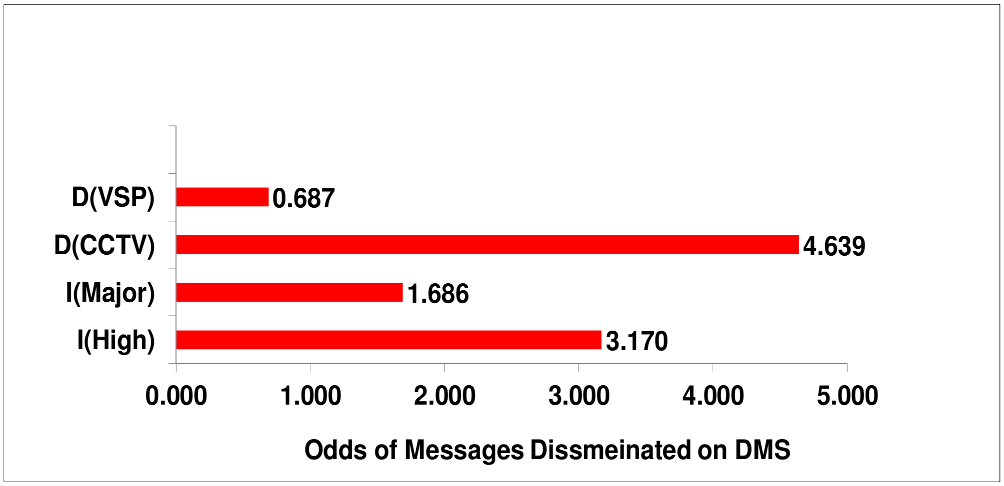


Figure 8.1 ITSOEM1 Results Interpretations for I-95 Northbound Urban 5am – 1pm Analyses Scenario

The odds ratio of 4.671 for D_{CCTV} serves as the measurable value of the influence of CCTV detections on DMS operations. This shows that of the three detection systems, D_{CCTV}, D_{VSPCAD} and D_{SSP}, the detections resulting from CCTV on southbound urban segments of the I-95 Study Corridor during 5am-1pm have an increased likelihood (4.639 times) of being associated with the successful message dissemination on DMS. The detections resulting from VSPCAD have a less likelihood (only 0.687times) of being associated with the message dissemination on DMS. In the same manner, the odds ratios of 3.170 and 1.686 for the incident profile descriptors I_{HIGH} and I_{MAJOR} serve as their respective measurable values of the influence on DMS operations.

The odds ratios from the ITSOEM1 model developed for I-95 SB 1pm – 9 pm analyses scenario with SSP detections (D_{SSP}) as reference are presented in Figure 8.2.

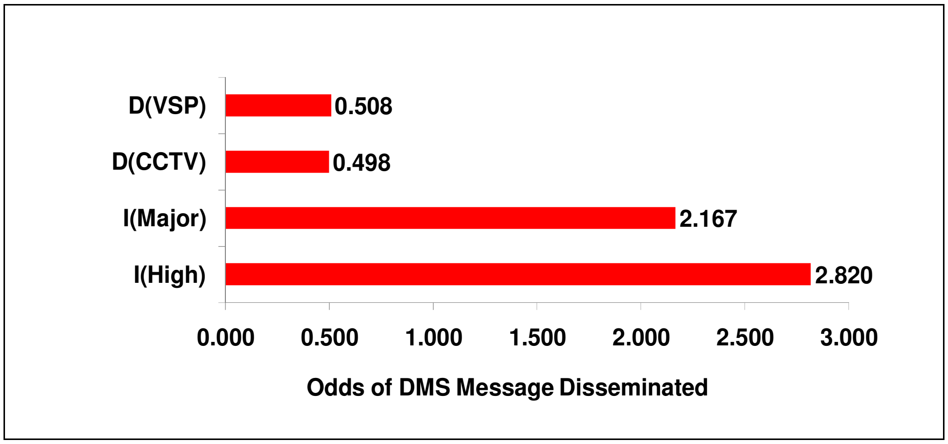


Figure 8.2 ITSOEM1 Results Interpretation for I-95 Southbound Urban 1pm-9pm Analyses Scenario (D_{SSP} as Reference Variable)

For the southbound I-95 corridor, during the 1pm – 9pm hours of operations, the odds ratio for D_{CCTV} and D_{SSP} are 0.498 and 0.508, respectively, and serve as the measurable values of the influence of CCTV and SSP detections on DMS operations as compared to the influence of detections resulting from SSP detection system. These odds ratios are noticeably lower than 1.0 indicating that both D_{CCTV}, $D_{VSP\text{-}CAD}$ are proving to be less influential as compared to the D_{SSP} detections on the southbound urban segments of the I-95

Study Corridor during 1 PM – 9 PM. They have less likelihood (0.498 times for D_{CCTV} and 0.508 times for D_{VSP}) of being associated with the message dissemination on DMS. The odds ratios of 2.167 and 2.820 for the incident profile descriptors I_{HIGH} and I_{MAJOR} serve as their respective measurable values of the influence on DMS operations for the SB I-95 corridor during 1pm – 9pm hours analyses scenario.

Figure 8.3 shows additional ITSOEM1 model results for the same I-95 SB 1PM – 9 pm analyses scenario, this time with CCTV detections (D_{CCTV}) as reference variable. These analyses further validate that the detections resulting from SSP and VSP-CAD detection system on the southbound I-95 corridor during 1pm – 9pm have an increased likelihood (2.009 and 1.020 respectively) of being associated with the successful message dissemination on DMS as compared to the CCTV detections.

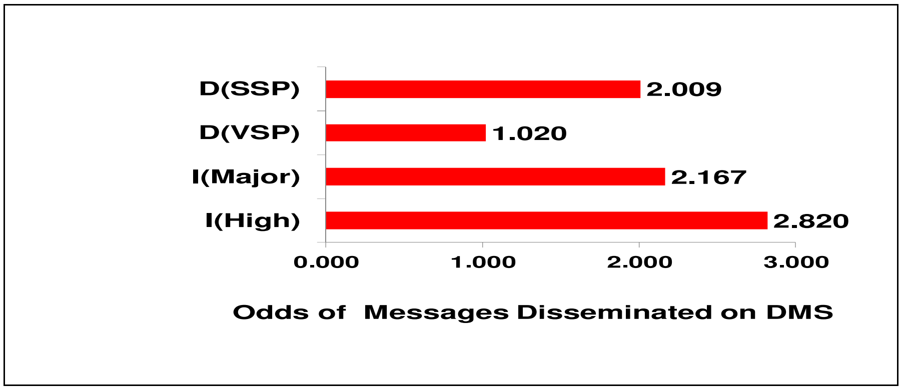


Figure 8.3 ITSOEM1 Results Interpretation for I-95 Southbound Urban 1pm-9pm Analyses Scenario (With D_{CCTV} as Reference Variable)

Also noted is that the VSPCAD detections continue to show lower likelihood of (1.020 time) influence as compared to SSP detections. The High Profile and Major Profile Incidents continue to have the same scale of influence as found in the results from ITSOEM1 models that were developed with SSP as a reference variable.

Figure 8.4 presents the ITSOEM1 model results that quantifies the corridor-wide influence of detection systems during the incidents on the north and southbound directions and for urban and transition segments of the I-95 Study Corridor.

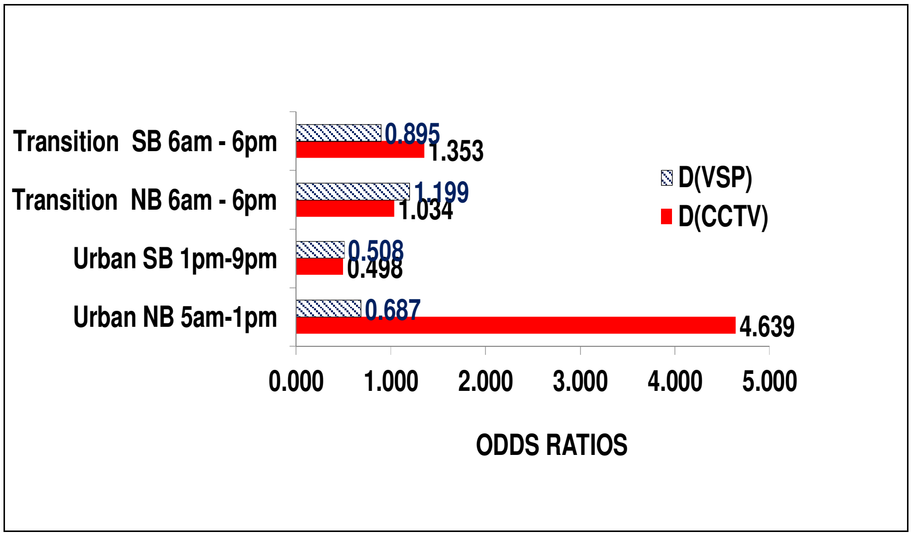


Figure 8.4 ITSOEM1 Results Interpretation for I-95 Urban and Transition Segments (With D_{SSP} as Reference Variable)

The incident detections resulting from CCTV surveillance systems are proving to be more effective in message dissemination for northbound urban segments of the I-95 Study Corridor for 5am-1pm analyses scenario. They indicate the 4.6 times more likelihood of the occurrence of CCTV detections leading to successful DMS message disseminations. However, for north and southbound transition segments of the I-95 Study Corridor for the 6am-6pm analyses scenario, the ITSOEM results indicate that there is a noticeable likelihood of 1.353 and 1.304 times occurrence of VSP-CAD detections respectively that lead to successful message dissemination on DMS signs.

8.4 ITSOEM2 Model Results Interpretation

While the ITSOEM1 models are developed to determine the measurable influence of the detection system in successfully disseminating messages on DMS, the ITSOEM2 models are primarily designed and developed to achieve this research's 2nd core objective: to develop ITS Operations evaluation models to determine the effectiveness of DMS messages during incidents. The ITSOEM2 models quantify the influence of DMS messages in the deterrence of secondary incidents on the I-95 Study Corridor.

The odds ratios from ITSOEM2 model coefficients are presented in Figure 8.5; the coefficient $DMS_{=0}$ (meaning that there was no message posted for the primary incidents that resulted in secondary incidents) has an odds ratio of 2.338 indicating the staggering influence of lack of DMS messages on the model's dependent variable secondary incidents. This shows that the likelihood of secondary incident occurrence on northbound urban segments of the I-95 Study Corridor between 5 AM – 1 PM is approximately 2.338 times more when the primary incidents are not detected and messages are not posted on DMS signs. The odds ratios estimated for DMS=1 condition, (meaning that the incident detection resulted in successful message dissemination for the primary incidents) shows that the likelihood of secondary incident occurrence dropped to 0.428 confirming the significant influence DMS messages have in the deterrence of secondary incidents on the I-95 northbound segment during the 5am – 1pm analyses scenario.

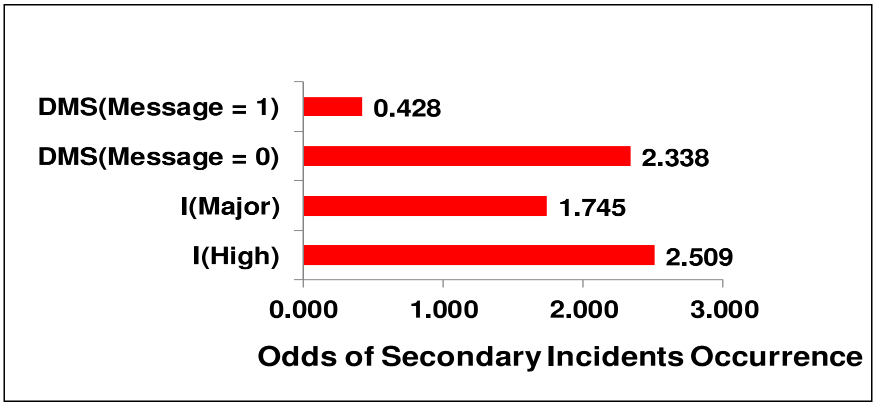


Figure 8.5 ITSOEM2 Results Interpretations for I-95 Urban Northbound Segment 5am-1pm Analyses Scenario (With I_{MINOR} as Reference Variable)

The other ITSOEM2 model coefficients I_{HIGH} and I_{MAJOR} have comparable high odds ratios confirming that the High and Major Profile Incidents do have the propensity of causing secondary incidents compared to the Minor Profile Incidents. Similar results were obtained for the I-95 southbound 1PM – 9 PM analyses scenario and are shown in Figure 8.6. Figure 8.7 shows the impact of DMS message dissemination on both north and southbound and for urban and transition segments of the I-95 Study Corridor.

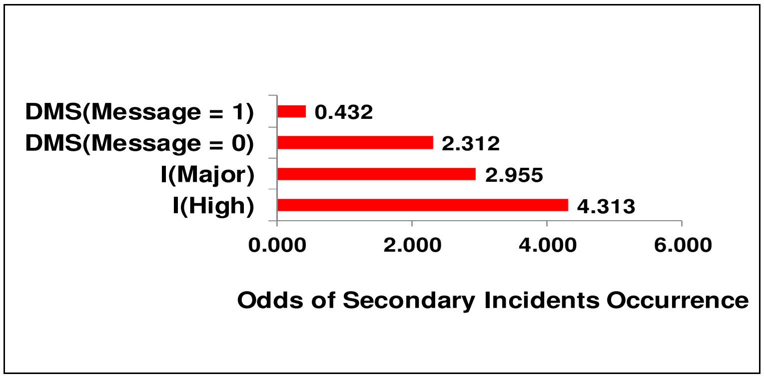


Figure 8.6 ITSOEM2 Results Interpretations for I-95 Urban Southbound Segment 1pm-9pm Analyses Scenario (With I_{MINOR} as Reference Variable)

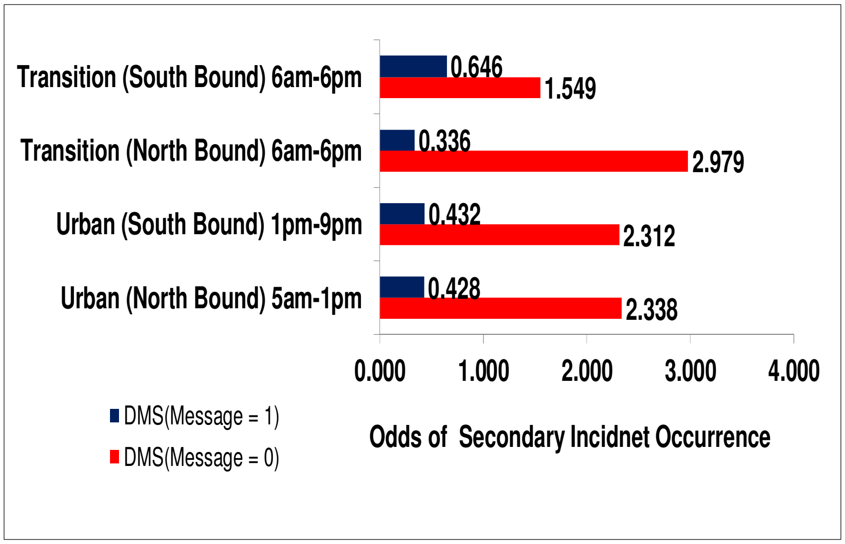


Figure 8.7 ITSOEM2 Results Interpretations I-95 Urban and Transition Segments ($DMS_{=0}$ and $DMS_{=1}$ Condition)

As evident from the odds ratios presented in figure 8.7, for both the I-95 urban and transition segments, the likelihood of secondary incident occurrence increases in the range of 2.979 to 1.549 times for $DMS_{=0}$ condition (meaning that there was no message posted for the primary incidents that resulted in secondary incidents) as compared to a lower likelihood of secondary incident in the range of 0.336 to 0.646 time for a $DMS_{=1}$ condition, thus confirming the deterrence of secondary incident occurrence induced by DMS $_{=1}$ condition on the I-95 Study Corridor. The model's only continuous variable is $I_{DURATION}$ (incident duration). For continuous variables, the odds ratio is interpreted as an increase of 1 unit of the independent variable increases the odds of the occurrence of the dependent variable. Figure 8.8 and 8.9 shows influence of incident duration on secondary incident occurrence for north and southbound urban segments of the I-95 Study Corridor.

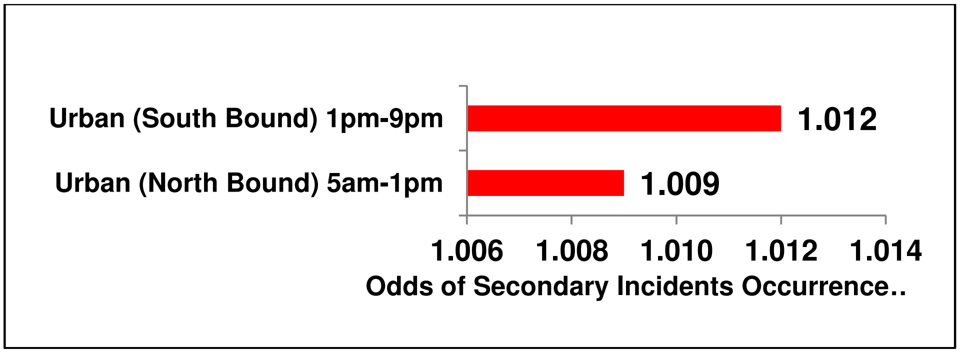


Figure 8.8 ITSOEM2 Results Interpretations Influence of Incident Duration on I-95 Urban Segments

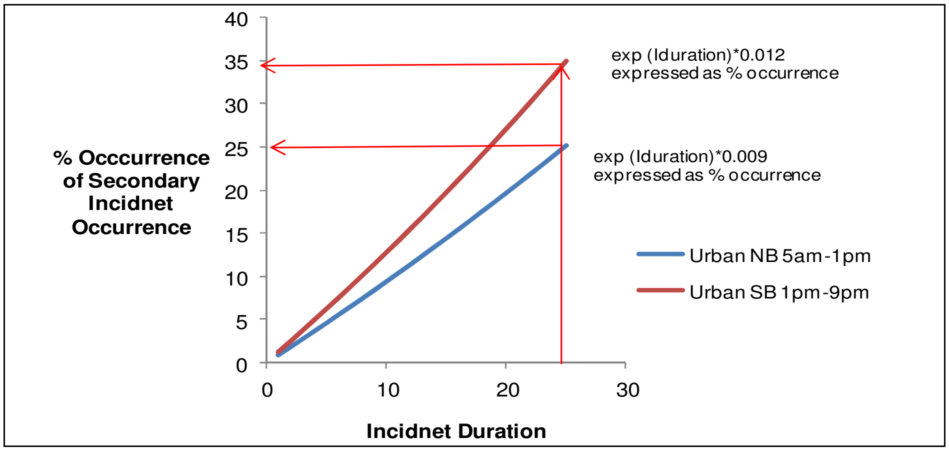


Figure 8.9 ITSOEM2 Percent of Secondary Incidents Occurrence on I-95 Urban Segments

As shown in Figure 8.9, the interpretation of the odds ratio of 1.009 for IDURATION means that in the first minute the likelihood of primary incident followed by secondary incident increases by 1.009 or $e^{(0.009*1.0)}$ for northbound and by 1.012 or $e^{(0.012*1.0)}$ for southbound urban segments of the I-95 corridor. If the incident duration increases by 25 minutes then the likelihood of secondary incident increases by $e^{(0.009*25.0)}$ accounting to 25% for northbound and by $e^{(0.012*25.0)}$ accounting to 35% for southbound urban segments of the I-95 Study Corridor.

