RESEARCH & DEVELOPMENT

Incident Management Assistance Patrols – Assessment of Benefits/Costs, Route Selection, and Prioritization

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16. Abstract

The NCDOT's IMAP program provides a critically important service to North Carolina's traveling public. The highly trained and well-equipped IMAP operators protect motorist safety while minimizing congestion and improving system reliability. While the costs of deploying IMAP routes are not trivial, the benefits are tangible and significant for locations where the patrols are truly needed. Therefore, it is essential that the NCDOT have appropriate and effective tools and methodologies for evaluating the costs and benefits of existing and potential IMAP deployments and for prioritizing route expansion alternatives.

The NCDOT has operated a highly successful and expanding IMAP program over the last two decades. Demand for continued system expansion is coming up against trends in budget tightening and workforce downsizing. The trends are nationwide and have fueled a parallel trend toward private operation of freeway service patrols. These trends in service patrol deployment and service delivery have been accompanied by a sustained national and international research thrusts providing important implementable findings in transportation system modeling and experimental knowledge in the safety and efficiency improvements that can be achieved through the provision of freeway service patrols.

Therefore, in pursuing this research project, NCDOT desired a synthesis of lessons learned and best practices as well as development of a methodology to incorporate this knowledge, along with applicable recent research findings, into a process that will enable criteria-based selection and prioritization of future IMAP system expansion. The project outcomes have addressed these needs.

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Executive Summary

The project team met the project research objectives through the development of a statewide IMAP screening framework and through the development of an IMAP benefit-cost analysis tool. The statewide IMAP screening framework classifies traffic message channel (TMC) segments on freeways and US primary routes based on the following criteria –

- Travel demand level
- Congestion frequency
- Secondary crash experience
- Crash severity

In the prototype application of the screening framework, the collision-related criteria were only evaluated on freeway TMC segments because the project team relied on a GIS database created by ITRE's Geovisual Analytics and Decision Management Group (GADA) for geospatial location of reported collisions. The GADA database was created under an ongoing NCDOT project with the primary objective of adding the Traffic Engineering Accident Analysis System (TEAAS) collision data to North Carolina's interstate routes for truck crash analysis. Therefore, the statewide TMC segment database used for the prototype application of the screening framework only included collisions for freeway TMC segments. The framework provides visual categorical highlighting of TMC segments in terms of the screening criteria. The locations of current IMAP patrol routes were also added to the GIS database, thereby allowing for overlay of current IMAP coverage.

In the urban areas, the prototype IMAP screening results largely affirmed that the current IMAP patrol routes are in the most appropriate locations. In the case of the recent removal of IMAP coverage from I-485 in Charlotte, the screening results indicate the negative impact of this loss of service. The screening results also affirmed the project team's hypothesis that the travel demand and congestion frequency criteria would be more important in urban areas, that the crash severity criterion would be more important in rural areas, and that the secondary crash criteria (secondary crashes were evaluated in two ways and therefore yielded two criteria) would apply with essentially equal importance across all areas. An example method for combining the criteria into a single comprehensive score was also developed and demonstrated. This method uses different

weighting schemes for urban and rural interstate segments consistent with the previous discussion. The results from the prototype statewide screening and the example composite weighted scoring are presented in Appendix D. These results are provided to demonstrate the effectiveness of the method only and should not be taken as actionable or definitive. However, it is noteworthy that the prototype statewide screening confirmed the notion held by members of the project steering and implementation committee that I-95 is a serious candidate for rural IMAP service.

The IMAP benefit-cost analysis tool is an easy to use JAVA program that generates costs based on default costing information provided by NCDOT but with the flexibility of user-adjusted cost information. The default or user-supplied cost rates are applied to user-supplied information on the patrol schedule (days and hours of operation), the patrol route length, and the number of IMAP vehicles that will be on simultaneous patrol. Benefits are derived by comparing the results from two FREEVAL runs, one with and one without IMAP service. Monetary benefits are calculated based on model-estimated delay and fuel savings, and a benefit-cost ratio is derived. Application of the IMAP benefit-cost analysis tool requires a previously developed FREEVAL input file. The FREEVAL input file includes the freeway route segmentation information and the 15-minute interval demands for the freeway entry and all intervening on and off ramps. Creation of a fully-specified FREEVAL input files with the current version of FREEVAL involves several hours of analysis effort. This represents a significant impediment to the in-house usability of the IMAP benefit-cost analysis tool for NCDOT.

However, the usability of the IMAP benefit-cost analysis tool will be greatly enhanced with the completion of a new version of FREEVAL that is currently in the final stages of development by ITRE researchers. The new version of FREEVAL provides for rapid creation of input files through point and click specification of freeway segmentation enabled by Google Maps integration and through use of user-selectable demand profiles applied to user-supplied AADT values. The new version of FREEVAL promises to reduce the time for creation of input files from hours to minutes.

Case study application of the IMAP benefit-cost analysis tool gives confidence that benefit-cost ratios will be very strong. The project team recommends that after the new FREEVAL version is available, NCDOT conduct a benefit-cost analysis for all existing IMAP patrol routes, a benefit-cost analysis for the former IMAP patrol routes on I-485, and a benefit-cost analysis on a candidate first patrol route on I-95. The project team plans to demonstrate the new FREEVAL (using a development version) in conjunction with the IMAP benefit-cost analysis tool at the project closeout meeting and will stand ready to provide a brief, informal training workshop when the new FREEVAL version is ready for general distribution. If more extensive training is needed at a later date, a technical assistance agreement or follow on research project could be used to enable the desired training.

As the project final report documents, the project team conducted extensive analysis of the available collision and operational data for freeway routes with and without IMAP service. Some before and after data was available for a few IMAP coverage areas, but such data was very limited. The project team was able to confidently establish a positive IMAP service impact on incident duration. The analyzed data also supported the project team's development of detailed incident duration distributions for the with and without IMAP cases. The monetary benefits reported by the benefit-cost analysis tool derive from this observed tendency of IMAP service to reduce incident duration.

The project team also hoped to establish a positive IMAP service impact on secondary crash frequencies and rates. However, the data available were not sufficient to establish this connection. Nonetheless, intuition strongly suggests (and the established impact of shortening incident duration further supports) the notion that, over the long term, IMAP operations will result in fewer secondary crashes. Therefore, the project team kept the secondary crash-based criteria in the IMAP screening framework. Furthermore, the project team recommends that the NCDOT Traffic Safety Unit conduct ongoing analyses with the goal of eventually providing sound statistical support for an IMAP secondary crash reduction factor. If such a factor is established, the IMAP benefit estimation should be revised to include an estimate of the monetary value of this crash reduction effect.

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1. Introduction

1.1. Project Motivation

The NCDOT's IMAP program provides a critically important service to North Carolina's traveling public. The highly trained and well-equipped IMAP operators protect motorist safety while minimizing congestion and improving system reliability. While the costs of deploying IMAP routes are not trivial, the benefits are tangible and significant for locations where the patrols are truly needed. Therefore, it is essential that the NCDOT have appropriate and effective tools and methodologies for evaluating the costs and benefits of existing and potential IMAP deployments and for prioritizing route expansion alternatives.