Figures 8.10 and 8.11 show similar results on the influence of incident duration on secondary incident occurrence for north and southbound Transition segments of the I-95 Study Corridor.

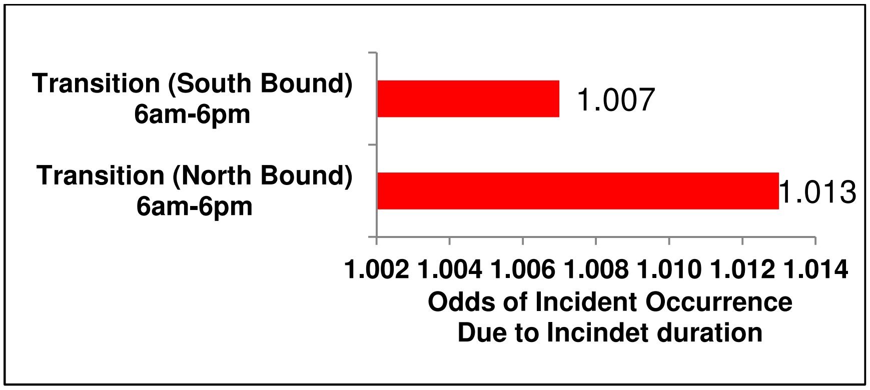


Figure 8.10 ITSOEM2 Results Interpretations Influence of Incident Duration on I-95 Transition Segments

As shown in Figure 8.11, the interpretation of the odds ratio of 1.007 for $I_{DURATION}$ means that in the first minute the likelihood of primary incident followed by secondary incident increases by 1.007 or $e^{(0.007*1.0)}$ for northbound and by 1.013 or $e^{(0.013*1.0)}$ for southbound transition segments of the I-95 Study Corridor.

If the incident duration increases by 20 minutes then the likelihood of secondary incident increases by $e^{(0.007*20.0)}$ accounting to 15 % for northbound and by $e^{(0.013*20.0)}$ accounting to 30% for southbound transition segments of the I-the 95 Study Corridor.

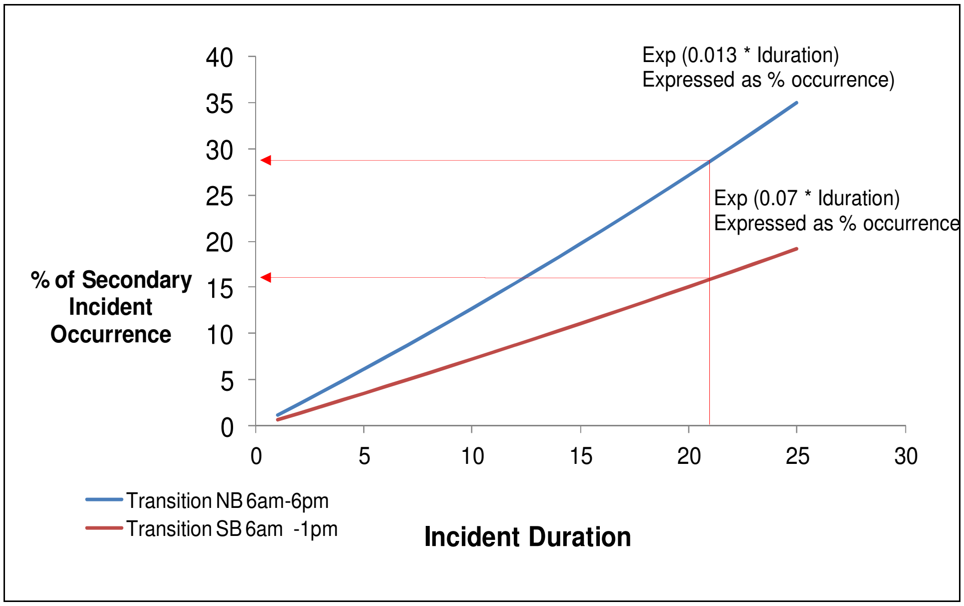


Figure 8.11 ITSOEM2 Percent of Secondary Incidents Occurrence on I-95 Transition Segments

The interpretation of the results of the ITSOEM1 and ITSOEM2 model presented in this chapter provide conclusive, meaningful and quantitative assessments of ITS operations for the I-95 Study Corridor. The odds ratios estimated using ITSOEM1 and ITSOEM2 model coefficients provide measurable influence of the independent variables on the dependent variable. In the next chapter the application guidelines of the ITSOEM1 and ITSOEM2 models are developed and applied to demonstrate how transportation engineers will be able to use these model results to carry out ITS operations assessment in a real world situation.

CHAPTER 9: APPLICATION OF ITS OPERATIONS EVALUATION MODELS (ITSOEM)

9.1 Introduction

One of the objectives of this research is to develop guidelines for transportation engineers to develop and apply ITSOEM models to perform evaluation and assessment of ITS Operations. In this chapter a suite of guidelines on data collection and syntheses required for ITSOEM development and application are developed. The guidelines are used as the basis to present a conceptual ITSOEM application framework. Using the guidelines and applications framework, the ITSOEM1 and ITSOEM2 models developed in this research are applied to demonstrate their ability to assess the role of ITS during a High Profile Incident management operation that occurred on the I-95 Study Corridor.

9.2 Guidelines for ITSOEM Development and Application

ITSOEM can be used to perform ITS operations evaluations at corridor level and / or for any isolated ITS applications. Most importantly, in order to develop and apply ITSOEM models it is essential to clearly identify the transportation operations strategies that are expected to be influenced by ITS operations. Further, in order to establish causal relationships between ITS applications and the operations strategies such as incident management, work zone operations, etc., and to quantify the effectiveness of ITS operations effectiveness, it is essential to have detailed data on incident management, work zone operations etc. and the pertinent ITS operations data. This is true for either corridor based ITS evaluations or isolated ITS applications. The following sections further describe a set of specific guidelines on operations strategies and data collection and syntheses needs for developing and applying ITSOEM.

9.2.1 Establish Effective ITS Operations Analyses Strategies

It is essential to define the type of operations strategies and clearly identify the role that ITS is designated to play. As demonstrated in this research, the identification and mapping of the operations strategies with ITS detection system and DMS operations (Chapter 4) was critical in the development of ITSOEM models. In this research, the development and application of ITSOEM to assess the effectiveness of ITS operations for the I-95 Study Corridor was feasible only when the incident management strategies and their relationship with ITS operations was hypothesized as depicted in Table 4.1, Chapter 4.

For instance, consider the application of the ITSOEM framework to assess the role and effectiveness of the RWIS (Road Weather Information System) in implementing one of the operations strategies: pavement pre-treatment with de-icing chemicals during snow and ice conditions. This operations strategy is expected to minimize road closure delays due to pavement freeze during inclement weather conditions. The objective here is to use ITSOEM modeling to quantify the extent of influence the RWIS has on the outcome of de-icing of the pavements through chemical treatments. Here, to evaluate the effectiveness of RWIS operations during pavement de-icing operations, the corresponding hypothesis will be that the RWIS Systems is able to successfully provide the required weather forecasts and alerts that are actionable for the snow and ice responders to successfully initiate pavement de-icing operations and avoid the impacts associated with not being able to de-ice the pavement due to lack of weather alerts from RWIS systems. It is essential to note that for a successful ITSOEM development and application, a series of expected outcomes or assessment criteria of these ITS operations scenarios or strategies need to be hypothesized that reflect field conditions and the targeted field applications.

9.2.2 Granular Operations Data on Incident Management and ITS Operations to Develop and Apply ITSOEM

The literature review of various ITS evaluation studies conducted as a part of this research and the type of data assembled to develop ITSOEM for the I-95 Study Corridor confirmed the importance of the real time field operations data and the ITS operations data to perform meaningful and accurate ITS evaluations. For instance, to carry out the RWIS assessments as described in the earlier pavement pre-treatment example, we need pavement treatment operations data that clearly identify if the pavement is pre-treated or not pre-treated, and RWIS operations data showing if weather alerts from RWIS are reliably effective or not effective to initiate pavement de-icing pre-treatments. If the objective is also to assess the role of additional operations elements such as lane closure duration, delays incurred due to pavement freeze, etc., one also needs the granular level operations data on "lane closure duration” and “delays incurred" as continuous variables. Such data, collected at a granular level, can be used to develop and apply the ITSOEM methods to determine if weather alerts from RWIS result in pavement pre-treatment operations that in turn led to reduced delays and lane closures. The data syntheses of operations data on pavement treatments and RWIS operations, lane closure duration, and delays incurred are essential for the application of ITSOEM framework developed in this research and to predict the success of pavement de-icing operations. Based on this discussion, the following stand out as essential guidelines on data requirements to develop and apply ITSOEM:

- It is vital that the filed operations data includes all pertinent details. For example, if this data is related to incidents, the data collected should be able to define the key phases of incident and event management including: incident detection, verification, response, clearance and recovery-restoration phases.
- This granularity in operations data is essential to determine the interdependencies amongst the different phases involved in implementing operations strategies. For example, in incident management, it is essential to have data on the ITS role during incident detection, verification, response and recovery phases.

- It is critical to have data on the type, nature and degree of impact due to the implementation or lack of implementation of the operations strategies.
- Data on actionable ITS operations is essential, this includes data on ITS subsystems and their operational protocols, ITS activation data and their actionable response to incident, events, weather response, etc. This contributes to the granularity of ITS data that will play a key role in the development and application of ITSOEMs.
- Data on interdependencies amongst competing facets of ITS infrastructure elements such as the role of CCTV and Detection systems, Safety Service Patrol operations, interdependencies on dispatch and response operations data from other responding entities such as Computer Aided Dispatch data from 911 and law enforcement etc., and their collective and individual influence on other ITS subsystems operations such as DMS, work-zone ITS, RWIS etc., are essential for a successful ITSOEM development and application.

9.2.3 Data Collection and Synthesis Methods

Data collection and syntheses is central to the ITSOEM development and application. The analyses data sets required for the development of ITSOEM need to be either binary or dichotomous and categorical in format. The ITSOEM models developed in this research are logistic regression models and require the dependent variables to be categorical variables and the independent variables or model descriptors can be categorical and/or continuous variables. Suitable data syntheses techniques, rules and guidance are established to transform the granular data to take the value 1 or 0. For example, in the pavement de-icing example discussed earlier, the response or dependent variable is pre-treatment of the pavement (either pre-treated or not with pre-treated as 1 and not pre-treated as 0), and the independent or explanatory variable is whether the RWIS was able to detect accurate pavement temperature and generate alerts in advance for the maintenance crew to initiate de-icing operations.

9.2.4 Selection of ITSOEM Analyses Variables

The selection of analyses variables and the data syntheses that results in categorical and continuous variables is significant to the successful ITSOEM development. Again, using the pavement de-icing example, the response variable ‘pavement de-icing’ needs to be converted into two levels (pre-treated pavement / not pre-treated pavement) and two responses in explanatory variables (RWIS effective/ RWIS not effective). If the objective is also to quantify the role of additional causal variables, such as lane closure duration, delays incurred due to pavement freeze, etc., one can add "lane closure duration” and “delays incurred" as continuous variables.

The ITSOEM model in this case will test whether the RWIS has an effect on the outcome “pavement treatment” and whether the delays further influenced the ability to initiate pavement treatments. The variables, (pavement treatment, RWIS operations, lane closure duration, and delays incurred) try to find the best model which can predict the success of pavement de-icing operations. Thus, the ability to identify the dependent and response variable and the data syntheses methods applied to convert them into categorical variables is key to the successful development of ITSOEM.

9.2.5 Screening of ITSOEM Variables Using Model Goodness-of-Fit Measures

As described in Chapter 7, appropriate field operations judgment and prudence is exercised in screening the aptness for inclusion and exclusion of analyses variables during the ITSOEM model building process. Mere dependence on the goodness-of-fit measures and statistical indicators may eliminate the necessary variables that are essential to capture the field conditions.

The number of models required for development and their application should be established based on the assessment needs and the operations strategies for which ITS effectiveness needs to be quantitatively estimated. The design variable creation method, as described in Appendix B, will be helpful in enhancing the model capabilities. Appropriate selection and employment of design variables, as demonstrated in Chapter 7, is principal to determining the number of models required for carrying out meaningful ITS operations assessments using the ITSOEMs.

9.2.6 Results Interpretations

The ITSOEM model coefficients' estimates are fundamental to the successful and meaningful interpretation of the ITSOEMs. As described in Chapter 8, the exponential determinant of the ITSOEM variable's coefficient is called the odds ratio which in turn will provide a mathematical quantitative value of likelihood of that particular variable's influence on the dependent variable's occurrence. For instance, in the pavement de-icing example, the odds ratio of RWIS will provide the quantitative value of RWIS influence (or lack of it) in enabling the pavement de-icing to take place. These model interpretations are key, and need to be established to measure ITSOEM outcomes in a meaningful manner. It is always essential to use engineering judgment and appropriate attention to ground truth validation is necessary for useful and effective interpretation and use of results from the ITSOEMs. The tendency to overstate and/or understate the ITSOEM results have the tendency to lead to erroneous conclusions and inaccurate ITS deployment decisions. Additionally, the ITSOEM application may need basic understanding of granular operations data syntheses skills and education to run the ITSOEMs and develop appropriate conclusions from the model applications.

9.3 ITSOEM Application Framework

A conceptual ITSOEM models application framework that portrays the ITSOEM application guidelines is presented in Figure 9.1. As shown in the Figure 9.1, the ITSOEM framework presents the chronological steps involved in the

ITSOEM development and application of ITSOEM1 and ITSOEM2 models which include: a) selection of Study Corridor and/or ITS systems to be assessed, b) ITS data collection and syntheses, c) ITSOEM1 and ITSOEM2 development, and d) application of ITSOEM1 and ITSOEM2.

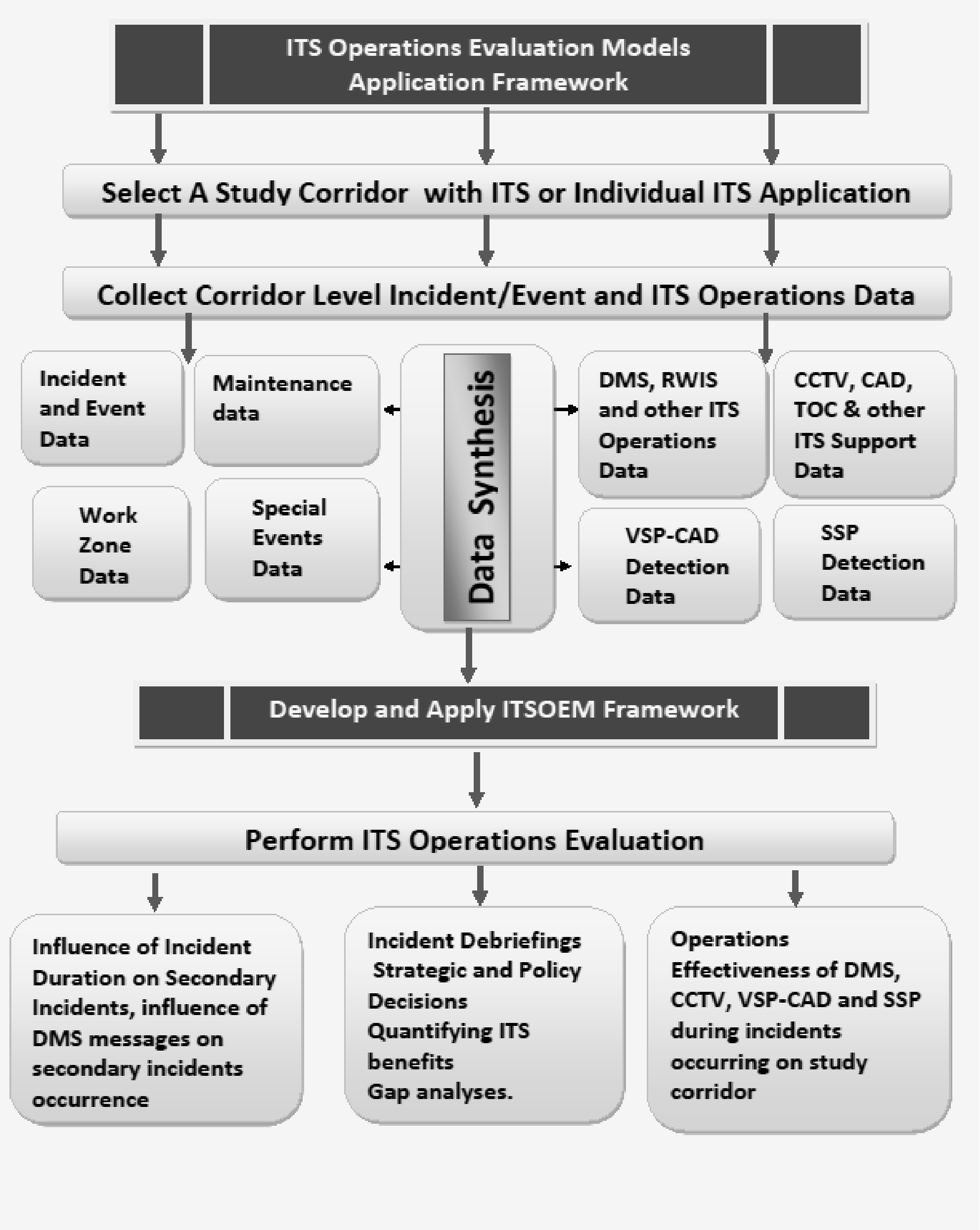


Figure 9.1 ITS Operation Models Application Framework

9.4 ITSOEM Application to Perform I-95 Corridor Level ITS Operations Evaluations

The developed ITSOEMs can be applied for almost any type of ITS operations assessment. However, field and engineering judgment is necessary for specific application of the types of models and granular data developed in this research. For instance, the I-95 corridor selected as the Study Corridor for this research has a rich granular data on incident and ITS operations and to have a similar ITSOEM framework that is developed in this research a matching study corridor with identical operations supported with similar ITS deployment density is recommended.

ITSOEMs presented in this research can be used to assess a corridor based ITS operations evaluations. These models are expected to provide insights on how ITS operations are proving to be effective in incident management on transportation corridors during different hours of the day. Figure 9.2 shows the use of ITSOEM1 model results for the I-95 Study Corridor developed as a part of this research to demonstrate the effectiveness of the role of ITS in incident detections that in turn result in successful dissemination of messages on DMS. From this figure it is evident that the ITSOEM results provide a comprehensive assessment on how ITS detections are performing in supporting incident management on the I-95 Corridor by a measure of the detections resulting successful message dissemination on DMS signs.