The NCDOT has operated a highly successful and expanding IMAP program over the last two decades. Demand for continued system expansion is coming up against trends in budget tightening and workforce downsizing. The trends are nationwide and have fueled a parallel trend toward private operation of freeway service patrols. These trends in service patrol deployment and service delivery have been accompanied by a sustained national and international research thrusts providing important implementable findings in transportation system modeling and experimental knowledge in the safety and efficiency improvements that can be achieved through the provision of freeway service patrols.

Therefore, in pursuing this research project, NCDOT desired a synthesis of lessons learned and best practices as well as development of a methodology to incorporate this knowledge, along with applicable recent research findings, into a process that will enable criteria-based selection and prioritization of future IMAP system expansion. The project outcomes have addressed these needs.

1.2. Project Objective

The primary objective of this research project was to provide NCDOT with a methodology for ongoing benefits and costs evaluation and prioritization of IMAP deployments. This primary objective enables NCDOT to effectively seek a balance between fiscal constraints and the mobility enhancements and increased traveler safety and satisfaction provided by IMAP service along North Carolina's interstate and primary highway network. Additionally, the project included an objective of providing an implementation and operations plan for the IMAP program that incorporates information learned through this research.

The project was organized into the following research tasks:

- Task 1 – Project Kickoff Meeting
- Task 2 – Literature and State of the Practice Review
- Task 3- Identify, Characterize, and Assess the Quality of Relevant Data Sources
- Task 4- Develop Criteria for IMAP Deployment Prioritization
- Task 5- Interim Report
- Task 6- Develop IMAP Cost Estimation Methods
- Task 7- Develop IMAP Benefit Estimation Methods
- Task 8- Develop Integrated Benefit/Cost Estimation Methodology and Associated Computational Engine
- Task 9 – Project Final Report and Deliverables

1.3. Report Organization

The project results and findings are documented in the following chapters. Chapter 2 presents literature and state of practice reviews of current IMAP trends and research. Chapter 3 describes available incident and contextual data sources and provides an assessment of their characteristics and quality. Chapter 4 discusses a GIS-based link framework that uses mobility, reliability, and safety characteristics to classify links in terms of IMAP potential. Chapter 5 presents the approaches developed for estimating benefits and costs. Chapter 6 presents the integrated IMAP estimation tool that compares estimated costs to benefits estimated by the *Highway Capacity Manual* FREEVAL route analysis tool. Chapter 7 describes a case study application of the proposed integrated IMAP estimation tool. Chapter 8 provides the overall project conclusions and recommendations.

2. Literature and State of Practice Review

Freeway Service Patrols (FSPs), referred to as IMAPs (Incident Management Assistance Patrols) in North Carolina, provide the critically important service of reducing the congestion impact of incidents, while simultaneously protecting the safety of the motorists and emergency responders involved. The mission of FSPs requires that operators, dispatchers, and system managers continuously cope with dynamic situations on the highway system within the fiscal and personnel constraints of the operating agencies. Working within these constraints, agencies can maximize overall FSP effectiveness through the development of deployment methods that take into account both the cost and benefits of FSP implementation at each location.

This chapter presents a detailed literature review of FSP systems. First, the state of practice with respect to roles and responsibilities and with respect to operational frameworks for FSP programs are addressed in Sections 2.1 and 2.2, respectively. Section 2.3 presents a review of methods for the selection and prioritization of routes for FSP system expansion, as well as for effective deployments under fiscal and personnel constraints. In support of the development of an analysis tool designed to enable NCDOT to carry out accurate assessments of IMAP program costs and benefits, Section 2.4 reviews benefit-cost analyses conducted for similar state-run FSP programs. Reported best practices for FSP systems are offered in Section 2.5. Finally, key findings for conducted the remaining tasks are presented in Section 2.6.

2.1. State of Practice of Roles and Responsibilities for FSP Programs

FSP service programs have been operating for many years in more than 130 U.S. metropolitan areas. Each FSP program provides services that are to one degree or another tailored to the local or regional traffic characteristics. Some DOTs operating FSP programs publish Standard Operating Procedures (SOP) defining the roles and responsibilities of personnel in order to effectively provide their services [1-6]. Additionally, Tennessee DOT (TDOT) publishes an annual report about benefits and successes from the HELP FSP service [7]. Although each state operates an FSP program with unique roles and responsibilities as defined in their respective SOPs, primary roles and responsibilities are very similar across the states. The primary FSP function is to quickly detect and respond to incidents and to clear incident or crash scenes as soon as possible. A handbook and field operation guidebook for FSPs published by the Federal Highway

Administration (FHWA) documents the priority roles for FSPs, categorized into 3 service levels, namely: baseline, mid-level, and full-function. [8, 9].

2.1.1. Roles and Responsibilities for FSP Systems

The priority FSP roles defined by the FHWA handbook are listed in the national incident management timeline [10] as shown in Appendix A. The specific roles are:

- Incident detection and verification
- Communication about incident details and traffic conditions to the TMC, or the TOC
- Traffic incident clearance (including response)
- Traffic control and scene management (including Temporary Traffic Control: TTC)
- Motorist assistance and debris removal
- Traveler information

It is essential to quickly detect and verify incidents as a first step toward enabling a prompt response, and therefore it is natural that incident detection and verification is one of the primary roles. Operating FSPs play a significant role in detecting and verifying incidents. Although cellular phone call-in incident detection from individuals on the scene has become the dominant method of first notification, incidents detection by the direct observation of FSP operators is the method of first notification in a higher proportion of cases than other alternative methods [11], and verification by FSP operators is a key element as well. For example, in Orange County, CA, 23% of the incidents were first detected by FSP service patrols, and in Chicago 28% of the incidents were verified by FSP operators.

In the Bay Area, FSP operators are tasked with continuously monitoring their coverage area for incidents during their shift, although the procedures allow for them to stop at designated drop locations if they have any other work or tasks that cannot be accomplished while actively patrolling. In an attempt to increase the effectiveness of incident detection and verification, TMC (Traffic Management Center) supervisors for the TDOT HELP program are given the responsibility to dynamically adjust patrol routes based on current and evolving traffic conditions [7]. The incidents detected by FSP operators include disabled vehicles, stranded motorists, debris in the roadway, spilled loads, vehicle crashes, obstruction to traffic, dead animals, and other potential hazards [3, 5, 6].

FSP operators, when serving as the primary verification function, must quickly and accurately relay the incident type to TMC supervisors or dispatchers as soon as practicable following incident verification. The FHWA handbook recommends that an integrated system is needed to efficiently communicate the type and extent of incidents to other responsible departments and agencies, for the full-function service patrol level to be achieved [9].

Incident clearance is the primary role and responsibility that comes into play after detection and verification has taken place. Rapid incident clearance reduces the likelihood of secondary incidents and minimizes potential disruption and delay to other motorists. The literature documents successful efforts by FSP operating agencies to reduce incident clearance through the applicaiotn of best practices. For example:

- San Francisco's I-880 corridor FSP reduced average response time from 28.9 to 18.4 (36%) minutes [12]
- The Puget Sound region in Washington estimated reduction in response time between 2.4 to 5.8 minutes for incidents serviced by patrols [13]
- Average clearance time decreased from 28.1 to 21.7 minutes in incidents monitored by SHA patrol of the Coordinated Highway Action Response Team (CHART) in Maryland [14]

It should be noted that FSP operators have no standing authority to tow abandoned or disabled vehicles [1, 3, 5, 6], they must contact their supervisors and the state police, and wait until authorized they receive the appropriate authorization. With respect to injury crash response, FSP patrol or TMC operators must also contact state police, medical services, and law enforcement in the appropriate cases and can assist motorists until authorized personnel arrive at a scene with first aid and CPR if needed [1-3, 6, 7, 9, 10].

Furthermore, FSP operators alert motorists regarding crash/incident scenes and provide for safe movement through the scene by setting highway flares, cones, flagging, flash amber/white lights, arrow boards, etc. They control traffic at the scene, assist the public safety and medical responders, and advise motorists of blocked lanes or other hazards ahead.

Motorist assistance services typically provided by FSP operator include: providing vehicle jump-starting, replacing flat tires, replenishing fuel and water, free push bumper use, and minor repair (in the case of Georgia, minor implies less than 15 minutes [10]). In addition, FSP operators remove debris from the roadway.

In terms of traveler information, FSP operators provide updates on traffic conditions to TMC operators using dedicated two-way communications. These updates play an important role in enhancing the timeliness and accuracy of information provided through 511 and/or Dynamic Message Signs (DMS).

In addition to their primary roles, FSP programs generally have additional supplementary roles and responsibilities such as:

- Onsite support public safety, law enforcement, emergency response, and medical responders
- Lost and found service for items recovered from the roadway
- Administer DOT questionnaire/response forms
- Special event assistance

FSP in California are tasked to retrieve lost valuables while on beat [3, 5, 6]. FSP operators must be also complete an incident report upon incident clear. This process do current the process followed in each task (direction, clearance, etc.). Often, FSP operators assist in special events such as sports events, fairs, civil unrest, etc. [5-7]. For example, the HELP operators provide assistance to traffic control and motorists during the University of Tennessee football season [7].

2.1.2. Summary

This chapter summarized the state of practice on the primary roles and responsibilities of FSP patrols around the US. A state by state summary of those roles is given in Table 2-1.

Table 2-1 Summary of Roles and Responsibilities for FSP Systems by State

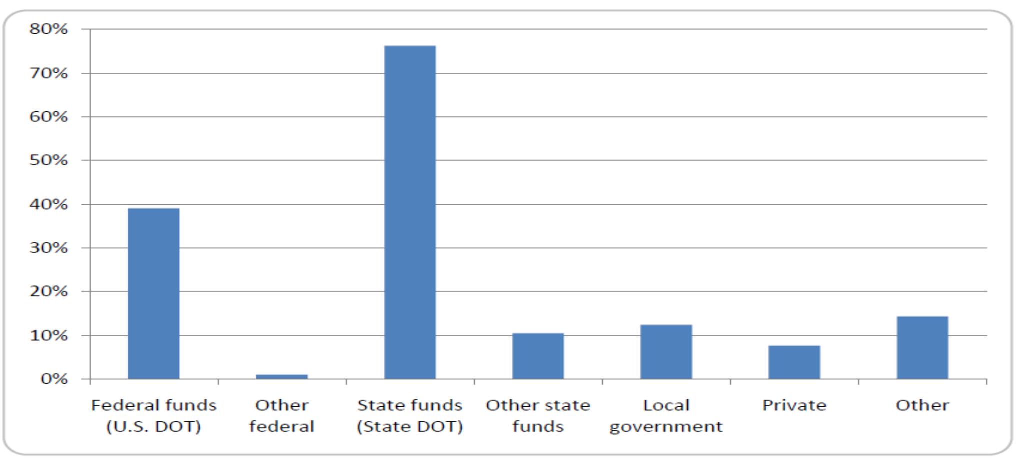
Roles and responsibilities for FSP systems		North Carolina-IMAP	Florida		Georgia-HERO	Tennessee-HELP	Indiana-Hoosier Helper	California		
			Road Rangers	State Farm Safety Service Patrol				Bay Area-FSP	Santa Barbara-FSP	Monterey-FSP
Primary roles and responsibilities	Incident detection and verification	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Communicating incident details and traffic conditions to the TMC, or the TOC	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Traffic incident clearance	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Traffic control and scene management	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Motorist assistance and debris removal	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Traveler information	✓	✓	✓	✓	✓	✓	✓	✓	✓
Additional roles and	Support State police, fire and rescue personnel, other law enforcement	✓	✓		✓	✓	✓	✓	✓	✓
	Lost and found service							✓	✓	✓
	Incident report		✓	✓	✓		✓	✓	✓	✓
	Assist with special events across the State	✓		✓		✓	✓	✓	✓	✓

2.2. Operational Frameworks

Building on the outline of the roles and responsibilities FSP programs, this section presents a review of FSP operational frameworks. In light of tight budgets, some states have implemented and others are considering alternative operational modes and funding sources including entering into Public Private Partnerships (PPPs) to supplement government FSP funding. The discussion in this section focuses on how PPP and/or co-operative sponsorships have worked in the states where they have been implemented. Additionally, operational framework information related to operating vehicles and personnel is also covered.

2.2.1. Fully State Funded, Partial Sponsorship or Public Private Partnership (PPP)

In a study by Baird et al. [15], a survey was conducted to investigate FSP funding sources. The survey was sent to system managers and responsible officials in each state. Respondents could choose from among multiple funding source categories. As shown in Figure 2-1, state DOT resources account for approximately 80% of FSP capital and operational funding. For example, at the time of the report, the SAFE Patrol program in Kentucky and the IMAP program in North Carolina were completely funded by the respective states [16].



* SOURCE: MALCOLM E. BAIRD [15], OVERVIEW OF FREEWAY SERVICE PATROLS IN THE UNITED STATES

Figure 2-1 FSP Funding Allocation by Source

Federal funds accounted for the second highest funding source according to the Baird study, accounting for nearly 40% of FSP Funding. As one example, Federal funds, principally under the Congestion Mitigation and Air Quality (CMAQ) program, paid the majority of the startup costs, including initial purchase of trucks and equipment, for the HELP system in Tennessee [7]. In addition to other federal, state, and local government funding sources, some states have engaged a private sponsor such as State Farm Insurance and Commerce Insurance. Table 2-2 lists the Public Private Partnership (PPP) sponsored FSP programs. Subsequent to the Baird study and the sponsorship summary detailed in Table 2-2, NCDOT entered into a sponsorship agreement with State Farm Insurance, which became effective in May 2015.