The ITSOEM1 results clearly indicate that CCTV detections are 4.7 times more successful in disseminating messages on DMS compared to other detection systems on the I-95 corridor. At the same time, the extent the influence of High Profile and Major Profile incidents warrant ITS operations support is evident from these results. The results indicate that the Major Profile incidents on the I-95 southbound corridor equally warrant message disseminations on DMS.

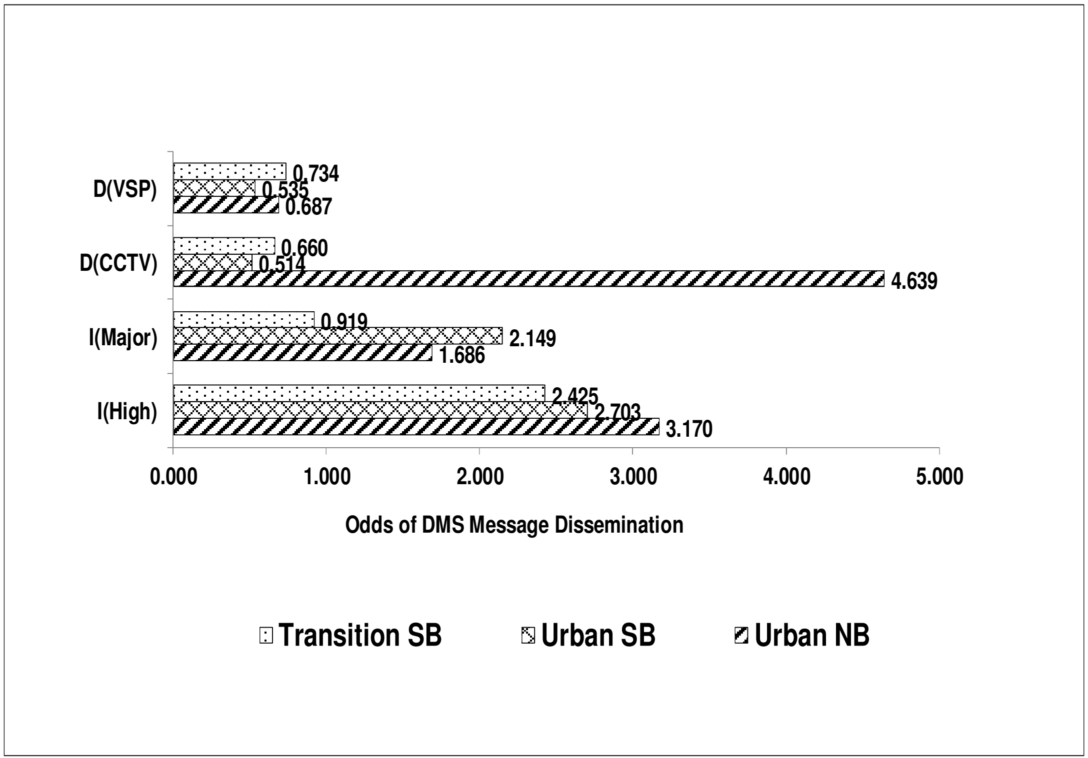


Figure 9.2 ITSOEM – Corridor Based ITS Operations Evaluations

ITSOEM2 models assess overall influence of ITS on corridor operations. Figure 9.3 shows the influence of DMS operations in the deterrence of secondary incidents. The results validate that the DMS message dissemination has a strong influence on I-95 corridor operations and show that DMS message dissemination results in a significant reduction in potential secondary incident occurrence. The overall likelihood of secondary incidents occurrence on the I-95 Corridor increases 2.3 times when no messages on incidents are disseminated on DMS. This reduces to 0.40 times when messages are disseminated on DMS. The same interpretations can be made to assess the influence of DMS for urban and transition segments of I-95 during all hours of operations. Such an assessment will enable transportation engineers to quantitatively evaluate the role of DMS in incident management.

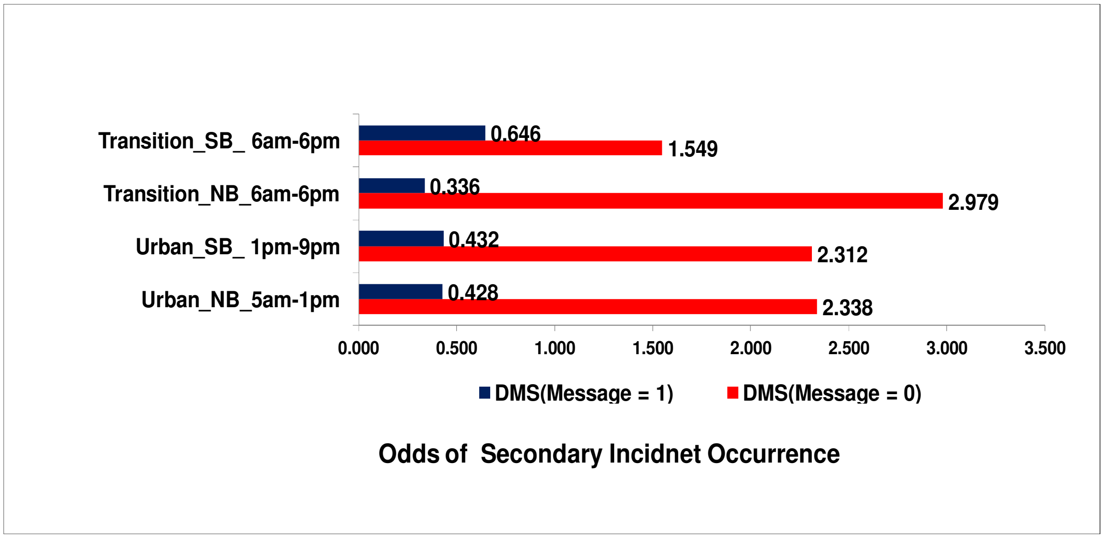


Figure 9.3 Influence of DMS Operations on I-95 Corridor

In Figure 9.4 similar corridor level operations assessments are made using results from ITSOEM2 models to evaluate how the incident duration influences the occurrence of secondary incidents on I-95 urban and transition segments. Such analyses will enable the operations engineers to demonstrate the need for mitigation of secondary incidents occurrence and the benefits associated in using DMS and ITS operations to better manage incidents.

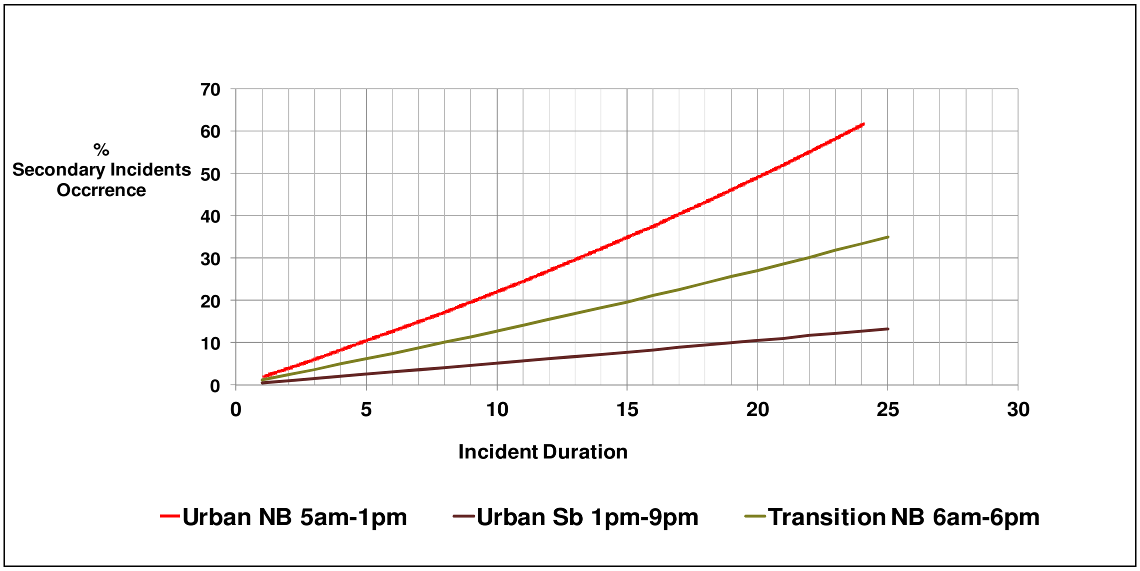


Figure 9.4 Influence of High Profile Incidents' Duration on I-95 Urban Corridor Operations

9.5 Use of ITSOEM Application Framework for Incident Debriefing – A Case Study

In the following sections the use of ITSOEM application framework is demonstrated by applying the ITSOEM1 and ITSOEM2 models developed in this research to perform debriefing analyses of a High Profile incident that occurred on the northbound urban segment of the I-95 Study Corridor.

9.5.1 Incident Scenario

A High Profile incident occurred on northbound urban segments of I-95 at mile marker location163 at 7am. A DMS is located 4 miles south of the incident location. The incident duration lasted till 9am. The SSP roving service was the sole detection available for this segment. This resulted in zero message dissemination on the DMS. The incident caused severe congestion. Agency incident debriefings revealed a need to assess the ITS detection needs and charged the operations engineer to prepare a report describing the potential benefits resulting from deploying ITS traffic surveillance and detection systems in this portion of the I-95 corridor.

The ITSOEM1 and ITSOEM2 models application to perform incident debriefings and ITS Operations assessments are presented in the following sections. The following data from the above described scenario were used:

- Incident Duration = 120 minutes,
- Distance $d_{DMS} = 4$ miles,
- Corridor Area Type = Urban,
- Assumptions made = D_{CCTV} detection is assumed to be available and $D_{CCTV} = 1$, e) Incident Profile = High therefore $I_{(HIGH)} = 1$ and $I_{(MAJOR)} = 0$ and $I_{(Minor)} = 0$

9.5.2 ITSOEM1 Application

ITSOEM1 application to performs the following ITS operation's evaluations:

- The odds and probability that a High Profile incident occurring on the northbound I-95 urban corridor warrants a DMS message dissemination as compared to the occurrence of Minor Profile incident;

- The success of CCTV detection that results in DMS message dissemination;
- The success of VSP-CAD detection that results in DMS message dissemination;
- The overall odds and success of the DMS message being disseminated for High Profile incident that is detected by CCTV detection and for a DMS that is located 4 miles south of the incident location; and
- The overall odds and success of DMS message being disseminated for a High Profile incident that is detected by VSP-CAD detection.

The ITSOEM1 for NB Urban Segments of I-95 Corridor for 5am – 1pm operating hours is:

$$\log \left(\frac{Pi}{1-Pi}\right)_{DMS=0/1} = -1.524 + 1.534\, D_{CCTV} - 0.375\, D_{VSPCAD} + 1.154\, I_{HIGH} + 0.522 I_{MAJOR} + 0.255\, d_{DMS} - 0.412 * D_{CCTV} * d_{DMS}$$

In the ITSOEM1model above, the exponential value of the coefficients of independent categorical variables (I_{HIGH}) and (I_{MAJOR}) for incident profile and ($D_{CCTV)}$, and (D_{VSP}) for detection system quantify their respective influence on

DMS operations. Further, I_{HIGH} and I_{MAJOR} are referenced or compared against the I_{MINOR}, Minor Profile incidents and D_{VSP} and D_{SSP} variables are referenced against D_{SSP} detection system. Using the ITSOEM1 model the following are determined.

The Odds for a for High Profile incident as compared to a minor profile incident that warrants a successful DMS message dissemination on DMS is given by the exponential of the coefficient of I_{HIGH} obtained from the above equation:

$$e^{(1.154)} = 3.170$$

The probability that a High Profile incident warrants DMS message dissemination as compared to minor profile incident is:

$$\frac{e^{1.154}}{1+e^{1.154}} = 0.76 \text{ or } 76\ \%$$

The Odds for an incident for a successful detection by CCTV as compared to detections resulting from SSP and that in turn resulted in message dissemination on DMS is given by the exponential of the coefficient of D_{CCTV} obtained from the above equation:

$$e^{(1.534)} = 4.669$$

The probability of successful CCTV detection (as compared to SSP detection) that will result in DMS message dissemination is:

$$\frac{e^{1.534}}{1+e^{1.534}} = 0.82 \text{ or } 82\ \%$$

In a similar manner, the success of VSP-CAD detection that results in DMS message dissemination as compared to SSP detection is:

$$e^{(-0.375)} = 0.687$$

The probability of successful VSP-CAD detection (as compared to SSP detection) that will result in DMS message dissemination is:

$$\frac{e^{(-0.375)}}{1+e^{(-0,375)}} = 0.407 \text{ or } 41\ \%$$

The overall odds and success of the DMS message being disseminated for a High Profile incident that is detected by CCTV detection for a DMS that is located 4 miles south of the incident location is:

$$Logit\ (p) = \frac{p}{(1-p)} = -1.524 + 1.534\ (1\ ) - 0.375\ (0\ ) + 1.154\ (1\ ) +$$

$$0.522(0) + 0.255(4) - 0.412\ (1\ \ * 4.0)$$

The odds that the DMS message dissemination occurs is:

$$Logit\ (p) = \frac{p}{(1-p)} = 0.534 \text{ and}$$

$$e^{0.534} = 1.176,$$

and the probability that the DMS message dissemination occurs for this high profile incident is:

$$Logit\ (p) = \frac{p}{(1-p)} = \frac{e^{0.534}}{1+e^{.534}} = 0.52 \text{ or } 52\ \% \text{ or}$$

There is a 52% chance that this High Profile incident is successfully detected by CCTV and followed by DMS message dissemination.

The overall odds and success of DMS message being disseminated for High Profile incident that is detected by VSP-CAD detection is:

$$Logit\ (p) = \frac{p}{(1-p)} =$$ -1.524 + 1.534 (0) - 0.375 (1) + 1.154 (1) +

0.522(0) + 0.255(4) - 0.412 (1 * 4.0)

and the odds that the DMS message dissemination occurs is:

$$Logit\ (p) = \frac{p}{(1-p)} = -1.373 \text{ and } e^{(-1.373)} = 0.253$$

and the probability that DMS message dissemination occurs for this High Profile incident is:

$$Logit\ (p) = \frac{p}{(1-p)} = \frac{e^{(-1.373)}}{1+e^{(-1.373)}} = 0.20 \text{ or } 20\ \%$$

There is a 20 % chance that this high profile incident is successfully detected by VSP-CAD and followed by DMS message dissemination.

9.5.3 ITSOEM2 Application

The ITSOEM2 model is used and the safety influence of DMS message dissemination on the I-95 Study Corridor Operations is made by quantifying:

- The likelihood and probability that a High Profile incident occurring on the northbound I-95 urban corridor causes the occurrence of secondary incidents;

- The failure of a DMS message dissemination and the resultant likelihood of secondary incident occurrence;
- The influence of incident duration on secondary incident occurrence
- The overall likelihood of secondary incident occurrence; and
- The safety benefits resulting from DMS message dissemination.

The ITSOEM2 for NB Urban Segments of I-95 Corridor for 5am – 1pm operating hours for DMS = 0 condition is:

$$\left(Logit\ (p) = \frac{p}{(1-p)}\right)_{\text{Sec Inc=0/1}} = -2.504 + 0.920\ (I_{HIGH}) + 0.557\ (I_{MAJOR}) + 0.849\ (D_{DMS=0}) + 0.009(I_{DURATION})$$

and for DMS = 1 condition is

$$\left(Logit\ (p) = \frac{p}{(1-p)}\right)_{\text{Sec Inc=0/1}} = -1.654 + 0.920\ (I_{HIGH}) + 0.557\ (I_{MAJOR}) - 0.849\ (D_{DMS=1}) + 0.009(I_{DURATION})$$

The likelihood and probability that a High Profile incident occurring on the northbound I-95 urban corridor causes the occurrence of secondary incidents is:

$$e^{(0.920)} = 2.51$$

The probability that secondary incident occurs is:

$$\frac{e^{(0.920)}}{1+e^{(0.920)}} = 0.72 \text{ or } 72\ \%$$

The failure of DMS message dissemination and the resultant likelihood of secondary incident occurrence is:

$$e^{(0.849)} = 2.34$$

The probability that secondary incident occurs due to the failure of DMS message dissemination is:

$$\frac{e^{(0.849)}}{1+e^{(0.849)}} = 0.71 \text{ or } 71\ \%$$

Similarly the deterrence of secondary incident occurrence due to this high profile incident on the I-95 Study Corridor increases by successfully posting the message on DMS. This reduced likelihood of secondary incident occurrence for DMS = 1 condition is observed as:

$$e^{(-0.849)} = 0.428$$

The reduced secondary incident occurrence probability due to the successful DMS message dissemination is:

$$\frac{e^{(-0.849)}}{1+e^{(-0.849)}} = 0.30 \text{ or } 30\ \%$$

As incident duration is a continuous variable, the probability for unit increase in incident duration is computed as

$$e^{(0.009*\text{Iduration})}$$

Therefore the influence of incident duration on secondary incident occurrence for 120 minute incident duration is:

$$e^{(0.009*120)} = 2.95$$

The overall probability that a secondary incident occurs for this High Profile incident for DMS message = 0 is:

$$\text{ITSOEM2}_{\text{secInc=1}} = Logit\ (p) = \frac{p}{(1-p)} = -2.504 + 0.920\ (\text{I}_{\text{HIGH}}) + 0.557\ (\text{I}_{\text{MAJOR}}) + 0.849\ (\text{D}_{\text{DMS=0}}) + 0.009(\text{I}_{\text{DURATION}})$$

The likelihood that the secondary incident occurs is:

$$Logit\ (p) = \frac{p}{(1-p)} = 0.345 \text{ and } e^{(0.345)} = 1.411,$$

The probability that Secondary Incident occurs for this High Profile incident is:

$$Logit\ (p) = \frac{p}{(1-p)} = \frac{e^{(0.345)}}{1+e^{(0.345)}} = \frac{1.411}{1+1.411} = 0.59 \text{ or } 59\ \%$$

This shows that there is a 59 % chance that this High Profile incident can cause secondary incident when there is no DMS message dissemination and with 120 minute incident duration.

The overall probability that a secondary incident occurs for this High Profile incident for DMS message = 1 is:

$$\text{ITSOEM2}_{\text{secInc=1}} = Logit\ (p) = \frac{p}{(1-p)} = -1.654 + 0.920\ (I_{\text{HIGH}}) + 0.557\ (I_{\text{MAJOR}}) - 0.849\ (D_{\text{DMS=1}}) + 0.009(I_{\text{DURATION}})$$

The likelihood that the secondary incident occurs is:

$$Logit\ (p) = \frac{p}{(1-p)}$$ = -0.503 and $e^{(-0.503)}$ = 0.605,

The probability that secondary incident occurs for this high profile incident is:

$$Logit\ (p) = \frac{p}{(1-p)} = \frac{e^{(0.-0.503)}}{1+e^{(-0.503)}} = \frac{0.605}{1+0.605} = 0.38 \text{ or } 38\ \%$$

This shows that there is a 38 % chance that this High Profile incident can cause secondary incident when there is DMS message dissemination and with a 120 minute incident duration. Therefore, the net reduction in probability in Secondary Incident deterrence due to DMS message dissemination is 59% - 38% = 21%.