Table 2-2 Sponsorship and Partnership for FSP Systems

Patrol (State)	Partnership or sponsorship	Level of sponsorship	Service allowed
SHA patrol (Maryland) [17]	State Farm Insurance	More than $ 3 million (over the next seven years from 2011)	Expansion to overnight coverage
Hoosier Helper patrol (Indiana) [18]	State Farm Insurance	$1.13 million (over the next seven years from 2011)	Support and replenish the operation of the Hoosier Helper
SSP patrol (New Jersey) [19]	State Farm Insurance	$5.4 million (over the three years from 2012)	Develop the newly designed SSP vehicles and reassign resources to other high-priority safety needs to benefit
HERO (Georgia) [20]	Private (20%) – State Farm Insurance Federal (80%)	$5.1 million (over the three years from 2009)	Sponsorship to support 11 supervisors, 87 operators, coverage 286 center line miles, 30 routes, 24/7 in weekday, Friday and Monday 5 a.m. to 9:30 p.m., Saturday and Sunday 7 a.m. to 10 p.m.
HAP (Massachusetts) [21]	MAPFRE | Commerce Insurance	$7.9 million (from 2003 to 2013)	35 vehicles, 25 patrol routes, 30 HAP operators, 982,000 miles annually
MAP (Houston in Texas) [22]	A PPP among TxDOT, Harris County Sheriff's office, the Metropolitan Transit Authority (Metro) of Harris County, Houston Automobile Dealers Association, and Verizon Wireless		

2.2.2. FSP Services Contracted by the Private Sector

Using contract services is another alternative to state run or PPP-sponsored FSPs. About 39% of safety service patrols nationwide are now run by private contractors according to Baird [15]. Road Rangers in Florida is a representative example of contracted services. The Florida DOT operates

Road Ranger by contracting in each service area [23]. Following this trend, the Ohio DOT recently requested a public-private partnership between the state of Ohio and a private proposer to provide FSP services on patrol beats at specified times and areas including Akron/Canton, Cincinnati/Northern Kentucky, Cleveland, Columbus, Dayton and Toledo [24]. Other examples of delivery of service options in terms of state versus contract employment are provided in Table 2-3.

Table 2-3 Delivery of Service Options for FSP Systems by State

State	State employees	Contract employees	FSP personnel	State	State employees	Contract employees	FSP personnel
NC	✓		66	MN	✓		24
CA		✓	Unknown	MO	✓		17
GA	✓		68	NV		✓	17
IA	✓		6	OH	✓	✓	Unknown
ID	✓		6	SC	✓		63
IL	✓		139	TN	✓		85
IN	✓		23	TX	✓		Unknown
KY	✓		14	UT	✓		12
LA		✓	30	VA	✓		34
MD	✓		Unknown	WA	✓		55
MI		✓	Unknown	WV		✓	Approx. 80

* SOURCE: FDOT[25], SURVEY OF OUT-OF-STATE FREEWAY SERVICE PATROL TRAINING PROGRAMS, 2006.

2.3. Approaches for Planning FSP Deployment Location and Prioritization

Identifying high-impact candidate locations and fleet allocation are two important components in FSP program planning. Properly located and staffed routes can play a vital role in reducing the likelihood of secondary incidents, fuel consumption, and delays caused by non-recurrent congestion. Decisions on route location and staffing in turn must be made within the constraints of available FSP program funding. Therefore, effective methods and tools to support fiscally-constrained FSP program planning are an increasingly important unmet need. Furthermore, only a few studies were found that address how FSP deployment locations are identified and prioritized. In this chapter, the available studies are described in terms of both selection of potential routes and allocation of FSP resources to selected routes.

2.3.1. Identifying High-Impact Candidate Patrol Routes

The literature does include a few studies of FSP route identification. These studies used differing methodologies and were driven by unique purposes. Khattak and Rouphail [26], in a prior NCDOT-sponsored research effort, developed a planning level method to identify beneficial IMAP route locations based on historical statistics of crashes per 100 million vehicle miles, crashes per mile per year, and average annual daily traffic (AADT) per lane.

Edara [27] developed a tool that used a segment-based ranking scheme for evaluating potential FSP deployment. In the study, the author developed the FSP-Assist Prediction Model (APM) to predict number of incidents per year statistically using freeway segment AADT, length, average daily percent of ADT served, and truck percentage. The APM then assigns each segment a score using the predicted parameters and ranks the potential routes using a computed segment average score.

Ma et al. [28] implemented a quantitative assessment of the impacts on incident duration of different FSP service strategies in the Paramics microsimulation software tool with the goal of providing guidance for FSP dispatching policy. Two dispatch policies were considered: 1) FSP vehicles follow predetermined routes responding to incidents as they are encountered in current direction of travel and 2) FSP will use the next available interchange to turn around and serve incidents that are identified in the opposite direction of travel. These two policies were compared under varying patrol headways (assigning more FSP patrol vehicles to a route will result in shorter headways between patrolling vehicles). The simulation study, as would be expected, found that the benefit of allowing FSP vehicles to turn around at the next opportunity and provide assistance in the opposite direction become greater as patrol headways become longer (fewer patrol vehicles) and lessen as the patrol headways become shorter (greater number of patrol vehicles). Given the intuitive nature of the study findings, this study was most valuable as a simple example of how microsimulation-based modeling can be used to evaluate FSP patrol strategies and vehicle allocation options.

2.3.2. Deciding Fleet Allocation

A predictor model (called Freeway Service Patrol Predict: FSPP) by Skabardonis and Mauch [29] was also developed to predict the number of FSP-assists and the impacts of operational changes on existing patrol beats based on the prospective beat's design and traffic characteristics. In the study, the final prediction model is a function of vehicle miles of travel served by FSPs divided by total vehicle miles of travels, one-way beat length (miles), the beat’s average hourly capacity, the beat’s average daily volumes divided by 10 times the beat’s hourly capacity. The model was also incorporated into the FSPE (FSP Beat Evaluation) model that predicts the benefit-cost ratio of new FSP beats using Excel workbook developed by using VBA module.

Shen and Ji [30] developed a patrol design process that included districting and response vehicle dispatching and routing. The design process minimizes both the workload balance for each FSP beat and the incident response time under budget constraints using a discrete simulation model within the Arena software tool. In particular, this study compared roving logic and pre-positioning logic. Roving logic was defined as the FSP operator continuously patrolling. Conversely, pre-positioning logic is defined as the FSP patrol vehicle returning to a set location after completing a motorist assist or incident clearance assignment and waiting there for a new assignment. As a result of the study, operating FSP systems using the pre-positioning logic did not provide an improvement in response time over roving logic. A similar study by Hadi et al. [31] proposed a tool-based on Arena to assess the impacts on FSP effectiveness under different operational strategies to support the selection of the most appropriate strategies given the system’s budget constraints. The authors were able use the tool to fine-tune beat boundaries based on equalizing the workload.

Yin [32] described a min-max bi-level programming model to determine optimal FSP fleet allocation and demonstrated how to allocate vehicles among patrol beats to maximize the effectiveness of the FSP services. Yin [33] also proposed a mixed-integer nonlinear programming model to strategically allocate FSP vehicles by minimizing the expected loss with regard to incident occurrence. Lou et al. [34] developed a non-linear mixed-integer models integrated beat design and fleet allocation of FSP program, considering FSP trucks roaming. The researchers used three heuristic algorithms to reduce the model's computing time.

2.3.3. Summary

Based on these reviews, Table 2-4 shows a summary of methods for selecting and prioritizing FSP deployment locations.

Table 2-4 The Summary of Methods Selecting FSP Deployment Locations and Allocating Trucks

Components	**Method**	**Measure of Effectiveness**	**Network applied**
Designing beat	Rank-based method	crashes per 100 M VMT crashers per mile per year AADT per lane	North Carolina
	SSP-assist prediction model (APM)	Number of incidents	Northern Virginia
	Microscopic simulation	Impacts on incident duration	South Carolina
Deciding fleet allocation	FSPE model – prediction model for FSP-assists	VMT served/Total VMT One-way beat length The beat's average hourly capacity The beat's average daily volumes divided by 10 times the beat's hourly capacity	California
	Discrete event based simulation	Minimizing balance of workload and response time	Florida
	Operation research model	Minimizing the expected loss with regard to incident occurrence	Sioux Fall network

2.4. Review of FSP Benefit-Cost Assessment Methods

Various methods for FSP benefit-cost analyses have been identified in the literature. Factors have included safety, reliability, public relations, and environmental effects in addition to reduction in incident duration and delay as the primary benefit of FSP systems. This section provides a review of candidate parameters for both benefits and costs along with methodologies to calculate the resulting benefit-cost ratios and a synthesis of developed benefit-cost evaluation tools. Table 2-5 introduces the discussion by presenting a summary of methods used by various states for assessing FSP programs in terms of benefits and costs.

Table 2-5 A Summary by State of Methods for Assessing FSP Benefits and Costs

State	Service Provider	Study Year	Selected Performance Measures	Evaluation Tool	Reported BCR ratio
North Carolina	State employees	2004	➢ Delay savings	FREEVAL	5.6:1
Alabama (ASAP) [35]	N/A	2009	➢ Delay savings ➢ Reduction in secondary or follow-on crashes ➢ Fuel consumption and emissions	CORSIM	15:1
California (FSP) [29]	Partially contracted employees	2005	➢ Delay savings	FSPE	8.3:1
Florida (Road Rangers) [31, 36]	Fully contracted employees	2013	➢ Delay savings ➢ Fuel consumption and emissions	FSPE	6.78:1
		2010	➢ Delay savings ➢ Fuel consumption and emissions ➢ Secondary incidents	ARENA	13:1 and 16.2:1
Georgia (HERO) [37]	State employees	2007	➢ Delay savings ➢ Fuel consumption and emissions ➢ Secondary incidents	Simple mathematical methods	4.4:1
Kentucky (SAFE patrol) [16]	State employees	2011	➢ The ratio of the number of rejections to the total number of assistance incident requests ➢ FSP fleet mileage ➢ Fuel consumption	ARENA	0.8:1~2:1 (50%~100% of fleet size, 100%~150% coverage)
Maryland (CHART) [38]	State employees	2012	➢ Delay savings ➢ Fuel consumption and emissions	CORSIM	3.08:1
Missouri (MA) [39]	State employees	2010	➢ Delay savings ➢ Secondary incidents	Calculate directly using actual data	38.25:1
New York (H.E.L.P) [40]	Partially contracted employees	2009	➢ Delay savings ➢ Fuel consumption and emissions ➢ Secondary incidents	CORSIM	2.68:1~16.5:1
Virginia (SSP) [41]	N/A	2006	➢ Delay savings ➢ Fuel consumption and emissions	FSPE	NOVA-5.4:1 Hampton Roads-4.7:1

2.4.1. Assessment of FSP Benefits

2.4.1.1. Mobility Attributes

Several studies have investigated factors that impact the benefits of FSP operations. The reduction of incident duration and delay for motorists plays a major role in benefit estimation, as is demonstrated by the fact that nearly all of the benefit-cost analyses reviewed included delay reduction as a mobility-related benefit [16, 26, 36, 37, 39-44]. In general, the methodologies for estimating delay aim to calculate the effects of incidents that are managed through an FSP program versus the impact of the same incidents in the absence of an FSP program [40, 42]. A variety of methods have been used to estimate non-recurrent congestion delay: analytical methods using deterministic queuing diagram [45, 46], shock wave theory [47, 48], heuristic methods [49, 50], and simulation methods [28, 51]. However, deterministic queuing methods [29, 36, 37, 41] and simulation methods [16, 40, 44] have been the most widely adopted analysis methods.

2.4.1.2. Safety Attributes

A reduction in the number of secondary incidents associated with a reduction in the average duration of primary incident impact is a potential FSP safety benefit. Methodologies to identify secondary incidents mainly use static or dynamic thresholds in terms of distance from primary incidents in space and time. Static thresholds employ a fixed spatial-temporal boundary for classifying secondary incidents. For example, in Raub [52], if an incident occurred within 15 minutes and within 1 mile upstream of a primary incident, it was classified as a secondary incident. Moore et al. [53] identified secondary incidents to occur within 2 hours and 2 miles of a primary incident using CA Highway Patrol data sources. This study found the frequency of secondary crashes to be about 1.5 ~ 3% of the frequency of primary crashes. Intuitively, static thresholds suffer from the weakness of the assumption that the congestion impact effect from primary incidents is the same for all incidents. Furthermore, static boundaries in time and space ignore the fact that the congestion queue from a primary incident grows and then dissipates upstream during the impact time period.

Therefore, methodologies using dynamic thresholds have been investigated in an effort to overcome the limitations of static thresholds. In 2007, Sun and Chilukuri [54] developed a dynamic threshold method by varying the back of queue location throughout the entire duration of incident. This study indicated that by using a dynamic approach up to a 30% difference in the number of incidents classified as secondary can arise. Chou and Miller-Hooks [55] proposed a simulation-based secondary incident filtering method (SBSIF) using the CORSIM microscopic simulation model. A regression model was also implemented for corner point identification along with the SBSIF method. In another research study performed in Virginia, Zhang and Khattak [56] analyzed the cascading incident event duration. They identified and analyzed not only single-pair events (one primary and one secondary incident) but also large-scale events (one primary and multiple secondary incidents) by categorizing them as either contained or extended, using a deterministic queuing method. In other words, if a secondary incident is the last one being cleared during such an event, it is considered an extended event; otherwise, it is classified as a contained event. Later, Zhang and Khattak [57] developed an incident management integration tool to calculate dynamic incident durations prediction, secondary incident occurrence and incident delays. Recently, Chung [58] introduced a procedure to identify secondary crashes caused by different types of primary crashes in the impact area and developed a method to separate the non-recurring congestion from recurring congestion. Yang et al. (71) proposed constructing a line in time and space between each pair of potential primary-secondary crashes. Crashes were defined as primary or secondary based on the line which is enclosed by the impact area. In addition, this study proposed the use of historical virtual sensor measurements to identify secondary crashes using a representative speed contour map (RSCM) with percentile speed of historical incident-free virtual sensor speed measurement of each spatiotemporal cell. Using the measurements, the study tried to show recurring congestion areas and non-recurring congestion areas in a speed contour map based solely on the RSCM. However, to find the precise recurring congestion area, the bottleneck point needs to be identified first. In addition, the distribution of speed collected from detectors does not follow a normal distribution. Therefore, it is difficult to determine a rigorous and representative historical speed.

2.4.1.3. Environmental Attributes

Environmental attributes considered in FSP benefit-cost analysis are fuel consumption and vehicle emissions [16, 36-38, 43, 44, 59]. Benefit values are calculated by multiplying a unit monetary equivalent by reduction in delay. Chang and Point-Du-Jour [60] used a statistical model of incident duration as impacted by traffic volume, and the number of lanes blocked to calculate savings in fuel consumption. On the other hand, the FSPE program developed by Sakabardonis [29] was used to estimate fuel consumption and emission (carbon monoxide-CO, hydrocarbons-HC, and oxides of nitrogen-NOx) and to calculate the environmental impacts on California's FSP and Florida's RR (Road Ranger) program. To calculate fuel and emission savings, the FSPE program utilized the EMissions FACtor (EMFAC) model with the latest emission rates. The EMFAC model was implemented based on average facility speed factors provided by the California Air Resource Board (CARB) [29].