9.6 ITSOEM Application – Summary

The ITSOEM application framework is useful to demonstrate the effectiveness of ITS operations in a quantifiable manner. The ITSOEM1 and ITSOEM2 model applications and their results presented in this chapter indicate that practicing transportation engineers can effectively use ITSOEMs to evaluate ITS operations, develop strategies to fill in the gaps in ITS deployments, effectively determine how ITS is useful in corridor operations, and quantitatively determine potential ITS benefits in incident management. In the case study presented in this chapter, the ITSOEM1 model results show that there is a 52%

likelihood when the High Profile incident is successfully detected by CCTV that leads to DMS message dissemination while this drops to 48 % if the detections are resulting solely from a VSPCAD system.

Similarly, the ITSOEM2 model quantifies the effectiveness of DMS operations stating that there is a 59% chance that this High Profile incident can cause secondary incident for a ‘$DMS_{=0}$’ condition (i.e., when there is no message dissemination on DMS) as compared to 38% for ‘$DMS_{=1}$’ condition (i.e., when there is a message dissemination on DMS) indicating a net reduction of 21% probability in secondary incident occurrence due t the likely secondary incident deterrence expected to be caused by DMS messages. Based on the 1 year incident data analyzed for the I-95 Study Corridor and based on the crash costs presented in several studies (118-122) the 21% reduction in secondary incidents resulting from ITSOEM2 model application translates to a net savings of $75,000 to $100,000.

CHAPTER 10: CONCLUSIONS

10.1 Introduction

This chapter lists the significant findings and conclusions from this study, the contributions of this research, as well as the recommendations for future research.

10.2 Research Findings and Conclusions

The goal of this research work is to develop ITS operations evaluation models (ITSOEM) that will enable transportation engineers to quantify the role of ITS in transportation corridor operations. Using the incident management data and ITS operations data provided by VDOT, the ITSOEM models developed in this research work for urban and transition segments of the I-95 Study Corridor have provided meaningful and conclusive results. The selection of logistic regression analyses and modeling methods proved prudent and yielded statistically significant model estimators. The research resulted in two distinct ITSOEM models: the ITSOEM1 models designed and developed to quantify the role of ITS detection systems in incident management and in successful dissemination of messages on Dynamic Message Signs, and the ITSOEM2 models are developed to quantify the influence of posted messages on DMS in the deterrence of secondary incident occurrences. The ITSOEM1 models developed in this research aid in quantitatively determining the measurable influence of the detection systems on DMS operations. Similarly, the ITSOEM2 models help quantify the potential influence of DMS messages dissemination (or lack of there) during primary incidents on the occurrence of secondary incidents on urban segments of the I-95 Study Corridor. The following are the key findings and conclusions of this research:

1. One of the major findings of this research is that it is plausible to identify the granular data on ITS operations and on Incident management data that are critical to the development of quantifiable methods to assess ITS operations.
2. Lack of granular operations data was one of the major findings in the literature review carried out as part of this research and is appearing to be fully realized in this research effort.
3. Without granular operations data and the ability to match incident detection data with the DMS message data, this research would not have resulted in the development of ITS Operations Evaluation Models (ITSOEMs).
4. ITSOEM results validated the research hypotheses established in this study. The granular data on ITS operations and incident management was found to be useful in establishing the causal relationship between the dependent and independent variables and to quantify the performance of ITS operations on the I-95 Study Corridor.

5. The data collection and syntheses framework developed and presented in this research work proved apt for establishing the design variables and developing the ITSOEM1 and ITSOEM2 models.
6. The decision framework to convert analyses variables identified for ITSOEM1 and ITSOEM2 model developments into dichotomous and binary variables has provided valuable insights in capturing the underlying operational features of incident detection systems and relating them to incident operations data.
7. Using the incident duration variable as one of the key ITSOEM2 model descriptors yielded conclusive and invaluable inferences on the extent the incident duration influences the secondary incident occurrence on the I-95 Study Corridor.
8. The model coefficient and the corresponding odds ratios developed for each of the explanatory variables for ITSOEM1 and ITSOEM2 models are found effective to quantify the impact of each of the detection system categorical variables and incident profile categorical variables and develop pragmatic inferences from the estimated ITSOEM1 and ITSOEM2 model coefficients.
9. The analyses hours and analyses scenarios selected for ITSOEM model building, the delineation of the I-95 Study Corridor into urban and transition corridors, and the field ITS deployment levels were all found well reflected in ITSOEM model results. For instance:

  - CCTV detection of incidents during 5am – 1pm analyses hours on I-95 north bound segments of the I-95 Study Corridor proved more likely to result in successful message dissemination on DMS. This inference is found consistent with the high ITS deployment intensity found in I-95 Study Corridor reconnaissance performed before commencing the model development.
  - Similarly, owing to the scarce ITS deployment in the southbound urban segments of I-95 Study Corridor, the SSP detection during 1pm – 9pm analyses scenario proved more likely to result in message dissemination on DMS signs as compared to CCTV detections.
  - However, for all analyses scenarios, the ITSOEM models quantitatively confirmed that DMS=1 condition always proved to have higher likelihood in the deterrence of secondary incidents as compared to DMS=0 and provided measurable values of DMS performance. For instance, during peak periods on I-95 northbound and southbound and for DMS = 0 condition, the results indicated a high likelihood in the range of 2.338-2.312 times of secondary incident occurrence and this dropped to 0.428 to 0.432 range for DMS = 1 condition respectively.

10. The use of ITSOEM1 and ITSOEM2 models to evaluate and quantify the role of ITS during incident management on the I-95

corridor provided conclusive results. In the case study presented in Chapter 9 for a High Profile incident with a 120 minutes incident duration, the ITSOEM1 model results reported a 52% likelihood of CCTV and 20 % for VSP-CAD of successfully posting messages on DMS signs respectively. Similar , assessments revealed that there is a 29 % reduction in secondary incidents occurrence on the I-95 Study Corridor when DMS=1versus DMS=0 condition.

10.3 Research Contributions

The major contributions resulting from this research study are listed here:

- The concept of granular operations data is addressed thoroughly, bringing forth several clarifications that were identified as research gaps in the literature review performed for this study.
- A pragmatic and plausible data collection and syntheses framework is now established for defining granular operations data, the methods to directly collect them from ITS operating systems, and the granular data collection and syntheses from the incident management programs that are routinely managed in respective transportation agencies. This is a significant contribution from this research.
- This data syntheses methodology is available for transportation professionals, operations engineers and researchers to develop and apply ITS Operations Evaluation Models in the future.

- Based on this data collection and syntheses framework methodology a new modeling methodology is established as ITS Operations Evaluation Models (ITSOEM). ITSOEMs are developed and demonstrated in this research. These models and modeling methodology are available for immediate practical application. This is one of the first studies that made such a comprehensive attempt to apply granular level ITS operations data and incident management data and develop ITS operations evaluation models that can quantitatively assess ITS operations.
- Two new ITS Operations Evaluations Models (ITSOEM) are developed and applied using ITS operations and incident management data for the I-95 Study Corridor. Both ITSOEM1 and ITSOEM2 models provided valuable practical inferences on the comparative evaluation of ITS operations for the I-95 Study Corridor.
- During the development of ITSOEM1 and ITSOEM2 models issues and concerns regarding prudence of use of logistic regression methods and validation methods as related to model chi square significance tests, Wald significance tests, odds ratios validation, appropriate model variables selection, block-wise model goodness-of-Fit assessments and final selection of fitted models were raised, discussed and analyzed in detail and resolved in this research study.

- The principles, models development and finalization technique and findings from this research study yielded the ITS Operations Evaluation Models building framework, guidelines for ITSOEM models application and an interpretations. of their results.

10.4 Recommendations for Research Extensions

The current research study could be extended in several directions. Major potential ideas for future research include the following:

- This research study employed a binary logistic regression methodology; thus, only one dependent variable for each time was used each time and ITSOEM models were developed. Ordinal logistic regression models that use more than two levels of a dependent variable may expand the power of ITSOEM models to simultaneously evaluate the effectiveness of multiple ITS operations. For instance, in its current form, the ITSOEM1 model uses DMS message dissemination as a dependent variable and in ordinal form this may take DMS, 511 and Highway Advisory Radio message dissemination systems as dependent variables and quantify the effectiveness of corresponding field ITS operations.
- Some of the ITSOEM model scenarios analyzed for urban and transition segments of the Study Corridor warranted additional exploration of field conditions to better achieve the model goodness-of-fit measures. All field conditions data can be further

explored for refining and strengthening the data syntheses methods that are successfully demonstrated in this research. Additionally, the research extension can also address various levels of ITS detection system deployments. For example CCTV Detections can be further categorized based on the density of CCTV deployments in time and/or space. Additional discussions will be included stating that such intricate treatment of ITS Detection System as categorical variable may lead to a complex but much vigorous ITSOEM structure. Also it should be noted that the upgrading and modernizing the ITSOEMs to apply for emerging concepts such as Active Traffic Management and or lane control applications may need a start-over to create new data syntheses for making best use of the ITSOEM framework developed in this research work.

- The ITSOEM application framework presented in this research has the potential to serve as extensions to the currently used sketch planning tools such as IDAS and USDOT’s ITS benefit-Cost models. Additional research work is recommended to achieve this key functionality that will enable transportation engineers to practically assess effectiveness of ITS operations in a larger application framework.

In closing, the research findings and conclusions summarized in this chapter demonstrate the successful completion and fulfillment of research core objectives. The research findings and contributions offer pragmatic and enhanced data collection and syntheses, modeling, and application frameworks to transportation engineers. The findings enable comprehensive and quantitative assessments of ITS operations, determine gaps in ITS deployments, perform ITS operations evaluations during the incident detection, verification and response phases of incident management and use the results to make necessary ITS deployment decisions. The research extensions presented here will offer additional insights to expand and enhance the ITSOEM application framework for more comprehensive applications.

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APPENDIX A: DESIGN VARIABLES

A.1 Development of Design Variables for ITSOEM1 and ITSOEM2 Models

The final analyses data sets developed in Chapter 4 are further refined and the data inputs for analyses variables and analyses scenarios are assembled to develop ITSOEM1 and ITSOEM2. As it can be observed from the final data sets, the detection system has three sub categories namely CCTV, VSP-CAD and SSP and the incident profile also consists of High, Major and Minor sub-categories. In order to account for the comparative characteristics of which of the three detection system are relatively effective in the detection of incidents followed by dissemination of messages on DMS signs, the three detection system independent variables are further formatted to fit into the logistic regression procedures by designating one of the detection systems as reference variable and ITSOEM1 are developed to quantify the relative influence of the other two detection variables. After specifying the reference variable within the analyses data the other two analyses variables used for ITSOEM1 and ITSOEM2 are recognized as Design Variables.

The selection of the reference variable is usually based on the research and analyses objectives. Based on discussion inputs from VDOT, for the

I-95 Study Corridor, the first iteration of ITSOEM1 are developed with SSP detection method as reference variable. VDOT operations management indicated the need for determining the relative effectiveness of CCTV and VSP-CAD detection systems which are more automated and integrated into VDOT's ATMS and VDOT VA Traffic database operations system and the SSP detection system is considered operational more on a demand-response operations protocol system and is frequently being subjected to severe budget severances. To comprehensively assess the detection system influence on DMS operations the second iteration ITSOEM were developed using CCTV as the reference variable and relative effectiveness of VSP-CAD and SSP detection were determined.

Also in the first set of model development iterations ITSOEM1, along with SSP the minor profile incidents data is designated as reference variable and the relative influence of High and Major Incident profiles on DMS message dissemination is determined. In the second iteration ITSOEM1 the High profile (along with CCTV detection system data) is designated as the reference variable and the relative influence of Major and Minor profile incidents on DMS message dissemination is determined. Additionally, to carry out sensitivity analyses the additional model development iterations are carried out and ITSOEM are developed for each of the incident profile categories. Design Variable syntax applied for the detection system and incident profile variables is presented in Figure A.1. A summary of ITSOEM development iterations, the employed design variables and reference variables matrix is presented in Table 6.1.

```
Design Variables

* Creating Design Variables, HIGH and MAJOR keeping MINOR as reference;
if Incident Profile =2 then do;
                high=1;
                major=0;
                end;
        else if Incident Profile =1 then do;
                high=0;
                major=1;
                end;
else do;
                high=0;
                major=0;
                end;
* Creating Design Variables, CCTV and VSP-CAD keeping SSP as reference;
if Incident detection=2 then do;
                cctv=1;
                vspcad=0;
                end;

        else if Incident detection =1 then do;
                cctv=0;
                vspcad=1;
                end;

        else do;
                cctv=0;
                vspcad=0;
                end;
```

Figure A.1 Design Variables Syntax ITSOEM1 and ITSOEM2 Design Variables

APPENDIX A (CONTINUED)

Table A.1 ITSOEM1 Model Design and Reference Variables

ITSOEM1 Design Variables				ITSOEM1 Reference Variables	
Detection System		Incident Profile		Detection System	Incident Profile
D_{CCTV}	D_{VSPCAD}	I_{HIGH}	I_{MAJOR}	D_{SSP}	I_{MINOR}
D_{SSP}	D_{VSPCAD}	I_{MINOR}	I_{MAJORR}	D_{CCTV}	I_{HIGH}
D_{CCTV}	D_{SSP}	I_{HIGH}	I_{MINOR}	D_{VSPCAD}	I_{MAJOR}
D_{SSP}	D_{VSPCAD}	For All High Profile Incidents		D_{CCTV}	
D_{CCTV}	D_{VSPCAD}	For All Major Profile Incidents		D_{SSP}	
D_{SSP}	D_{VSPCAD}	For All Minor Profile Incidents		D_{VSPCAD}	

Table A.2 ITSOEM2 Model Design and Reference Variables

ITSOEM1 Design Variables		ITSOEM1 Reference Variables
Incident Profile		Incident Profile
I_{HIGH}	I_{MAJOR}	I_{MINOR}
I_{MINOR}	I_{MAJORR}	I_{HIGH}
I_{HIGH}	I_{MINOR}	I_{MAJOR}

APPENDIX B: ITSOEM1 AND ITSOEM2 MODEL GOODNESS-OF-FIT SUMMARY

B.1 ITSOEM1 and ITSOEM2 Model Presentations

The primary objective in presentation of the ITS model goodness-of-fit estimates is to highlight how the model estimates are used to screen and select model variables for both at the ITSOEM block wise models building stage and serve as the basis for the selection of final effects ITSOEM models. For the analyses scenarios described earlier (in section 7.3) and based on the design variables selection criteria (as described in appendix A), the ITSOEM model building process is implemented using SPSS Version 19 and 180 ITSOEM1 models and 60 ITSOEM2 models (a total of 240 models) are developed. To demonstrate the application potential of ITSOEM models the ITSOEM1 and ITSOEM2 models are also developed for High Profile only, Major Profile only and Minor Profile only incidents. The analyses scenarios along with design variables options are presented in Tables B 1 and B 2. As evident from the figures the 240 ITSOEM models are developed using all design variable and reference variable matrix options feasible within this research scope and for all the five analyses time periods identified in section 7.3. A complete listing of all model estimates for 240 ITSOEM models is shown in Tables B19 and B20. The complete model goodness-of-fit measures estimates for the scenarios discussed in

Chapter 7 are summarized in Tables B1 – B18 and the 240 model coefficient estimates along with model X2 significance results are summarized in Tables B19 and B20.

Table B.1 ITSOEM 1 Models

Analyses Scenarios	**Reference Variable Scenario**	**ITSOEM1 Models**
Northbound	High & CCTV Detection	10
5am-1pm (U)	High & SSP Detection	10
1pm-9pm (U)	High & VSP Detection	10
9pm-5am (U)	Major & CCTV Detection	10
6am-6pm (T)	Major & SSP Detection	10
6pm-6am (T)	Major & VSP Detection	10
Southbound	Minor & CCTV Detection	10
5am-1pm (U)	Minor & SSP Detection	10
1pm-9pm (U)	Minor & VSP Detection	10
9pm-5am (U)		
6am-6pm (T)		
6pm-6am (T)		
	Total	90
Analyses Scenarios	Reference Variable Scenario By Incident Profile	Total ITSOEM1 Models
Northbound	High Only	10
5am-1pm (U)	CCTV Detection	10
1pm-9pm (U)	SSP Detection	10
9pm-5am (U)	VSP Detection	
6am-6pm (T)	Major Only	
6pm-6am (T)	CCTV Detection	10
Southbound	SSP Detection	10
5am-1pm (U)	VSP Detection	10
1pm-9pm (U)	Minor Only	
9pm-5am (U)	CCTV Detection	10
6am-6pm (T)	SSP Detection	10
6pm-6am (T)	VSP Detection	10
	Total	90
	Total ITSOEM 1 Models	180

APPENDIX B (CONTINUED)

Table B.2 ITSOEM2 Models

Analyses Scenarios	Variable Scenario	ITSOEM2 Models
Northbound		
5am-1pm (U)		
1pm-9pm (U)	High as Ref variable	10
9pm-5am (U)	Major as Ref variable	10
6am-6pm (T)	Minor as Ref variable	10
6pm-6am (T)	High Profile Only	10
Southbound	Major profile Only	10
5am-1pm (U)	Minor Profile Only	10
1pm-9pm (U)		
9pm-5am (U)		
6am-6pm (T)		
6pm-6am (T)		
	Total ITSOEM 2 Models	60

APPENDIX B (CONTINUED)

Table B.3 ITSOEM1 Final Effects Model Estimates Urban I-95 NB 5am – 1pm Analyses Scenario