2.4.1.4. Public Relations Attributes

Public relations impacts were defined as the value of services provided to motorists. This attribute has been added to benefit-cost analysis of FSPs in some cases. For example, a survey was conducted to ascertain the customer service value of the HERO system in Georgia [37]. The authors noted cost savings due to motorist assistance was estimated to be in line with the average value of an individual motorist assistance, i.e. about $60 per motorist assist.

2.4.1.5. Reliability Attributes

A simple study by Li et al. [61] considered reliability in the analysis of benefit-cost for the SAFE program in Kentucky. High FSP operator response rates were correlated with high reliability, and vice versa. The FSP operator non-response rate obviously changes with patrol-coverage size and fleet size. Using the non-response rate, this study estimated the benefit-cost ratios for major and minor incidents (direct savings to stranded drivers) using the following relationship:

$$Benefit: \$X \times N_{incident} \times (1-\delta) \times \varepsilon + C_{FSP} \times (1-\varepsilon) \times r \qquad \textbf{Equation 2-1}$$

Where $\$X$ = average cost of roadside assistance; $N_{incident}$ = number of assisted incidents; δ = help non-response rate; ε = ratio of minor to all incidents; C_{FSP} = total operational cost of FSP service; and r = benefit-cost ratio for major incidents (10:1 was used).

2.4.2. Assessment of FSP Costs

When it comes to the estimation of the cost of offering FSP service, each operating agency calculates the costs differently. Various parameters associated with operating an FSP program are considered: hourly rate of personnel, number of trucks operated, operating hours/day, cost of gas, cost for maintenance, secondary incident costs, the number of incidents serviced by FSP, reduction delay rate, and value of time.

In the case of H.E.L.P in New York, the total cost of operating the FSP program is calculated by multiplying the cost per truck-hour, number of roving trucks, number of working hours in each day, and day number of workdays in the study period [40]. Total cost of ASAP (Alabama Service and Assistance Patrol) was estimated one year using amortized capital costs, in addition to annual operations and maintenance cost [35]. The benefit-cost analysis of Hoosier Helper in Indiana included some additional items such as equipment cost (equivalent annual investment cost), employee salaries and benefits, overhead cost, maintenance cost, and change in fuel consumption associated with variations in the price of gasoline. On the other hand, the total cost of the RR service in Florida is calculated on the basis of contracted services, including estimated truck types, hours of operation (which may range from 24 to peak service hours only), and the number of trucks in that distinct zone provided by local private agencies [36]. A summary of reported FSP operational costs, miles patrolled, fleet size, and hours of operation is shown in Table 2-6.

Table 2-6 The Total Cost, Miles Patrolled, Fleet size, and Hours of Operation of FSP service for Each State

State	Costs (million)	Miles Patrolled	Fleet Size	Hours of Operation
North Carolina (IMAP) [26]	$ 3.9	384	About 55	Different operation of hours from peak hour period to 24/7
California (FSP) [62]	$25.5	1750	Over 350	Monday-Friday: peak commute hours
Florida (RRs) [16]	$16	1262	126*	Different operation of hours from peak hour period to 24/7
Georgia (HERO) [63]	$16 (combined with TMC operations and ITS device maintenance)	310	100*	7days: 24hours
Indiana (Hoosier Helper) [16]	$1.5	157	53	5:30 a.m. to 7:30 p.m. and different depends on weather condition
New Jersey (SSP) [64]	$6	225	52	Monday – Friday: 4:30 a.m. to 8 p.m. Saturday-Sunday:10:30 a.m. to 8 p.m.
Northern Virginia (SSP) [16]	$3.5	198	22	7days: 24hours
Kentucky (SAFE patrol) [16]	$3.4	N/A	30	7 days: 6 a.m. to 10:00 p.m.

* SOURCE: FDOT[25], SURVEY OF OUT-OF-STATE FREEWAY SERVICE PATROL TRAINING PROGRAMS, 2006.

2.4.3. Benefits-Costs Analyses

Each cited benefit-cost analysis for FSP programs uses different methods to estimate benefits and costs based on the implied data availability. Dixon [42] estimated the ASAP benefit-cost ratio by calculating the value of travel time mobility benefit, which was estimated at $8,992,082. This was computed by multiplying the total estimated hours saved due to ASAP and the travel time value. The benefit-cost ratio resulting from the analysis of ASAP program was approximately 23:1.

In California, Skabardonis and Mauch [29] developed the FSPE model and proposed a method to calculate a benefit-cost ratio with the model, considering incident delays, fuel consumption, air pollutant emissions, and inicdent response and clearance time. The benefit-cost ratio for FSP program in California was found to be 8.3:1.

The RR program in Florida was also analyzed using the FSPE model. Lin at al. [36] used delay and fuel savings to calculate costs and benefits. The benefit-cost ratio was 6.8:1 with about total $135.3 million in benefits estimated and about $19.9 million of contract cost.

Another study by Dougald and Demetsky [41] used the FSPE model to estimate FSP benefits. One of the main components to estimate the benefits was the difference in motorist delay with and without FSP. The benefit-cost ratio was estimated 5.4:1 and 4.7:1 for Northern Virginia (NOVA) and Hampton Roads in Virginia, respectively.

Simulation was used for the analysis of benefit-cost of H.E.L.P in New York [40]. For a 10-mile study segment and a six-month study period, annual savings (assuming 20 min reduction in incident delay) were estimated using CORSIM as 24,000 vehicle-hours in travel delay, 2,900 gallons of fuel, 0.32 tons of hydrocarbons (HC), 3.6 tons of carbon monoxide (CO), 0.2 ton of nitrogen oxide (NO), and 18 secondary incidents.

In Kentucky, most interstates and parkways where traffic volumes are low are serviced by the SAFE Patrol. The major benefits of operating the patrols are to provide free and quick roadside service, not necessaries to reduce delays or secondary incidents. Focusing on a benefit-cost analysis of SAFE patrols in low-traffic areas, Li and Walton [61] noted that non-response rate is considered a principal performance measurement of the service. They also pointed out that the benefit-cost ratios varied according to the coverage area and fleet size within each subdivision (East, Central, and West Kentucky). In the case of West Kentucky, when the fleet size and coverage increased, the benefit-cost ratios barely improved. Based on the results, decision makers could prioritize deployment based on relative benefit-cost ratios.

The CHART program in Maryland is an incident management program that includes FSP services. The program does not report any benefit-cost ratio for its FSP program. Chang and Point-Du-Jour [60] and Chang and Rochon [38, 65] evaluated benefits annually considering reduction in delay, secondary incidents, fuel consumption and emissions with available data to be able to calculate benefit for CHART.

In the case of HERO in Georgia, various studies calculated the cost savings of preventing secondary incidents (15% of crashes were assumed secondary incidents from the data), savings due to motorist assistance ($60.25 $\times$ number of assists), cost savings of pollutants reduced (pollutant emissions $\times$ savings per ton of pollutant), cost savings of fuel reduction (total fuel reduced $\times$ fuel market rate(cost/gallon)) to determine savings due to Traffic Incident Management including HERO [37]

Sun et al. [39] were estimated a benefit-cost ratio of about 38:1 for the Motorist Assist (MA) program supported by Missouri DOT. A significant reduction in secondary crashes was found to be an import factor in improving the benefit-cost ratio after MA was implemented. Annual net social benefits of $78,264,017 from 1,082 secondary crashes reduced per year were even greater than the reduced annual congestion cost of $ 1,130,000.