ITSOEM1 - 1 _FINAL-EFFCTS_U_NB_Minor_SSP_As Ref variable_5am-1pm						
ITSOEM1 Variables	Parameter	ITSOEM1 Block 0	ITSOEM1 Block 1	ITSOEM1 Block 2	ITSOEM1 Block 3	ITSOEM1 Block 4
		Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate
	-2LL	568.381	552.100	532.209	531.992	525.627
	ChiSuqare	-	16.270	19.901	2.973	6.365
	Sig	0.000	0.000	0.000	0.218	0.012
	ModelChi		16.270	36.171	36.389	42.754
	ModelSig		0.000	0.000	0.000	0.000
	H & L		1.000	0.755	0.166	0.522
Constant	β	-0.417	-0.788	-0.946	-1.032	-1.524
	SE	0.099	0.156	0.336	0.384	0.437
	Wald	17.636	25.644	7.922	7.230	12.175
	sig	0.000	0.000	0.005	0.007	0.000
	OR	0.659	0.455	0.388	0.356	0.218
I(High)	β		1.116	1.219	1.215	1.154
	SE		0.282	0.293	0.293	0.296
	Wald		15.607	17.353	17.238	15.217
	sig		0.000	0.000	0.000	0.000
	OR		3.052	3.385	3.371	3.170
	CI		1.754-5.308	1.907-6.007	1.899-5.983	1.775-5.659
I(Major)	β		0.441	0.552	0.547	0.522
	SE		0.225	0.232	0.233	0.235
	Wald		3.852	5.654	5.530	4.957
	sig		0.050	0.017	0.019	0.026
	OR		1.554	1.737	1.728	1.686
	CI		1.001-2.414	1.102-2.739	1.095-2.727	1.065-2.671
D(CCTV)	β			0.559	0.556	1.534
	SE			0.350	0.350	0.527
	Wald			2.549	2.516	8.469
	sig			0.110	0.113	0.004
	OR			1.749	1.743	4.639
	CI			0.881 - 3.473	0.877-3.465	1.650-13.039
D(VSP)	β			-0.418	-0.412	-0.375
	SE			0.360	0.361	0.365
	Wald			1.349	1.302	1.055
	sig			0.245	0.254	0.304
	OR			0.658	0.662	0.687
	CI			0.325-1.333	0.327-1.344	0.336-1.406
dDMS	β				0.038	0.255
	SE				0.081	0.118
	Wald				0.218	4.616
	sig				0.640	0.032
	OR				1.039	1.290
	CI				0.885-1.219	1.023-1.627
App Volume	β				0.067	
	SE				0.041	
	Wald				2.745	
	sig				0.098	
	OR				1.070	
	CI				0.988-1.159	
CCTV*dDMS	β					-0.412
	SE					0.164
	Wald					6.311
	sig					0.012
	OR					0.662
	CI					0.480-0.913

APPENDIX B (CONTINUED)

Table B.4 ITSOEM1 Final Effects Model Estimates Urban I-95 SB 1pm-9pm Analyses Scenario

2 U_SB_Minor_SSP_As Ref variable_1PM-9PM					
ITSOEM1 Variables	**Parameter**	**ITSOEM1 Block 0**	**ITSOEM1 Block 1**	**ITSOEM1 Block 2**	**ITSOEM1 Block 3**
		Parameter Estimate	**Parameter Estimate**	**Parameter Estimate**	**Parameter Estimate**
	-2LL	626.823	608.560	603.497	597.860
	ChiSuqare		18.263	5.063	5.637
	Sig	0.280	0.000	0.080	0.060
	MODEL Chi		0.000	0.000	0.000
	MODEL Sig		18.263	23.326	28.963
	H & L Sig		1.000	0.954	0.104
Constant	β	-0.102	-0.616	0.031	0.866
	SE	0.094	0.159	0.307	0.562
	Wald	1.167	15.055	0.010	2.374
	sig	0.280	0.000	0.919	0.123
	OR	0.903	0.540	0.969	2.378
I(High)	β		0.960	1.037	0.994
	SE		0.263	0.268	0.269
	Wald		13.350	15.020	13.637
	sig		0.000	0.000	0.000
	OR		2.612	2.820	2.703
	CI		1.561-4.372	1.669-4.765	1.595-4.582
I(Major)	β		0.757	0.773	0.765
	SE		0.217	0.218	0.221
	Wald		12.207	12.526	12.011
	sig		0.000	0.000	0.001
	OR		2.132	2.167	2.149
	CI		1.394-3.261	1.412-3.325	1.394-3.312
D(CCTV)	β			-0.698	-0.665
	SE			0.331	0.332
	Wald			4.455	4.011
	sig			0.035	0.045
	OR			0.498	0.514
	CI			0.260-0.951	0.268-0.986
D(VSP)	β			-0.678	-0.625
	SE			0.322	0.323
	Wald			4.438	3.735
	sig			0.035	0.053
	OR			0.508	0.535
	CI			0.270-0.954	0.284-1.009
dDMS	β				-0.017
	SE				0.016
	Wald				1.157
	sig				0.282
	OR				0.983
	CI				0.953-1.014
App Volume	β				-0.180
	SE				0.098
	Wald				3.371
	sig				0.066
	OR				0.835
	CI				1.012

APPENDIX B (CONTINUED)

Table B.5 ITSOEM1 Final Effects Model Estimates Urban I-95 NB 9pm – 5am Analyses Scenario

		3_ ITSOEM1_U_NB_Minor_SSP_As Ref variable_9PM-5AM			
ITSOEM1 Variables	**Parameter**	**ITSOEM1 Block 0**	**ITSOEM1 Block 1**	**ITSOEM1 Block 2**	**ITSOEM1 Block 3**
		Parameter Estimate	**Parameter Estimate**	**Parameter Estimate**	**Parameter Estimate**
	-2LL	**185.644**	**182.564**	**182.264**	**182.031**
	ChiSuqare		**3.080**	**0.299**	**0.233**
	Sig	**0.060**	**0.214**	**0.861**	**0.890**
	MODEL Chi		**3.080**	**3.380**	**3.613**
	MODEL Sig		**0.214**	**0.496**	**0.729**
	H & L Sig		**1.000**	**0.686**	**0.533**
Constant	**β**	**0.600**	**-0.256**	**-0.081**	**-0.088**
	SE	**0.173**	**0.272**	**0.467**	**0.702**
	Wald	**0.119**	**0.886**	**0.030**	**0.016**
	sig	**0.730**	**0.347**	**0.862**	**0.901**
	OR	**1.062**	**0.774**	**0.922**	**0.916**
I(High)	**β**		**0.752**	**0.760**	**0.769**
	SE		**0.435**	**0.437**	**0.439**
	Wald		**2.998**	**3.029**	**3.070**
	sig		**0.083**	**0.082**	**0.080**
	OR		**2.122**	**2.139**	**2.158**
	CI		**0.905-4.973**	**0.909-5.037**	**0.913-5.100**
I(Major)	**β**		**0.351**	**0.353**	**0.381**
	SE		**0.412**	**0.414**	**0.424**
	Wald		**0.728**	**0.727**	**0.807**
	sig		**0.393**	**0.394**	**0.369**
	OR		**1.421**	**1.424**	**1.464**
	CI		**0.634-3.183**	**0.632-3.208**	**0.637-3.363**
D(CCTV)	**β**			**-0.143**	**-0.143**
	SE			**0.528**	**0.529**
	Wald			**0.072**	**0.073**
	sig			**0.788**	**0.787**
	OR			**0.868**	**0.867**
	CI			**0.308-2.441**	**0.308-2.443**
D(VSP)	**β**			**-0.263**	**-0.297**
	SE			**0.502**	**0.506**
	Wald			**0.275**	**0.345**
	sig			**0.600**	**0.557**
	OR			**0.769**	**0.743**
	CI			**0.288-2.054**	**0.275-2.004**
dDMS	**β**				**-0.045**
	SE				**0.166**
	Wald				**0.072**
	sig				**0.788**
	OR				**0.956**
	CI				**0.691-1.323**
App Volume	**β**				**0.071**
	SE				**0.197**
	Wald				**0.128**
	sig				**0.721**
	OR				**1.073**
	CI				**0.729-1.580**

APPENDIX B (CONTINUED)

Table B.6 ITSOEM1 Final Effects Model Estimates Urban I-95 SB 9pm – 5am Analyses Scenario

		4_ ITSOEM1_U_SB_Minor_SSP_As Ref variable_9PM-5AM			
ITSOEM1 Variables	**Parameter**	**ITSOEM1 Block 0**	**ITSOEM1 Block 1**	**ITSOEM1 Block 2**	**ITSOEM1 Block 3**
		Parameter Estimate	**Parameter Estimate**	**Parameter Estimate**	**Parameter Estimate**
	-2LL	**219.659**	**214.742**	**198.130**	**198.097**
	ChiSuqare		**4.917**	**16.612**	**0.033**
	Sig		**0.086**	**0.000**	**0.984**
	MODEL Chi		**4.917**	**21.529**	**21.562**
	MODEL Sig		**0.086**	**0.000**	**0.001**
	H & L Sig		**1.000**	**0.357**	**0.624**
Constant	**β**	**-0.139**	**0.230**	**1.005**	**1.058**
	SE	**0.159**	**0.241**	**0.464**	**0.597**
	Wald	**0.760**	**0.910**	**4.697**	**3.137**
	sig	**0.383**	**0.340**	**0.030**	**0.077**
	OR	**0.871**	**1.258**	**2.733**	**2.880**
I(High)	**β**		**-0.424**	**-0.897**	**-0.877**
	SE		**0.434**	**0.477**	**0.491**
	Wald		**0.954**	**3.540**	**3.186**
	sig		**0.329**	**0.060**	**0.074**
	OR		**0.655**	**0.408**	**0.416**
	CI		**0.280-1.532**	**0.160-1.038**	**0.159-1.090**
I(Major)	**β**		**-0.796**	**-0.827**	**-0.819**
	SE		**0.364**	**0.388**	**0.392**
	Wald		**4.780**	**4.536**	**4.367**
	sig		**0.029**	**0.033**	**0.037**
	OR		**0.451**	**0.437**	**0.441**
	CI		**0.221-0.921**	**0.204-0.936**	**0.204-0.950**
D(CCTV)	**β**			**0.033**	**0.015**
	SE			**0.496**	**0.506**
	Wald			**0.004**	**0.001**
	sig			**0.947**	**0.976**
	OR			**1.034**	**1.015**
	CI			**0.391-2.731**	**0.376-2.738**
D(VSP)	**β**			**-1.386**	**-1.401**
	SE			**0.475**	**0.484**
	Wald			**8.495**	**8.393**
	sig			**0.004**	**0.004**
	OR			**0.250**	**0.246**
	CI			**0.099-0.635**	**0.095-0.636**
dDMS	**β**				**0.002**
	SE				**0.081**
	Wald				**0.001**
	sig				**0.978**
	OR				**1.002**
	CI				**0.855-1.175**
App Volume	**β**				**-0.030**
	SE				**0.165**
	Wald				**0.033**
	sig				**0.856**
	OR				**0.971**
	CI				**0.703-1.341**

APPENDIX B (CONTINUED)

Table B.7 ITSOEM1 Final Effects Model Estimates Transition I-95 NB 6am – 6pm Analyses Scenario

		5_ ITSOEM1_T_NB_Minor_SSP_As Ref variable_6AM-6PM			
ITSOEM1 Variables	Parameter	ITSOEM1 Block 0	ITSOEM1 Block 1	ITSOEM1 Block 2	ITSOEM1 Block 3
		Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate
	-2LL	551.870	549.430	548.791	548.751
	ChiSuqare		2.439	0.639	0.040
	Sig		0.295	0.726	0.980
	MODEL Chi		2.439	3.079	3.119
	MODEL Sig		0.295	0.545	0.794
	H & L Sig		1.000	0.996	0.893
Constant	β	-0.405	-0.535	-0.630	-0.669
	SE	0.101	0.133	0.240	0.308
	Wald	16.177	16.080	6.912	4.702
	sig	0.000	0.000	0.009	0.030
	OR	0.667	0.586	0.532	0.512
I(High)	β		0.228	0.228	0.230
	SE		0.295	0.297	0.298
	Wald		0.595	0.590	0.592
	sig		0.441	0.442	0.442
	OR		1.256	1.256	1.258
	CI		0.704-2.240	0.702-2.248	0.701-2.257
I(Major)	β		0.353	0.349	0.348
	SE		0.233	0.234	0.234
	Wald		2.286	2.232	2.216
	sig		0.131	0.135	0.137
	OR		1.423	1.418	1.417
	CI		0.901-2.249	0.897-2.242	0.895-2.242
D(CCTV)	β			0.034	0.035
	SE			0.289	0.289
	Wald			0.014	0.014
	sig			0.907	0.905
	OR			1.034	1.035
	CI			0.587-1.822	0.588-1.823
D(VSP)	β			0.182	0.180
	SE			0.271	0.272
	Wald			0.447	0.442
	sig			0.504	0.506
	OR			1.199	1.198
	CI			0.704-2.041	0.703-2.040
dDMS	β				0.002
	SE				0.017
	Wald				0.019
	sig				0.891
	OR				1.002
	CI				0.969-1.037
App Volume	β				0.005
	SE				0.034
	Wald				0.025
	sig				0.874
	OR				1.005
	CI				0.941-1.074

APPENDIX B (CONTINUED)

Table B.8 ITSOEM1 Final Effects Model Estimates Transition I-95 SB 6am – 6pm Analyses Scenario

		6_ ITSOEM1_T_SB_Minor_SSP_As Ref variable_6AM-6PM			
ITSOEM1 Variables	Parameter	ITSOEM1 Block 0	ITSOEM1 Block 1	ITSOEM1 Block 2	ITSOEM1 Block 3
		Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate
	-2LL	597.212	586.973	583.365	581.377
	ChiSuqare		10.239	3.608	1.988
	Sig		0.006	0.165	0.370
	MODEL Chi		10.239	13.847	15.835
	MODEL Sig		0.006	0.008	0.015
	H & L Sig		1.000	0.993	0.382
Constant	β	-0.051	-0.148	-0.186	-0.701
	SE	0.096	0.125	0.240	0.501
	Wald	0.281	1.402	0.600	1.961
	sig	0.596	0.236	0.439	0.161
	OR	0.950	0.862	0.830	0.496
I(High)	β		0.892	0.864	0.886
	SE		0.305	0.308	0.309
	Wald		8.538	7.851	8.196
	sig		0.003	0.005	0.004
	OR		2.441	2.372	2.425
	CI		1.342-4.441	1.296-4.339	1.322-4.448
I(Major)	β		-0.079	-0.112	-0.084
	SE		0.226	0.227	0.229
	Wald		0.122	0.243	0.135
	sig		0.726	0.622	0.713
	OR		0.924	0.894	0.919
	CI		0.594-1.438	0.572-1.396	0.587-1.440
D(CCTV)	β			0.303	0.309
	SE			0.288	0.291
	Wald			1.107	1.131
	sig			0.293	0.288
	OR			1.353	1.362
	CI			0.770-2.377	0.771-2.408
D(VSP)	β			-0.111	-0.106
	SE			0.272	0.273
	Wald			0.166	0.152
	sig			0.684	0.697
	OR			0.895	0.899
	CI			0.525-1.526	0.527-1.535
dDMS	β				-0.004
	SE				0.008
	Wald				0.235
	sig				0.628
	OR				0.996
	CI				0.981-1.012
App Volume	β				0.134
	SE				0.105
	Wald				1.625
	sig				0.202
	OR				1.144
	CI				0.930-1.407

APPENDIX B (CONTINUED)

Table B.9 ITSOEM1 Final Effects Model Estimates Transition I-95 NB 6pm – 6am Analyses Scenario

		7_ ITSOEM1_T_NB_Minor_SSP_As Ref variable_6PM-6AM			
ITSOEM1 Variables	Parameter	ITSOEM1 Block 0	ITSOEM1 Block 1	ITSOEM1 Block 2	ITSOEM1 Block 3
		Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate
	-2LL	238.851	230.844	225.653	224.181
	ChiSuqare		8.007	5.191	1.472
	Sig		0.018	0.075	0.479
	MODEL Chi		8.007	13.198	14.670
	MODEL Sig		0.018	0.010	0.023
	H & L Sig		1.000	0.892	0.733
Constant	β	-0.151	-0.464	-0.905	-0.581
	SE	0.152	0.192	0.372	0.467
	Wald	0.975	5.824	5.918	1.546
	sig	0.323	0.016	0.015	0.214
	OR	0.860	0.629	0.405	0.559
I(High)	β		0.783	1.072	1.110
	SE		0.503	0.533	0.537
	Wald		2.422	4.050	4.273
	sig		0.120	0.044	0.039
	OR		2.187	2.922	3.033
	CI		0.816-5.862	1.028-8.300	1.059-8.685
I(Major)	β		0.975	1.134	1.172
	SE		0.379	0.395	0.399
	Wald		6.618	8.245	8.662
	sig		0.100	0.004	0.003
	OR		2.651	3.109	3.229
	CI		1.261-5.574	1.433-6.744	1.477-7.063
D(CCTV)	β			0.102	0.114
	SE			0.426	0.435
	Wald			0.057	0.069
	sig			0.811	0.792
	OR			1.107	1.121
	CI			0.480-2.554	0.478-2.628
D(VSP)	β			0.811	0.804
	SE			0.421	0.426
	Wald			3.702	3.562
	sig			0.054	0.059
	OR			2.250	2.234
	CI			0.985-5.139	0.969-5.147
dDMS	β				-0.026
	SE				0.026
	Wald				1.063
	sig				0.303
	OR				0.974
	CI				0.926-1.024
App Volume	β				-0.056
	SE				0.100
	Wald				0.312
	sig				0.577
	OR				0.946
	CI				0.777-1.151

APPENDIX B (CONTINUED)

Table B.10 ITSOEM1 Final Effects Model Estimates Transition I-95 SB 6pm – 6am Analyses Scenario

		8_ ITSOEM1_T_SB_Minor_SSP_As Ref variable_6PM-6AM			
ITSOEM1 Variables	Parameter	ITSOEM1 Block 0	ITSOEM1 Block 1	ITSOEM1 Block 2	ITSOEM1 Block 3
		Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate
	-2LL	256.438	251.027	245.498	244.391
	ChiSuqare		5.417	5.523	1.107
	Sig		0.067	0.063	0.575
	MODEL Chi		5.417	10.940	12.047
	MODEL Sig		0.067	0.027	0.061
	H & L Sig		1.000	0.997	0.228
Constant	β	0.300	-0.577	-0.876	-0.835
	SE	0.148	0.195	0.335	0.562
	Wald	4.139	8.737	6.840	2.212
	sig	0.042	0.003	0.009	0.137
	OR	0.741	0.562	0.417	0.434
I(High)	β		0.459	0.556	0.547
	SE		0.524	0.533	0.549
	Wald		0.769	1.089	0.994
	sig		0.381	0.297	0.319
	OR		1.583	1.744	1.729
	CI		0.567-4.417	0.614-4.956	0.589-5.073
I(Major)	β		0.753	0.705	0.709
	SE		0.330	0.335	0.340
	Wald		5.208	4.415	4.346
	sig		0.022	0.036	0.037
	OR		2.123	2.023	2.032
	CI		1.112-4.052	1.049-3.904	1.043-3.959
D(CCTV)	β			0.767	0.756
	SE			0.395	0.419
	Wald			3.768	3.258
	sig			0.052	0.071
	OR			2.153	2.129
	CI			0.993-4.670	0.937-4.836
D(VSP)	β			0.052	0.114
	SE			0.394	0.439
	Wald			0.017	0.067
	sig			0.895	0.796
	OR			1.053	1.120
	CI			0.486-2.281	0.474-2.647
dDMS	β				-0.033
	SE				0.036
	Wald				0.821
	sig				0.365
	OR				0.968
	CI				0.902-1.039
App Volume	β				0.041
	SE				0.122
	Wald				0.111
	sig				0.739
	OR				1.042
	CI				0.819-1.324

APPENDIX B (CONTINUED)

Table B.11 ITSOEM2 Final Effects Model Estimates Urban I-95 NB 5am – 1pm Analyses Scenario

		1_U_NB_MINOR_AS REF_5AM-1PM_ITSOEM2_DMS0				
ITSOEM2 Variables	Parameter	ITSOEM2 Block 0	ITSOEM2 Block 1	ITSOEM2 Block 2	ITSOEM2 Block 3	ITSOEM2 Block 4
		Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate
	-2LL	486.927	479.662	468.39	458.551	458.494
	ChiSquare		7.265	11.272	9.839	0.057
	Sig	0	0.026	0.001	0.002	0.972
	ModelChi		7.265	18.537	28.377	28.433
	ModelSig		0.026	0	0	0
	H & L		1	0.365	0.345	0.533
Constant	β	-1.033	-1.367	-1.962	-2.504	-2.481
	SE	0.111	0.179	0.266	0.337	0.476
	Wald	87.445	58.064	54.277	55.165	27.111
	sig	0	0	0	0	0
	OR	0.356	0.255	0.141	0.082	0.084
I(High)	β		0.754	0.986	0.92	0.923
	SE		0.302	0.317	0.324	0.324
	Wald		6.211	9.699	8.073	8.109
	sig		0.013	0.002	0.004	0.004
	OR		2.125	2.681	2.509	2.518
	CI		1.175-3.844	1.441-4.988	1.330-4.731	1.334-4.754
I(Major)	β		0.486	0.567	0.557	0.558
	SE		0.251	0.255	0.258	0.258
	Wald		3.753	4.927	4.667	4.679
	sig		0.053	0.026	0.031	0.031
	OR		1.626	1.762	1.745	1.748
	CI		0.994-2.658	1.069-2.907	1.056-2.893	1.054-2.899
DMS(Message = 0)	β			0.811	0.849	0.846
	SE			0.249	0.254	0.255
	Wald			10.597	11.205	11.017
	sig			0.001	0.001	0.001
	OR			2.25	2.338	2.33
	CI			1.381-3.666	1.422-3.844	1.414-3.840
DMS(Message = 1)	β			-0.811	-0.849	-0.846
	SE			0.249	0.254	0.255
	Wald			10.597	11.205	11.017
	sig			0.001	0.001	0.001
	OR			0.444	0.428	0.4291
	CI			0.273-0.724	0.260-0.703	
I(DURATION)	β				0.009	0.009
	SE				0.003	0.003
	Wald				8.302	0.795
	sig				0.004	0.005
	OR				1.009	1.009
	CI				1.003-1.016	1.003-1.016
dDMS	β					0.012
	SE					0.066
	Wald					0.031
	sig					0.86
	OR					1.012
	CI					0.889-1.151
App Volume	β					-0.007
	SE					0.047
	Wald					0.025
	sig					0.874
	OR					0.993
	CI					0.905-1.089

APPENDIX B (CONTINUED)

Table B.12 ITSOEM2 Final Effects Model Estimates Urban I-95 SB 1pm-9pm Analyses Scenario

10_U_SB_MINOR_AS REF_1PM-9PM_ITSOEM2_DMS0 and DMS1						
ITSOEM2 Variables	Parameter	ITSOEM2 Block 0	ITSOEM2 Block 1	ITSOEM2 Block 2	ITSOEM2 Block 3	ITSOEM2 Block 4
		Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate
	-2LL	513.285	494.947	481.115	467.399	465.848
	ChiSquare		18.338	13.832	13.716	1.551
	Sig	0.000	0.000	0.000	0.000	0.460
	ModelChi		18.338	32.170	45.886	47.437
	ModelSig		0.000	0.000	0.000	0.000
	H & L		0.999	0.914	0.333	0.449
Constant	β	-1.078	-1.739	-2.350	-3.504	-3.302
	SE	0.108	0.213	0.281	0.362	0.656
	Wald	99.734	66.875	69.698	71.134	25.295
	sig	0.000	0.000	0.000	0.000	0.000
	OR	0.340	0.176	0.095	0.047	0.037
I(High)	β		1.171	1.404	1.462	1.468
	SE		0.302	315.000	0.323	0.324
	Wald		15.015	19.863	20.497	20.544
	sig		0.000	0.000	0.000	0.000
	OR		3.224	4.073	4.313	4.339
	CI		1.783-5.829	2.196-7.554	2.291-8.121	2.300-8.184
I(Major)	β		0.879	1.056	1.084	1.069
	SE		0.267	0.275	0.282	0.283
	Wald		10.858	14.736	14.774	14.246
	sig		0.001	0.000	0.000	0.000
	OR		2.407	2.875	2.955	2.913
	CI		1.428-4.060	1.677-4.929	1.701-5.135	1.672-5.074
DMS(Message = 0)	β			0.854	0.838	0.815
	SE			0.235	0.240	0.241
	Wald			13.256	12.225	11.409
	sig			0.000	0.000	0.001
	OR			2.350	2.312	2.259
	CI			1.484-3.723	1.445-3.699	1.408-3.626
DMS(Message = 1)	β			-0.854	-0.838	-0.815
	SE			0.235	0.240	0.241
	Wald			13.256	12.225	11.409
	sig			0.000	0.000	0.001
	OR			0.426	0.432	0.443
	CI			0.269-0.674	0.270-0.692	
I(DURATION)	β				0.012	0.012
	SE				0.003	0.003
	Wald				12.812	13.111
	sig				0.000	0.000
	OR				1.012	1.012
	CI				1.005-1.018	1.005-1.018
dDMS	β					0.017
	SE					0.019
	Wald					0.745
	sig					0.388
	OR					1.017
	CI					0.979-1.056
App Volume	β					0.043
	SE					0.111
	Wald					0.152
	sig					0.697
	OR					1.044
	CI					0.840-1.298

APPENDIX B (CONTINUED)

Table B.13 ITSOEM2 Final Effects Model Estimates Urban I-95 NB 9pm – 5am Analyses Scenario

11_U_NB_MINOR_AS REF_9PM-5AM_ITSOEM2_DMS0 and DMS1						
ITSOEM2 Variables	Parameter	ITSOEM2 Block 0	ITSOEM2 Block 1	ITSOEM2 Block 2	ITSOEM2 Block 3	ITSOEM2 Block 4
		Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate
	-2LL	125.969	125.502	121.074	121.052	120.326
	ChiSquare		0.466	4.428	0.022	0.726
	Sig		0.792	0.035	0.882	0.695
	ModelChi		0.466	4.895	4.917	5.643
	ModelSig		0.792	0.180	0.296	0.464
	H & L		1.000	0.963	0.290	0.414
Constant	β	-1.522	-1.631	-2.267	-2.304	-1.845
	SE	0.225	0.364	0.508	0.566	0.883
	Wald	45.661	20.032	19.910	16.568	4.361
	sig	0.000	0.000	0.000	0.000	0.037
	OR	0.218	0.196	0.104	0.100	0.158
I(High)	β		0.343	0.541	0.514	0.557
	SE		0.541	0.560	0.588	0.592
	Wald		0.403	0.933	0.767	0.884
	sig		0.525	0.334	0.381	0.347
	OR		1.410	1.717	1.673	1.745
	CI		0.489-4.068	0.573-5.145	0.529-5.291	0.547-5.572
I(Major)	β		0.022	0.107	0.095	0.129
	SE		0.552	0.561	0.567	0.579
	Wald		0.002	0.036	0.028	0.049
	sig		0.968	0.850	0.867	0.824
	OR		1.022	1.112	1.099	1.137
	CI		0.347-3.013	0.370-3.343	0.362-3.341	0.366-3.538
DMS(Message = 0)	β			0.988	0.982	0.985
	SE			0.484	0.485	0.488
	Wald			4.174	4.106	4.085
	sig			0.041	0.043	0.043
	OR			2.685	2.670	2.679
	CI			1.041-6.928	1.033-6.904	1.030-6.964
DMS(Message = 1)	β			-0.988	-0.982	-0.985
	SE			0.484	0.485	0.488
	Wald			4.174	4.106	4.085
	sig			0.041	0.043	0.043
	OR			0.372	0.375	0.373
	CI			0.144-0.961	0.145-0.968	0.144-0.971
I(DURATION)	β				0.047	0.009
	SE				0.312	0.313
	Wald				0.022	0.001
	sig				0.882	0.978
	OR				1.048	1.009
	CI				0.568-1.931	0.546-1.864
dDMS	β					-0.032
	SE					0.205
	Wald					0.025
	sig					0.875
	OR					0.968
	CI					0.648-1.448
App Volume	β					-0.231
	SE					0.282
	Wald					0.667
	sig					0.414
	OR					0.794
	CI					0.456-1.381

APPENDIX B (CONTINUED)

Table B.14 ITSOEM2 Final Effects Model Estimates Urban I-95 SB 9pm – 5am Analyses Scenario

12_U_SB_MINOR_AS REF_9PM-5AM_ITSOEM2_DMS0 and DMS1						
ITSOEM2 Variables	Parameter	ITSOEM2 Block 0	ITSOEM2 Block 1	ITSOEM2 Block 2	ITSOEM2 Block 3	ITSOEM2 Block 4
		Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate
	-2LL	144.877	142.991	142.628	141.548	141.254
	ChiSquare		1.886	0.362	1.081	0.294
	Sig		0.390	0.547	0.299	0.863
	ModelChi		1.886	2.248	3.329	3.623
	ModelSig		0.390	0.523	0.504	0.728
	H & L		1.000	0.879	0.834	0.501
Constant	β	-1.587	-1.576	-1.697	-2.030	-1.805
	SE	0.211	0.317	0.382	0.503	0.656
	Wald	56.447	24.681	19.730	16.297	7.582
	sig	0.000	0.000	0.000	0.000	0.006
	OR	0.205	0.207	0.183	0.131	0.164
I(High)	β		-0.658	-0.687	-0.881	-0.836
	SE		0.685	0.688	0.724	0.749
	Wald		0.922	0.998	1.483	1.246
	sig		0.337	0.318	0.223	0.264
	OR		0.518	0.503	0.414	0.433
	CI		0.135-1.984	0.131-1.936	0.100-1.711	0.100-1.882
I(Major)	β		0.232	0.182	0.110	0.150
	SE		0.453	0.461	0.469	0.475
	Wald		0.261	0.155	0.055	0.100
	sig		0.609	0.694	0.814	0.752
	OR		1.261	1.199	1.117	1.162
	CI		0.518-3.067	0.485-2.962	0.445-2.799	0.458-2.950
DMS(Message = 0)	β			0.263	0.257	0.254
	SE			0.438	0.440	0.440
	Wald			0.359	0.342	0.334
	sig			0.549	0.558	0.563
	OR			1.300	1.293	1.289
	CI			0.551-3.067	0.546-3.061	0.545-3.052
DMS(Message = 1)	β			-0.263	-0.257	-0.254
	SE			0.438	0.440	0.440
	Wald			0.359	0.342	0.334
	sig			0.549	0.558	0.563
	OR			0.769	0.773	0.776
	CI			0.326-1.814	0.327-1.830	0.328-1.836
I(DURATION)	β				0.365	0.356
	SE				0.345	0.350
	Wald				1.125	1.032
	sig				0.289	0.310
	OR				1.441	1.427
	CI				0.734-2.831	0.545-3.052
dDMS	β					-0.034
	SE					0.106
	Wald					0.105
	sig					0.746
	OR					0.966
	CI					0.785-1.189
App Volume	β					-0.072
	SE					0.212
	Wald					0.117
	sig					0.733
	OR					0.930
	CI					0.614-1.410

APPENDIX B (CONTINUED)

Table B.15 ITSOEM2 Final Effects Model Estimates Transition I-95 NB 6am – 6pm Analyses Scenario

13_ITSOEM2_T_NB_MINOR_AS REF_6AM-6PM_ITSOEM2_DMS0_DMS1						
ITSOEM2 Variables	Parameter	ITSOEM2 Block 0	ITSOEM2 Block 1	ITSOEM2 Block 2	ITSOEM2 Block 3	ITSOEM2 Block 4
		Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate
	-2LL	457.790	427.401	409.998	396.726	393.588
	ChiSquare		30.389	17.402	13.272	3.138
	Sig	0.000	0.000	0.000	0.000	0.208
	ModelChi		30.389	47.791	61.064	64.201
	ModelSig		0.000	0.000	0.000	0.000
	H & L		0.999	0.414	0.930	0.357
Constant	β	-1.118	-1.707	-2.475	-3.153	-3.397
	SE	0.115	0.179	0.281	0.360	0.442
	Wald	95.181	91.268	77.804	76.520	58.394
	sig	0.000	0.000	0.000	0.000	0.000
	OR	0.327	0.181	0.084	0.430	0.033
I(High)	β		1.605	1.739	1.478	1.555
	SE		0.316	0.329	0.342	0.348
	Wald		25.791	27.936	18.640	19.994
	sig		0.000	0.000	0.000	0.000
	OR		4.978	5.691	4.386	4.734
	CI		2.680-9.249	2.986-10.845	2.242-8.582	2.395-9.358
I(Major)	β		0.986	1.103	1.050	1.085
	SE		0.271	0.279	0.284	0.287
	Wald		13.288	15.605	13.677	14.320
	sig		0.000	0.000	0.000	0.000
	OR		2.681	3.012	2.859	2.960
	CI		1.578-4.557	1.743-5.206	1.638-4.988	1.687-5.193
DMS(Message = 0)	β			1.081	1.092	1.104
	SE			0.272	0.277	0.279
	Wald			15.814	15.482	15.660
	sig			0.000	0.000	0.000
	OR			2.946	2.979	3.016
	CI			1.730-5.018	1.730-5.131	1.746-5.210
DMS(Message =1)	β			-1.081	-1.092	
	SE			0.272	0.277	
	Wald			15.814	15.482	
	sig			0.000	0.000	
	OR			0.339	0.336	
	CI			0.199-0.578	0.195-0.578	
I(DURATION)	β				0.012	0.012
	SE				0.004	0.004
	Wald				11.018	10.899
	sig				0.001	0.001
	OR				1.013	1.012
	CI				1.005-1.020	1.005-1.020
dDMS	β					0.036
	SE					0.021
	Wald					2.891
	sig					0.089
	OR					1.037
	CI					0.995-1.080
App Volume	β					-0.015
	SE					0.046
	Wald					0.111
	sig					0.739
	OR					0.985
	CI					0.900-1.078

APPENDIX B (CONTINUED)

Table B.16 ITSOEM2 Final Effects Model Estimates Transition I-95 SB 6am – 6pm Analyses Scenario

14_ITSOEM2_T_SB_MINOR_AS REF_6AM-6PM_DMS0_DMS1						
ITSOEM2 Variables	Parameter	ITSOEM1 Block 0	ITSOEM1 Block 1	ITSOEM1 Block 2	ITSOEM1 Block 3	ITSOEM1 Block 4
		Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate
	-2LL	454.650	452.298	448.594	443.032	442.242
	ChiSquare		2.352	3.704	5.562	0.790
	Sig	0.000	0.308	0.054	0.018	0.674
	ModelChi		2.352	6.056	11.618	12.408
	ModelSig		0.308	0.109	0.020	0.053
	H & L		1.000	0.521	0.372	0.462
Constant	β	-1.263	-1.396	-1.658	-2.034	-2.094
	SE	0.116	0.156	0.214	0.289	0.593
	Wald	118.182	79.670	59.951	49.392	12.459
	sig	0.000	0.000	0.000	0.000	0.000
	OR	0.283	0.248	0.190	0.131	0.123
I(High)	β		0.492	0.597	0.420	0.443
	SE		0.327	0.334	0.347	0.349
	Wald		2.256	3.190	1.469	1.615
	sig		0.133	0.074	0.225	0.204
	OR		1.635	1.816	1.523	1.558
	CI		0.861-3.105	0.944-3.494	0.772-3.005	0.786-3.086
I(Major)	β		0.215	0.207	0.243	0.247
	SE		0.270	0.271	0.273	0.274
	Wald		0.632	0.586	0.796	0.812
	sig		0.427	0.444	0.372	0.367
	OR		1.239	1.231	1.275	1.280
	CI		0.730-2.103	0.723-2.094	0.747-2.176	0.748-2.191
DMS(Message = 0)	β			0.459	0.437	0.450
	SE			0.240	0.243	0.244
	Wald			3.644	3.245	3.411
	sig			0.056	0.072	0.065
	OR			1.583	1.549	1.568
	CI			0.988-2.535	0.962-2.493	0.973-2.528
DMS(Message = 0)	β			-0.459	-0.437	
	SE			0.240	0.243	
	Wald			3.644	3.245	
	sig			0.056	0.072	
	OR			0.632	0.646	
	CI			0.394-1.012	0.401-1.039	
I(DURATION)	β				0.007	0.007
	SE				0.003	0.003
	Wald				3.909	3.689
	sig				0.048	0.055
	OR				1.007	1.007
	CI				1.000-1.014	1.000-1.013
dDMS	β					-0.009
	SE					0.013
	Wald					0.541
	sig					0.462
	OR					0.991
	CI					0.967-1.016
App Volume	β					0.031
	SE					0.127
	Wald					0.060
	sig					0.806
	OR					1.032
	CI					0.805-1.322

APPENDIX B (CONTINUED)

Table B.17 ITSOEM2 Final Effects Model Estimates Transition I-95 NB 6pm – 6am Analyses Scenario

15_ITSOEM2_T_NB_MINOR_AS REF_6PM-6AM_ITSOEM2_DMS0_DMS1						
ITSOEM2 Variables	Parameter	ITSOEM2 Block 0	ITSOEM2 Block 1	ITSOEM2 Block 2	ITSOEM2 Block 3	ITSOEM2 Block 4
		Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate
	-2LL	142.920	141.521	141.325	141.324	140.515
	ChiSquare		1.399	0.196	0.001	0.810
	Sig		0.497	0.658	0.975	0.667
	ModelChi		1.399	1.595	1.596	2.405
	ModelSig		0.497	0.660	0.810	0.879
	H & L		1.000	0.960	0.461	0.646
Constant	β	-1.778	-1.609	-1.735	-1.729	-2.112
	SE	0.216	0.251	0.384	0.438	0.635
	Wald	67637.000	41.013	20.386	15.576	11.058
	sig	0.000	0.000	0.000	0.000	0.001
	OR	0.169	0.200	0.176	0.178	0.121
I(High)	β		-0.531	-0.493	-0.493	-0.536
	SE		0.789	0.793	0.793	0.796
	Wald		0.453	0.386	0.386	0.453
	sig		0.501	0.534	0.535	0.501
	OR		0.588	0.911	0.611	0.585
	CI		0.125-2.760	0.129-2.893	0.129-2.893	0.123-2.787
I(Major)	β		-0.588	-0.541	-0.541	-0.584
	SE		0.584	0.593	0.593	0.597
	Wald		1.013	0.831	0.831	0.955
	sig		0.314	0.362	0.362	0.328
	OR		0.556	0.582	0.582	0.558
	CI		0.177-1.745	0.182-1.863	0.182-1.863	0.173-1.798
DMS(Message = 0)	β			0.199	0.198	0.167
	SE			0.450	0.450	0.453
	Wald			0.195	0.194	0.136
	sig			0.659	0.660	0.712
	OR			1.220	1.219	1.182
	CI			0.505-2.947	0.505-2.947	0.486-2.871
DMS(Message =1)	β			-0.199	-0.198	-0.167
	SE			0.450	0.450	0.453
	Wald			0.195	0.194	0.136
	sig			0.659	0.660	0.712
	OR			0.820	0.820	0.846
	CI			0.339-1.981	0.339-1.982	0.348-2.056
I(DURATION)	β				-0.005	0.022
	SE				0.176	0.179
	Wald				0.001	0.015
	sig				0.978	0.902
	OR				0.995	1.022
	CI				0.705-1.406	0.720-1.451
dDMS	β					0.022
	SE					0.034
	Wald					0.422
	sig					0.516
	OR					1.022
	CI					0.957-1.092
App Volume	β					0.080
	SE					0.134
	Wald					0.353
	sig					0.552
	OR					1.083
	CI					0.833-1.408