2.4.4. The 2004 NCDOT IMAP Study

The previous IMAP study by Khattak and Rouphail [26] focused on developing criteria to select expansion service areas or patrol beats and on creating an evaluation tool to incorporate evaluation of the developed criteria. IMAP planning and operational analyses were conducted as part of the study. For the recommended framework and evaluation tool, planning analysis was defined as identifying a potential IMAP deployment location based principally on crash frequency and traffic level. Operational analysis was defined as a benefit-cost analysis for candidate IMAP locations. The results of the preliminary planning and operational analyses were used to develop an IMAP evaluation tool.

The planning analysis developed by this earlier project was introduced in Section 2.3.1. For the operational analysis, incident-induced delays, IMAP benefits and costs, and fleet size were estimated. The IMAP benefit-cost analysis estimated non-recurrent delay caused by an individual incident with and without IMAP, along with the costs in case IMAP services implemented. The reduction in delay by the IMAP services was then used as the primary benefit. To calculate the reduction in delay, the study used the assumption that IMAP services reduce incident durations by 25%. The effect of queuing and vehicle delays were calculated using a FREEVAL analysis that considered different incident severity levels, facilities, and time periods.

Total cost of offering IMAP services was estimated with aggregate cost data provided by NCDOT including number of patrol vehicles, number of drivers, length of route, service hours, and total annual costs. These data were used to calculate cost per route mile (per year), cost per service hour, and cost per vehicle. A regression model was formulated and estimated using AADT and route length as the explanatory variables and number of FSP vehicles as the response variable to estimate how many IMAP's vehicles would be required for candidate expansion routes.

The study's key findings indicated that the most promising locations for operating IMAP services were high traffic, high crash locations, and the main candidates for IMAP expansion were I-26 and I-40 around Asheville and I-440 in Raleigh, as shown in Figure 2-2.

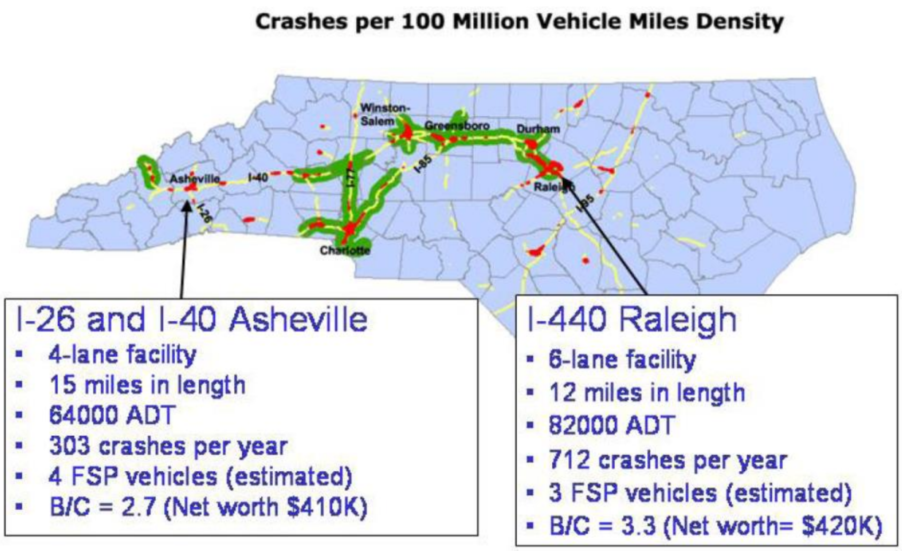


Figure 2-2 Planning and Benefit Cost Analysis Results for Raleigh and Asheville from NCDOT Research Project 2003-06

2.4.5. Evaluation Tools

This section provides a summary of macroscopic modeling approaches, a review of microscopic simulation-based approaches, and a synthesis of discrete event simulation methods applied in various tools for assessing FSP benefits and costs.

Skabardonis and Mauch [29] developed the FSPE package which includes a FSP evaluation and FSP predictor model in an Excel workbook with VBA modules. The benefits evaluation of the RR in Florida [36] and NOVA SSP in Virginia [41] were estimated using the FSPE package, including savings in travel delay, fuel consumption and pollution.

Computer simulation models are an alternative method for evaluating the performance of FSP when data prior to implementation is not available [40]. A simulation approach can include various factors associated with delay-induced incidents not utilized with other approaches. For example, CORSIM was used to develop a tool for estimating benefits-costs for FSP in New York [40] and Alabama [42]. Tariverdi [59] developed a Safety Service Patrol Benefit-Cost (SSP-BC) tool based on VISSIM. In this tool, a variety of factors such as incident duration, traffic volume and composition, ramp density, roadway characteristics, and weather conditions that impact FSP operations were considered.

Arena, a discrete event-based simulation software tool, was used to simulate FSP operations. Because of its computational efficiency in terms of run time, the model could be applied to a large network and a full year analysis. For example, Li and Walton [16] built incident process models for the state of Kentucky that can simulate each step of the SAFE Patrol services by inputting the spatial distribution of SAFE patrol road assistance, as well as daily, weekly and monthly incidents distributions, distribution of time intervals between road assistance, distribution of incident clearance time, and service and time schedules. Arena simulation was further used to determine the optimal number of patrol beats and tow trucks within each beat required for different shifts, as well as the optional operation time of each shift [31].

2.5. Reported Best Practices for FSP Systems

A report by Kentucky DOT reviewed best practices for FSP programs operating in the surrounding states including Florida, Georgia, Indiana, Tennessee, Virginia, West Virginia, and Alabama. Best practice topics included program history, current service patrol operations, provision of services, costs and benefits, and funding sources for each FSP operated in those states [16]. At the time of the literature and practice review for this research project, the Kentucky DOT report represented the only best practice review available.

The report documents when the FSP programs started and the primary mission of each program and details current service patrol operations in each state, including patrol coverage area and operating hours for each route. Additionally, explanations for given for the standard services provided and patrol fleet makeup in each state. Descriptions were also provided for any FSP program benefit-cost analyses that had been performed in the reviewed states. As application, final analysis results in terms of program budget, system operating costs, and benefit-cost ratio were provided. Finally, information was given on each state's FSP program funding sources.

2.6. Key Findings

Based on the literature and practice review described in this chapter, some key findings have emerged that will provided the research team with a solid foundation for the subsequent project tasks. In terms of the development of methodologies for identifying candidate FSP deployment locations and prioritizing the identified locations, the following considerations are critical:

- Effectively modeling the impact on congested queue length and congestion duration of the various incident time elements (detection, verification, response, and clearance)
- Definition of appropriate candidate IMAP route locations

In addition, the review underscored the importance of reasonably estimated benefit/cost ratios for candidate deployments. However, the review also revealed a lack of consensus in terms of the input factors and estimation methods for FSP program benefit-cost ratios even for state's with similar operational frameworks. Therefore, the research team was faced with the necessary task of crafting a workable and effective benefit-cost framework for NCDOT based on the availability of data.