APPENDIX B (CONTINUED)

Table B.18 ITSOEM2 Final Effects Model Estimates Transition I-95 SB 6pm – 6am Analyses Scenario

16_ITSOEM2_T_SB_MINOR_AS REF_6PM-6AM_ITSOEM2_DMS0_DMS1						
ITSOEM2 Variables	Parameter	ITSOEM2 Block 0	ITSOEM2 Block 1	ITSOEM2 Block 2	ITSOEM2 Block 3	ITSOEM2 Block 4
		Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate	Parameter Estimate
	-2LL	195.525	193.967	193.396	193.396	192.078
	ChiSquare		5.758	0.571	0.000	1.318
	Sig		0.056	0.450	0.996	0.517
	ModelChi		5.758	6.329	6.329	7.647
	ModelSig		0.056	0.097	0.176	0.265
	H & L		1.000	0.294	0.389	0.137
Constant	β	-1.246	-0.985	-1.168	-1.166	-0.808
	SE	0.175	0.210	0.326	0.459	0.556
	Wald	50.633	21.892	12.820	6.441	2.107
	sig	0.000	0.000	0.000	0.011	0.147
	OR	0.288	0.373	0.311	0.312	0.446
I(High)	β		-1.787	-1.761	-1.761	-1.613
	SE		1.052	1.053	1.053	1.062
	Wald		2.887	2.796	2.796	2.307
	sig		0.089	0.094	0.094	0.129
	OR		0.167	0.172	0.172	0.199
	CI		0.021-1.316	0.022-1.354	0.022-1.354	0.025-1.597
I(Major)	β		-0.563	-0.513	-0.513	-0.457
	SE		0.407	0.412	0.412	0.416
	Wald		1.912	1.551	1.550	1.209
	sig		0.167	0.213	0.213	0.272
	OR		0.570	0.598	0.598	0.633
	CI		0.257-1.265	0.267-1.343	0.267-1.343	0.280-1.430
DMS(Message = 0)	β			0.279	0.279	0.289
	SE			0.371	0.371	0.375
	Wald			0.565	0.564	0.597
	sig			0.452	0.453	0.440
	OR			1.322	1.322	1.336
	CI			0.638-2.736	0.638-2.737	0.641-2.783
DMS(Message =1)	β			-0.279	-0.279	-0.289
	SE			0.371	0.371	0.375
	Wald			0.565	0.564	0.597
	sig			0.452	0.453	0.440
	OR			0.757	0.757	0.749
	CI			0.365-1.566	0.365-1.567	0.359-1.560
I(DURATION)	β				-0.002	0.011
	SE				0.319	0.323
	Wald				0.000	0.001
	sig				0.996	0.973
	OR				0.998	1.011
	CI				0.534-1.867	0.537-1.904
dDMS	β					-0.015
	SE					0.042
	Wald					0.119
	sig					0.730
	OR					0.985
	CI					0.907-1.071
App Volume	β					-0.145
	SE					0.130
	Wald					1.230
	sig					0.267
	OR					0.865
	CI					0.670-1.117

APPENDIX B (CONTINUED)

Table B.19 ITSOEM1 Model Coefficient Estimates (All Scenarios)

	Study Corridor		ITSOEM1 Model Analyses Variables							
			Design Variables				Constant	Model χ2	Reference Variables	
	AnalysesSegment	Analyses Scenario	MAJOR	MINOR	VSP	SSP				
1	I-95 NB Urban	5am - 1pm	-0.667	-1.219	-0.977	-0.559	0.832	0.000	High	CCTV
2	I-95 NB Urban	1pm-9pm	-0.731	-1.873	-0.035	0.346	0.247	0.557	High	CCTV
3	I-95 NB Urban	9pm-5am	-0.407	-0.760	-0.121	0.142	0.537	0.861	High	CCTV
4	I-95 NB Transition	6am-6pm	0.121	-0.228	0.148	-0.034	-0.368	0.726	High	CCTV
5	I-95 NB Transition	6pm-6am	0.062	-1.072	0.709	-0.102	0.269	0.075	High	CCTV
6	I-95 SB Urban	5am-1pm	0.045	-0.072	-0.281	-0.130	-0.086	0.631	High	CCTV
7	I-95 SB Urban	1pm-9pm	-0.264	-1.037	0.020	0.698	0.308	0.080	High	CCTV
8	I-95 SB Urban	9pm-5am	0.070	0.897	-1.419	-0.033	0.142	0.000	High	CCTV
9	I-95 SB Transition	6am-6pm	-0.976	-0.864	-0.413	-0.303	0.980	0.165	High	CCTV
10	I-95 SB Transition	6pm-6am	0.148	-0.556	-0.715	-0.767	0.448	0.063	High	CCTV
	Study Corridor		ITSOEM1 Model Analyses Variables							
			Design Variables				Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	MAJOR	MINOR	CCTV	SSP				
11	I-95 NB Urban	5am - 1pm	-0.667	-1.219	0.977	0.418	-0.145	0.000	High	VSP
12	I-95 NB Urban	1pm-9pm	-1.873	-0.731	0.035	0.381	0.212	0.557	High	VSP
13	I-95 NB Urban	9pm-5am	-0.407	-0.760	0.263	0.121	0.416	0.861	High	VSP
14	I-95 NB Transition	6am-6pm	0.121	-0.228	-0.148	-0.182	-0.221	0.726	High	VSP
15	I-95 NB Transition	6pm-6am	0.062	-1.072	-0.811	-0.709	0.978	0.075	High	VSP
16	I-95 SB Urban	5am-1pm	0.045	-0.072	0.152	0.281	-0.367	0.631	High	VSP
17	I-95 SB Urban	1pm-9pm	-0.264	-1.037	-0.020	0.678	0.328	0.080	High	VSP
18	I-95 SB Urban	9pm-5am	0.070	0.897	1.386	1.419	-1.277	0.000	High	VSP
19	I-95 SB Transition	6am-6pm	-0.976	-0.864	0.413	0.111	0.567	0.165	High	VSP
20	I-95 SB Transition	6pm-6am	-0.148	-0.705	0.715	-0.052	-0.119	0.063	High	VSP
	Study Corridor		ITSOEM1 Model Analyses Variables							
			Design Variables				Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	MAJOR	MINOR	CCTV	VSP				
21	I-95 NB Urban	5am - 1pm	-0.667	-1.219	0.559	-0.418	0.273	0.000	High	SSP
22	I-95 NB Urban	1pm-9pm	-0.731	-1.873	-0.346	-0.381	0.593	0.557	High	SSP
23	I-95 NB Urban	9pm-5am	-0.407	-0.760	-0.142	-0.263	0.679	0.861	High	SSP
24	I-95 NB Transition	6am-6pm	0.121	-0.228	0.034	0.182	-0.402	0.726	High	SSP
25	I-95 NB Transition	6pm-6am	0.062	-1.072	0.102	0.811	0.168	0.075	High	SSP
26	I-95 SB Urban	5am-1pm	0.045	-0.072	0.130	-0.152	-0.215	0.631	High	SSP
27	I-95 SB Urban	1pm-9pm	-0.264	-1.037	-0.698	-0.678	1.006	0.080	High	SSP
28	I-95 SB Urban	9pm-5am	0.070	0.897	0.033	-1.386	0.109	0.000	High	SSP
29	I-95 SB Transition	6am-6pm	-0.976	-0.864	0.303	-0.111	0.678	0.165	High	SSP
30	I-95 SB Transition	6pm-6am	-0.556	0.148	0.767	0.052	-0.319	0.063	High	SSP
	Study Corridor		ITSOEM1 Model Analyses Variables							
			Design Variables				Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	HIGH	MINOR	VSP	SSP				
31	I-95 NB Urban	5am - 1pm	0.667	-0.552	-0.977	-0.559	0.166	0.000	Major	CCTV
32	I-95 NB Urban	1pm-9pm	0.731	-1.143	-0.035	0.346	-0.483	0.557	Major	CCTV
33	I-95 NB Urban	9pm-5am	0.407	-0.353	-0.121	0.142	0.130	0.861	Major	CCTV
34	I-95 NB Transition	6am-6pm	-0.121	-0.349	0.148	-0.034	-0.247	0.726	Major	CCTV
35	I-95 NB Transition	6pm-6am	-0.062	-1.134	0.709	-0.102	0.332	0.075	Major	CCTV
36	I-95 SB Urban	5am-1pm	-0.045	-0.117	-0.281	-0.130	-0.040	0.631	Major	CCTV
37	I-95 SB Urban	1pm-9pm	0.264	-0.773	0.020	0.698	0.044	0.080	Major	CCTV
38	I-95 SB Urban	9pm-5am	-0.070	0.827	-1.419	-0.033	0.212	0.000	Major	CCTV
39	I-95 SB Transition	6am-6pm	0.976	0.112	-0.413	-0.303	0.004	0.165	Major	CCTV
40	I-95 SB Transition	6pm-6am	-0.148	-0.705	-0.715	-0.767	0.596	0.063	Major	CCTV
	Study Corridor		ITSOEM1 Model Analyses Variables							
			Design Variables				Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	HIGH	MINOR	VSP	SSP				
41	I-95 NB Urban	5am - 1pm	0.667	-0.552	-0.977	-0.559	0.166	0.000	Major	VSP
42	I-95 NB Urban	1pm-9pm	0.731	-1.143	-0.035	0.346	-0.483	0.557	Major	VSP
43	I-95 NB Urban	9pm-5am	0.407	-0.353	-0.121	0.142	0.130	0.861	Major	VSP
44	I-95 NB Transition	6am-6pm	-0.121	-0.349	0.148	-0.034	-0.247	0.726	Major	VSP
45	I-95 NB Transition	6pm-6am	-0.062	-1.134	0.709	-0.102	0.332	0.075	Major	VSP
46	I-95 SB Urban	5am-1pm	-0.045	-0.117	-0.281	-0.130	-0.040	0.631	Major	VSP
47	I-95 SB Urban	1pm-9pm	0.264	-0.773	0.020	0.698	0.044	0.080	Major	VSP
48	I-95 SB Urban	9pm-5am	-0.070	0.827	-1.419	-0.033	0.212	0.000	Major	VSP
49	I-95 SB Transition	6am-6pm	0.976	0.112	-0.413	-0.303	0.004	0.165	Major	VSP
50	I-95 SB Transition	6pm-6am	-0.148	-0.705	-0.715	-0.767	0.596	0.063	Major	VSP
	Study Corridor		ITSOEM1 Model Analyses Variables							
			Design Variables				Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	HIGH	MINOR	CCTV	VSP				
51	I-95 NB Urban	5am - 1pm	0.667	-0.552	0.559	-0.418	-0.393	0.000	Major	SSP
52	I-95 NB Urban	1pm-9pm	0.731	-1.143	-0.346	-0.381	-0.137	0.557	Major	SSP
53	I-95 NB Urban	9pm-5am	0.407	-0.353	-0.142	-0.263	0.272	0.861	Major	SSP
54	I-95 NB Transition	6am-6pm	-0.121	-0.349	0.034	0.182	-0.281	0.726	Major	SSP
55	I-95 NB Transition	6pm-6am	-0.062	-1.134	0.102	0.811	0.230	0.075	Major	SSP
56	I-95 SB Urban	5am-1pm	-0.045	-0.117	0.130	-0.152	-0.170	0.631	Major	SSP
57	I-95 SB Urban	1pm-9pm	0.264	-0.773	-0.698	-0.678	0.742	0.080	Major	SSP
58	I-95 SB Urban	9pm-5am	-0.070	0.827	0.033	-1.386	0.178	0.000	Major	SSP
59	I-95 SB Transition	6am-6pm	0.976	0.112	0.303	-0.111	-0.298	0.165	Major	SSP
60	I-95 SB Transition	6pm-6am	-0.148	-0.705	0.767	0.052	-0.171	0.063	Major	SSP

APPENDIX B (CONTINUED)

Table B.19 (Continued)

	Study Corridor		ITSOEM1 Model Analyses Variables							
			Design Variables				Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	HIGH	MAJOR	VSP	SSP				
61	I-95 NB Urban	5am - 1pm	1.219	0.552	-0.977	-0.559	-0.387	0.000	Minor	CCTV
62	I-95 NB Urban	1pm-9pm	1.873	1.143	-0.035	0.346	-1.626	0.557	Minor	CCTV
63	I-95 NB Urban	9pm-5am	0.760	0.353	-0.121	0.142	-0.223	0.861	Minor	CCTV
64	I-95 NB Transition	6am-6pm	0.228	0.349	0.148	-0.034	-0.596	0.726	Minor	CCTV
65	I-95 NB Transition	6pm-6am	1.072	1.134	0.709	-0.102	-0.803	0.075	Minor	CCTV
66	I-95 SB Urban	5am-1pm	0.072	0.117	-0.281	-0.130	-0.157	0.631	Minor	CCTV
67	I-95 SB Urban	1pm-9pm	1.037	0.773	0.020	0.698	-0.729	0.080	Minor	CCTV
68	I-95 SB Urban	9pm-5am	-0.897	-0.827	-1.419	-0.033	1.039	0.000	Minor	CCTV
69	I-95 SB Transition	6am-6pm	0.864	-0.112	-0.413	-0.303	0.117	0.165	Minor	CCTV
70	I-95 SB Transition	6pm-6am	0.556	0.705	-0.715	-0.767	-0.109	0.063	Minor	CCTV

	Study Corridor		ITSOEM1 Model Analyses Variables							
			Design Variables				Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	HIGH	MAJOR	CCTV	SSP				
71	I-95 NB Urban	5am - 1pm	1.219	0.552	0.977	0.418	-1.364	0.000	Minor	VSP
72	I-95 NB Urban	1pm-9pm	1.873	1.143	0.035	0.381	-1.661	0.557	Minor	VSP
73	I-95 NB Urban	9pm-5am	0.760	0.353	0.121	0.263	-0.344	0.861	Minor	VSP
74	I-95 NB Transition	6am-6pm	0.228	0.349	-0.148	-0.182	-0.449	0.726	Minor	VSP
75	I-95 NB Transition	6pm-6am	1.072	1.134	-0.709	-0.811	-0.094	0.075	Minor	VSP
76	I-95 SB Urban	5am-1pm	0.072	0.117	0.281	0.152	-0.439	0.631	Minor	VSP
77	I-95 SB Urban	1pm-9pm	1.037	0.773	-0.020	0.678	-0.709	0.080	Minor	VSP
78	I-95 SB Urban	9pm-5am	-0.897	-0.827	1.419	1.386	-0.380	0.000	Minor	VSP
79	I-95 SB Transition	6am-6pm	0.864	-0.112	0.413	0.111	-0.297	0.165	Minor	VSP
80	I-95 SB Transition	6pm-6am	0.556	0.705	0.715	-0.052	-0.824	0.063	Minor	VSP

	Study Corridor		ITSOEM1 Model Analyses Variables							
			Design Variables				Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	HIGH	MAJOR	CCTV	VSP				
81	I-95 NB Urban	5am - 1pm	1.219	0.552	0.559	-0.418	-0.946	0.000	Minor	SSP
82	I-95 NB Urban	1pm-9pm	1.873	1.143	-0.346	-0.381	-1.280	0.557	Minor	SSP
83	I-95 NB Urban	9pm-5am	0.760	0.353	-0.142	-0.263	-0.081	0.861	Minor	SSP
84	I-95 NB Transition	6am-6pm	0.228	0.349	0.034	0.182	-0.630	0.726	Minor	SSP
85	I-95 NB Transition	6pm-6am	1.072	1.134	0.102	0.811	-0.905	0.075	Minor	SSP
86	I-95 SB Urban	5am-1pm	0.072	0.117	0.130	-0.152	-0.287	0.631	Minor	SSP
87	I-95 SB Urban	1pm-9pm	1.037	0.773	-0.698	-0.678	-0.031	0.080	Minor	SSP
88	I-95 SB Urban	9pm-5am	-0.897	-0.827	0.033	-1.386	1.005	0.000	Minor	SSP
89	I-95 SB Transition	6am-6pm	0.864	-0.112	0.303	-0.111	-0.186	0.165	Minor	SSP
90	I-95 SB Transition	6pm-6am	0.556	0.705	0.767	0.052	-0.876	0.063	Minor	SSP

	Study Corridor		ITSOEM1 Model Analyses Variables					
			Design Variables		Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	VSP	SSP				
91	I-95 NB Urban	5am - 1pm	-0.248	-0.210	-0.400	0.342	CCTV	High Profile Incident Only
92	I-95 NB Urban	1pm-9pm	0.416	-1.227	-2.200	0.118	CCTV	
93	I-95 NB Urban	9pm-5am	1.703	1.918	0.636	0.566	CCTV	
94	I-95 NB Transition	6am-6pm	-0.006	-0.292	0.104	0.627	CCTV	
95	I-95 NB Transition	6pm-6am	7.455	-2.537	4.056	0.318	CCTV	
96	I-95 SB Urban	5am-1pm	-0.783	-2.021	0.389	0.947	CCTV	
97	I-95 SB Urban	1pm-9pm	0.460	1.209	1.058	0.274	CCTV	
98	I-95 SB Urban	9pm-5am	-1.115	-0.665	0.552	0.734	CCTV	
99	I-95 SB Transition	6am-6pm	-0.576	-0.608	2.056	0.771	CCTV	
100	I-95 SB Transition	6pm-6am	0.968	-0.866	-1.992	0.641	CCTV	

	Study Corridor		ITSOEM1 Model Analyses Variables					
			Design Variables		Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	CCTV	SSP				
101	I-95 NB Urban	5am - 1pm	0.248	0.038	-0.648	0.342	**VSP**	**High Profile Incidnts Only**
102	I-95 NB Urban	1pm-9pm	-0.416	-1.643	-1.784	0.118	**VSP**	
103	I-95 NB Urban	9pm-5am	-1.703	0.215	2.339	0.566	**VSP**	
104	I-95 NB Transition	6am-6pm	0.006	-0.286	0.098	0.627	**VSP**	
105	I-95 NB Transition	6pm-6am	-7.455	-9.992	11.511	0.318	**VSP**	
106	I-95 SB Urban	5am-1pm	0.783	-1.238	-0.394	0.947	**VSP**	
107	I-95 SB Urban	1pm-9pm	-0.460	0.749	1.519	0.274	**VSP**	
108	I-95 SB Urban	9pm-5am	1.115	0.450	-0.563	0.734	**VSP**	
109	I-95 SB Transition	6am-6pm	0.576	-0.032	1.479	0.771	**VSP**	
110	I-95 SB Transition	6pm-6am	-0.968	-1.833	-1.024	0.641	**VSP**	

	Study Corridor		ITSOEM1 Model Analyses Variables					
			Design Variables		Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	CCTV	VSP				
111	I-95 NB Urban	5am - 1pm	0.210	-0.038	-0.610	0.342	**SSP**	**High Profile Incidnts Only**
112	I-95 NB Urban	1pm-9pm	1.227	1.643	-3.427	0.118	**SSP**	
113	I-95 NB Urban	9pm-5am	-1.918	-0.215	2.554	0.566	**SSP**	
114	I-95 NB Transition	6am-6pm	0.292	0.286	-0.189	0.627	**SSP**	
115	I-95 NB Transition	6pm-6am	2.537	9.992	1.519	0.318	**SSP**	
116	I-95 SB Urban	5am-1pm	2.021	1.238	-1.632	0.947	**SSP**	
117	I-95 SB Urban	1pm-9pm	-1.209	-0.749	2.268	0.274	**SSP**	
118	I-95 SB Urban	9pm-5am	0.665	-0.450	-0.114	0.734	**SSP**	
119	I-95 SB Transition	6am-6pm	0.608	0.032	1.448	0.771	**SSP**	
120	I-95 SB Transition	6pm-6am	0.866	1.833	-2.858	0.641	**SSP**	

APPENDIX B (CONTINUED)

Table B.19 (Continued)

	Study Corridor		ITSOEM1 Model Analyses Variables					
			Design Variables		Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	VSP	SSP				
121	I-95 NB Urban	5am - 1pm	-1.298	-0.862	0.250	0.634	**CCTV**	**Major Profile Incidents Only**
122	I-95 NB Urban	1pm-9pm	-0.265	0.477	-0.028	0.789	**CCTV**	
123	I-95 NB Urban	9pm-5am	-0.845	-0.791	1.420	0.548	**CCTV**	
124	I-95 NB Transition	6am-6pm	0.445	0.184	-2.677	0.014	**CCTV**	
125	I-95 NB Transition	6pm-6am	-0.177	-0.470	1.286	0.573	**CCTV**	
126	I-95 SB Urban	5am-1pm	-0.469	0.147	0.664	0.176	**CCTV**	
127	I-95 SB Urban	1pm-9pm	-0.157	0.712	1.461	0.050	**CCTV**	
128	I-95 SB Urban	9pm-5am	-1.115	-0.665	0.552	0.734	**CCTV**	
129	I-95 SB Transition	6am-6pm	-0.678	-0.830	-1.588	0.143	**CCTV**	
130	I-95 SB Transition	6pm-6am	-1.031	-1.366	-0.264	0.267	**CCTV**	

	Study Corridor		ITSOEM1 Model Analyses Variables					
			Design Variables		Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	CCTV	SSP				
131	I-95 NB Urban	5am - 1pm	1.298	0.436	-1.048	0.634	**VSP**	**Major Profile Incidents Only**
132	I-95 NB Urban	1pm-9pm	0.265	0.742	-0.293	0.789	**VSP**	
133	I-95 NB Urban	9pm-5am	0.845	0.054	0.575	0.548	**VSP**	
134	I-95 NB Transition	6am-6pm	-0.445	-0.261	-2.232	0.014	**VSP**	
135	I-95 NB Transition	6pm-6am	0.177	-0.293	1.109	0.573	**VSP**	
136	I-95 SB Urban	5am-1pm	0.469	0.615	0.195	0.176	**VSP**	
137	I-95 SB Urban	1pm-9pm	0.157	0.869	1.304	0.050	**VSP**	
138	I-95 SB Urban	9pm-5am	1.115	0.450	-0.563	0.734	**VSP**	
139	I-95 SB Transition	6am-6pm	0.678	-0.153	-2.266	0.143	**VSP**	
140	I-95 SB Transition	6pm-6am	1.031	-0.335	-1.295	0.267	**VSP**	

	Study Corridor		ITSOEM1 Model Analyses Variables					
			Design Variables		Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	CCTV	VSP				
141	I-95 NB Urban	5am - 1pm	0.862	-0.436	-0.612	0.634	**SSP**	**Major Profile Incidents Only**
142	I-95 NB Urban	1pm-9pm	-0.477	-0.742	0.449	0.789	**SSP**	
143	I-95 NB Urban	9pm-5am	0.791	-0.054	0.629	0.548	**SSP**	
144	I-95 NB Transition	6am-6pm	-0.184	0.261	-2.493	0.014	**SSP**	
145	I-95 NB Transition	6pm-6am	0.470	0.293	0.816	0.573	**SSP**	
146	I-95 SB Urban	5am-1pm	-0.147	-0.615	0.811	0.176	**SSP**	
147	I-95 SB Urban	1pm-9pm	-0.712	-0.869	2.173	0.050	**SSP**	
148	I-95 SB Urban	9pm-5am	0.665	-0.450	-0.114	0.734	**SSP**	
149	I-95 SB Transition	6am-6pm	-0.089	-0.315	-0.274	0.471	**SSP**	
150	I-95 SB Transition	6pm-6am	1.366	0.335	-1.630	0.267	**SSP**	

	Study Corridor		ITSOEM2 Model Analyses Variables					
			Design Variables		Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	VSP	SSP				
151	I-95 NB Urban	5am - 1pm	-0.964	-0.510	-1.096	0.289	**CCTV**	**Minor Profile Incidents Only**
152	I-95 NB Urban	1pm-9pm	-0.334	0.252	-1.249	0.906	**CCTV**	
153	I-95 NB Urban	9pm-5am	-0.569	-0.405	-0.464	0.245	**CCTV**	
154	I-95 NB Transition	6am-6pm	0.200	0.146	-0.357	0.658	**CCTV**	
155	I-95 NB Transition	6pm-6am	0.984	0.290	-0.766	0.434	**CCTV**	
156	I-95 SB Urban	5am-1pm	-0.040	-0.181	-0.305	0.481	**CCTV**	
157	I-95 SB Urban	1pm-9pm	-0.040	0.466	-0.581	0.792	**CCTV**	
158	I-95 SB Urban	9pm-5am	-1.669	8.067	0.302	0.496	**CCTV**	
159	I-95 SB Transition	6am-6pm	-0.315	-0.089	-0.274	0.471	**CCTV**	
160	I-95 SB Transition	6pm-6am	-0.696	-0.404	0.569	0.193	**CCTV**	

	Study Corridor		ITSOEM1 Model Analyses Variables					
			Design Variables		Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	CCTV	SSP				
161	I-95 NB Urban	5am - 1pm	0.964	0.454	-2.060	0.289	**VSP**	**Minor Profile Incidents Only**
162	I-95 NB Urban	1pm-9pm	-0.334	0.252	-1.249	0.906	**VSP**	
163	I-95 NB Urban	9pm-5am	0.569	0.164	-1.032	0.245	**VSP**	
164	I-95 NB Transition	6am-6pm	-0.200	-0.055	-0.157	0.658	**VSP**	
165	I-95 NB Transition	6pm-6am	-0.984	-0.694	0.218	0.434	**VSP**	
166	I-95 SB Urban	5am-1pm	0.040	-0.141	-0.345	0.481	**VSP**	
167	I-95 SB Urban	1pm-9pm	0.040	0.506	-0.621	0.792	**VSP**	
168	I-95 SB Urban	9pm-5am	1.669	9.737	-1.367	0.496	**VSP**	
169	I-95 SB Transition	6am-6pm	0.315	0.226	-0.589	0.471	**VSP**	
170	I-95 SB Transition	6pm-6am	0.696	0.293	-0.128	0.193	**VSP**	

	Study Corridor		ITSOEM1 Model Analyses Variables					
			Design Variables		Constant	Model χ2	Reference variable	
	AnalysesSegment	Analyses Scenario	CCTV	VSP				
171	I-95 NB Urban	5am - 1pm	0.510	-0.454	-1.606	0.289	**SSP**	**Minor Profile Incidents Only**
172	I-95 NB Urban	1pm-9pm	-0.252	-0.586	-0.997	0.906	**SSP**	
173	I-95 NB Urban	9pm-5am	0.405	-0.164	-0.869	0.245	**SSP**	
174	I-95 NB Transition	6am-6pm	-0.146	0.055	-0.211	0.658	**SSP**	
175	I-95 NB Transition	6pm-6am	-0.290	0.694	-0.476	0.434	**SSP**	
176	I-95 SB Urban	5am-1pm	0.181	0.141	-0.486	0.481	**SSP**	
177	I-95 SB Urban	1pm-9pm	-0.466	-0.506	-0.115	0.792	**SSP**	
178	I-95 SB Urban	9pm-5am	-8.067	-9.737	8.370	0.496	**SSP**	
179	I-95 SB Transition	6am-6pm	0.089	-0.226	-0.363	0.471	**SSP**	
180	I-95 SB Transition	6pm-6am	0.404	-0.293	0.165	0.193	**SSP**	

APPENDIX B (CONTINUED)

Table B.20 ITSOEM2 Model Coefficient Estimates (All Scenarios)

			ITSOEM2 Model Analyses Variables							
Model Run	**Study Corridor**		**Design Variables**		**Other Model Indeprndent Variables**					**Reference variable**
	AnalysesSegment	**Analyses Scenario**	**MAJOR**	**MINOR**	**DMS=1**	**DMS=0**	**IDUR**	**Constant**	**Model χ2**	
1	I-95 NB Urban	5am - 1pm	0.363	0.920	-0.849	0.849	0.009	-2.017	0.000	High Profile
2	I-95 NB Urban	1pm-9pm	0.281	0.603	-0.746	0.746	0.272	-2.035	0.092	High Profile
3	I-95 NB Urban	9pm-5am	-0.420	-0.514	-0.982	0.982	0.047	-0.808	0.290	High Profile
4	I-95 NB Transition	6am-6pm	0.428	1.478	-1.092	1.092	0.012	-2.490	0.000	High Profile
5	I-95 NB Transition	6pm-6am	-0.048	0.493	-0.198	0.198	-0.005	-2.023	0.810	High Profile
6	I-95 SB Urban	5am-1pm	-1.166	-1.225	-0.007	0.007	0.404	-0.986	0.009	High Profile
7	I-95 SB Urban	1pm-9pm	-0.378	-1.462	-0.838	0.838	0.012	-0.754	0.000	High Profile
8	I-95 SB Urban	9pm-5am	0.992	0.881	-0.257	0.257	0.365	-2.654	0.504	High Profile
9	I-95 SB Transition	6am-6pm	-0.177	-0.420	-0.438	0.438	0.007	-1.177	0.0200	High Profile
10	I-95 SB Transition	6pm-6am	1.247	1.761	-0.279	0.279	-0.002	-2.647	0.1760	High Profile
			ITSOEM2 Model Analyses Variables							
Model Run	**Study Corridor**		**Design Variables**		**Other Model Indeprndent Variables**					**Reference variable**
	AnalysesSegment	**Analyses Scenario**	**High**	**MINOR**	**DMS=1**	**DMS=0**	**IDUR**	**Constant**	**Model χ2**	
11	I-95 NB Urban	5am - 1pm	0.363	-0.557	-0.849	0.849	0.009	-1.097	0.000	Major Profile
12	I-95 NB Urban	1pm-9pm	-0.281	0.322	-0.746	0.746	0.272	-1.754	0.092	Major Profile
13	I-95 NB Urban	9pm-5am	0.420	-0.095	-0.982	0.982	0.047	-1.228	0.296	Major Profile
14	I-95 NB Transition	6am-6pm	0.428	-1.050	-1.092	1.092	0.012	-2.103	0.000	Major Profile
15	I-95 NB Transition	6pm-6am	0.048	0.541	-0.198	0.198	-0.005	-2.270	0.810	Major Profile
16	I-95 SB Urban	5am-1pm	1.166	-0.060	0.007	-0.007	0.404	-2.144	0.009	Major Profile
17	I-95 SB Urban	1pm-9pm	0.378	-1.084	-0.838	0.838	0.012	-1.971	0.000	Major Profile
18	I-95 SB Urban	9pm-5am	-0.992	-0.110	-0.257	0.257	0.365	-1.919	0.504	Major Profile
19	I-95 SB Transition	6am-6pm	0.177	-0.243	-0.437	0.437	0.007	-1.791	0.0200	Major Profile
20	I-95 SB Transition	6pm-6am	-1.247	0.513	-0.279	0.279	-0.002	-1.679	0.176	Major Profile
			ITSOEM2 Model Analyses Variables							
Model Run	**Study Corridor**		**Design Variables**		**Other Model Indeprndent Variables**					**Reference variable**
	AnalysesSegment	**Analyses Scenario**	**High**	**Major**	**DMS=1**	**DMS=0**	**IDUR**	**Constant**	**Model χ2**	
21	I-95 NB Urban	5am - 1pm	0.920	0.557	-0.849	0.849	0.009	-2.504	0.000	Minor Profile
22	I-95 NB Urban	1pm-9pm								Minor Profile
23	I-95 NB Urban	9pm-5am	0.514	0.095	-0.982	0.982	0.047	-2.304	0.296	Minor Profile
24	I-95 NB Transition	6am-6pm	1.478	1.050	-1.092	1.092	0.012	-3.153	0.000	Minor Profile
25	I-95 NB Transition	6pm-6am	-0.493	-0.541	-0.198	0.198	-0.005	-1.729	0.810	Minor Profile
26	I-95 SB Urban	5am-1pm	1.225	0.060	0.007	-0.007	0.404	-2.204	0.009	Minor Profile
27	I-95 SB Urban	1pm-9pm	1.462	1.084	-0.838	0.838	0.012	-3.054	0.000	Minor Profile
28	I-95 SB Urban	9pm-5am	-0.881	0.110	-0.257	0.257	0.365	-2.030	0.504	Minor Profile
29	I-95 SB Transition	6am-6pm	0.420	0.243	-0.437	0.437	0.007	-2.034	0.020	Minor Profile
30	I-95 SB Transition	6pm-6am	-1.761	-0.513	-0.279	0.279	-0.002	-1.166	0.176	Minor Profile

APPENDIX B (CONTINUED)

Table B.20 (Continued)

Model Run	Study Corridor		ITSOEM2 Model Analyses Variables For High Profile Incidents Only							
	AnalysesSegment	Analyses Scenario			DMS=1	DMS=0	IDUR	Constant	Model χ2	
31	I-95 NB Urban	5am - 1pm			-1.930	1.930	0.018	-2.639	0.469	
32	I-95 NB Urban	1pm-9pm			-0.830	0.830	0.046	-1.007	0.417	
33	I-95 NB Urban	9pm-5am			-1.790	1.790	-0.938	-0.974	0.077	
34	I-95 NB Transition	6am-6pm			-2.317	2.317	0.012	-2.450	0.000	
35	I-95 NB Transition	6pm-6am			-0.346	0.346	-0.015	-2.279	0.972	
36	I-95 SB Urban	5am-1pm			-0.037	0.037	0.697	-1.318	0.120	
37	I-95 SB Urban	1pm-9pm			-0.926	0.926	0.005	-1.241	0.081	
38	I-95 SB Urban	9pm-5am			-0.388	0.388	-0.373	-2.008	0.820	
39	I-95 SB Transition	6am-6pm			-1.338	1.338	-0.014	-0.422	0.033	
40	I-95 SB Transition	6pm-6am			*Insufficent data*					

Model Run	Study Corridor		ITSOEM2 Model Analyses Variables For Major Profile Incidents Only							
	AnalysesSegment	Analyses Scenario			DMS=1	DMS=0	IDUR	Constant	Model χ2	
41	I-95 NB Urban	5am - 1pm			-0.922	0.922	0.004	-1.688	0.040	
42	I-95 NB Urban	1pm-9pm			-0.812	0.812	0.376	-1.073	0.100	
43	I-95 NB Urban	9pm-5am			-0.492	0.492	0.225	-2.128	0.786	
44	I-95 NB Transition	6am-6pm			-0.829	0.829	0.014	-2.018	0.013	
45	I-95 NB Transition	6pm-6am			*Insufficent data*					
46	I-95 SB Urban	5am-1pm			-0.080	0.080	0.450	-2.252	0.449	
47	I-95 SB Urban	1pm-9pm			-1.094	1.094	0.019	-2.567	0.000	
48	I-95 SB Urban	9pm-5am			*Insufficent data*					
49	I-95 SB Transition	6am-6pm			0.099	-0.099	0.015	-1.918	0.185	
50	I-95 SB Transition	6pm-6am			0.826	-0.826	-0.327	-0.904	0.467	

Model Run	Study Corridor		ITSOEM2 Model Analyses Variables For Minor Profile Incidents Only							
	AnalysesSegment	Analyses Scenario			DMS=1	DMS=0	IDUR	Constant	Model χ2	
51	I-95 NB Urban	5am - 1pm			-0.204	0.204	0.010	-2.066	0.064	
52	I-95 NB Urban	1pm-9pm			0.610	-0.610	0.439	-0.954	0.301	
53	I-95 NB Urban	9pm-5am			-1.314	1.314	1.450	-3.923	0.048	
54	I-95 NB Transition	6am-6pm			-0.725	0.725	0.013	-2.916	0.020	
55	I-95 NB Transition	6pm-6am			-0.370	0.370	-0.047	-1.794	0.826	
56	I-95 SB Urban	5am-1pm			0.038	-0.038	-0.195	-1.552	0.692	
57	I-95 SB Urban	1pm-9pm			-0.352	0.352	0.007	-2.409	0.224	
58	I-95 SB Urban	9pm-5am			-0.661	0.661	0.400	-2.273	0.555	
59	I-95 SB Transition	6am-6pm			-0.264	0.264	0.025	-3.065	0.000	
60	I-95 SB Transition	6pm-6am			-0.866	0.866	-0.014	-1.566	0.001	

ABOUT THE AUTHOR

Mr. Gummada Murthy, Associate Program Director, Operations, AASHTO, since June 2012, is responsible for several operations programs. Prior to joining AASHTO, Mr. Murthy served as Senior Program Officer, TRB, National Academy of Sciences, responsible for implementation of Reliability research focus area outcomes from the Academy's ongoing Strategic Highway Research Program (SHRP2). Mr. Murthy also served as Director of the Operations Division at the Virginia Department of Transportation (VDOT) and was responsible for statewide operations and technology programs that support incident management, roadway weather information system, snow and ice removal programs, High Occupancy Tolling and pricing programs, research and implementation of innovative technology in the VDOT operations programs such as GPS based roadway information mining programs, Active Traffic Management and Commercial Vehicle Operations. Prior to joining VDOT, Mr. Murthy served as Director of Operations for Washington State and as Asst. Turnpike Operations Engineer for Florida Turnpike Enterprise at FDOT, Florida. Mr. Murthy has MS and BS in Civil Engineering from India and holds a second Master's of Science Degree in Civil Engineering from USF. He is a licensed Professional Engineer in Virginia.