Key performance measures gleaned from the literature included:

- Reduced travel delays
- Reduced secondary incidents and/or crashes
- Reduced fuel consumption and pollutant emissions
- Improved safety and peace of mind for motorists in distress

Protocols for conducting benefit-cost analysis included the following factors:

- Comparing traffic operations with and without FSP service
- Reliability of FSP service in terms of FSP service non-response
- Predicting primary and secondary incident risk

The previous NCDOT IMAP study was also helpful in defining the objectives for the current research project. With this background and practice review information in mind, the project team defined the following key objectives that would be addressed in the IMAP evaluation tool.

- To accurately estimate the difference in incident delays with and without IMAP service
- To include other attributes such as fuel savings, emissions reductions, and reduction in secondary incidents as benefits to the degree possible and appropriate
- To use actual North Carolina experience using archived, statewide incident and collision data to the maximum degree possible
- To consider the following factors as appropriate: IMAP operation hours, patrol route lengths, number of patrol vehicles, peak and non-peak incidents, differing roadway geometries, and differing weather conditions

A few final points from the literature and practice review are worth noting. First, there is documented evidence of the tangible public relations value of FSP systems. A few states such as Florida [66], Tennessee [7], Kentucky [16], and Georgia [37] have conducted motorist surveys to document how drivers perceive that service and in all cases confirmed the high value that the traveling public places on these systems. A second observation is the need to align the FSP service recommendations cited by Federal Highway Administration [9] to clearly define roles and responsibilities (However, this is a general point, and NCDOT's IMAP program is well-designed in terms of the FHWA recommendations). Finally, the increasing momentum in private sector sponsorship was clearly evident in the review, with the State Farm Insurance sponsorship in Maryland [17] and New Jersey [19] as prime examples. This trend pointed to NCDOT's State Farm Insurance IMAP sponsorship agreement that went into effect with the creation of the NCDOT State Farm Safety Patrol in May 2015.

3. Identify, Characterize, and Assess the Quality of Relevant Data Sources

A core research task involved the review of available incident data sources and the assessment of their quality and usefulness. In addition to incident data sources, several contextual data sources are necessary to support the research objectives. For example, historical speed data is a key parameter to identify areas of recurring congestion and became the basis for categorizing crashes as a means of providing a surrogate measure for secondary crashes. This chapter documents this data source evaluation.

3.1. Available Incident Characteristics Data Sources

NCDOT has three major databases that collect statewide incident and/or collision data: the Statewide Traffic Operations Center (STOC) incident management log, the Traffic Information Management System (TIMS), and the Traffic Engineering Accident Analysis System (TEAAS). The project team recognized all of these databases as candidate data sources. Detailed characterization and assessment of these data sources are presented below.

3.1.1. Incident Management Log

All incident events served by IMAPs has been reported to the incident management log since August 2013. The North Carolina IMAP program service is managed on the basis of NCDOT's highway division structure. Therefore, the log entries are reported by division. These log data include the following information: incident codes, vehicle types, service provided, detection source, timeline information, county, route, direction, mile marker, lanes blocked, total lanes, and any other events related information. It also provides trucks and drivers information. Further detail on the log entry fields is provided in Appendix F.

Based on the log data reported from each division, IMAP locations were drawn as of September, 2013 into a GIS map in Figure 3-1. Divisions where IMAP service was active were divisions 3, 5, 7, 10, 12, 13, and 14. In the figure, the blue lines highlight locations where service was provided via patrolling IMAP vehicles during weekdays, while the red lines highlight the locations where service was provided via patrolling IMAP vehicles 7 days a week. Finally, the black lines indicate locations where service was provided when IMAP vehicles were dispatched in response to a specific incident (i.e. no routine patrolling).

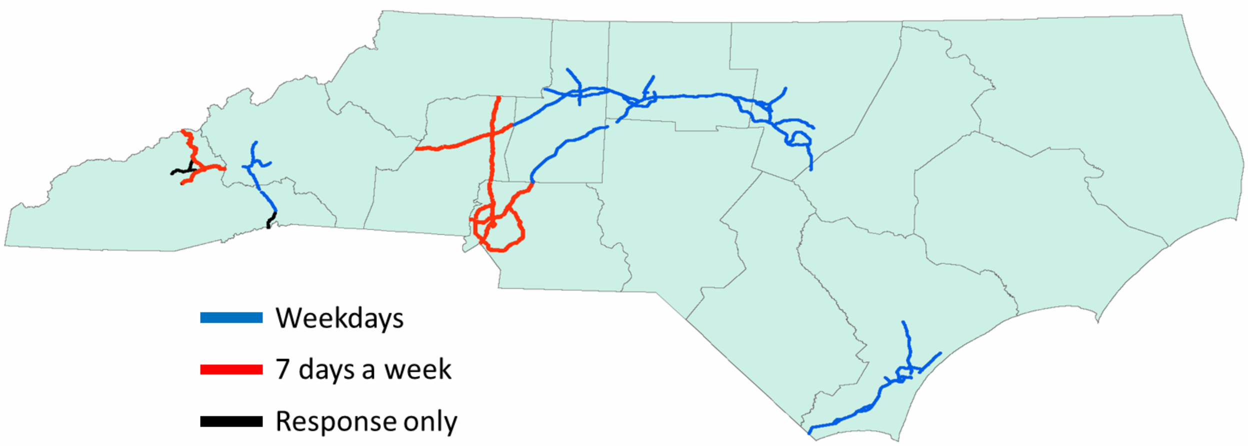


Figure 3-1 IMAP Locations (as of 2013)

Year 2014 major incident frequency in divisions with IMAP service is presented in Table 3-1. As expected, the highest incident frequencies occurred in the Triangle and Charlotte metropolitan areas (Division 5, 10 and 12). The proportion of crashes to total incidents reported ranged from 7 to 18% while the proportion of disabled vehicles to total incidents was in the range of 40 to 50%.

Table 3-1 Incident Frequency for Major Incidents from Incident Management Log

Division	Number of total incidents reported	Crashes reported	Debris reported	Disabled vehicles reported
3*	3,966	488 (13%)	480 (12%)	1533 (39%)
5	21,394	3,765 (18%)	1,708 (8%)	9,028 (42%)
7*	15,255	1,177 (8%)	1,730 (11%)	5,975 (40%)
10 and 12	23,414	1,690 (7%)	2,260 (10%)	10,155 (43%)
13	5,505	663 (12%)	793 (14%)	2,774 (50%)
14	n/a			

*: 11 months in 2014, if not 12 months in 2014

The log data reported for division 5 was used to evaluate data quality in terms of completeness. Figure 3-2 describes summary of log data entry rate for critical incident characteristics. The log data were found to be relatively complete for the IMAP unit and incident type fields. However, the roadway characteristics data fields, such as county, route, direction, and mile marker were more subject to missing entry. Of note, information on the number of lanes blocked was reported for fewer than 10% of the entries. For purposes of assessing IMAP service impact, incident management time-line information is especially critical. Time line information completeness was highest for response arrival and departure with a reporting rate of greater than 90%. However, the remaining time-line incident response data point were reported of arrival and departure time were reported at a very low rate with only slightly more than ¼ of dispatch times reported and the time for remaining time-line events reported at rates less than 10%.

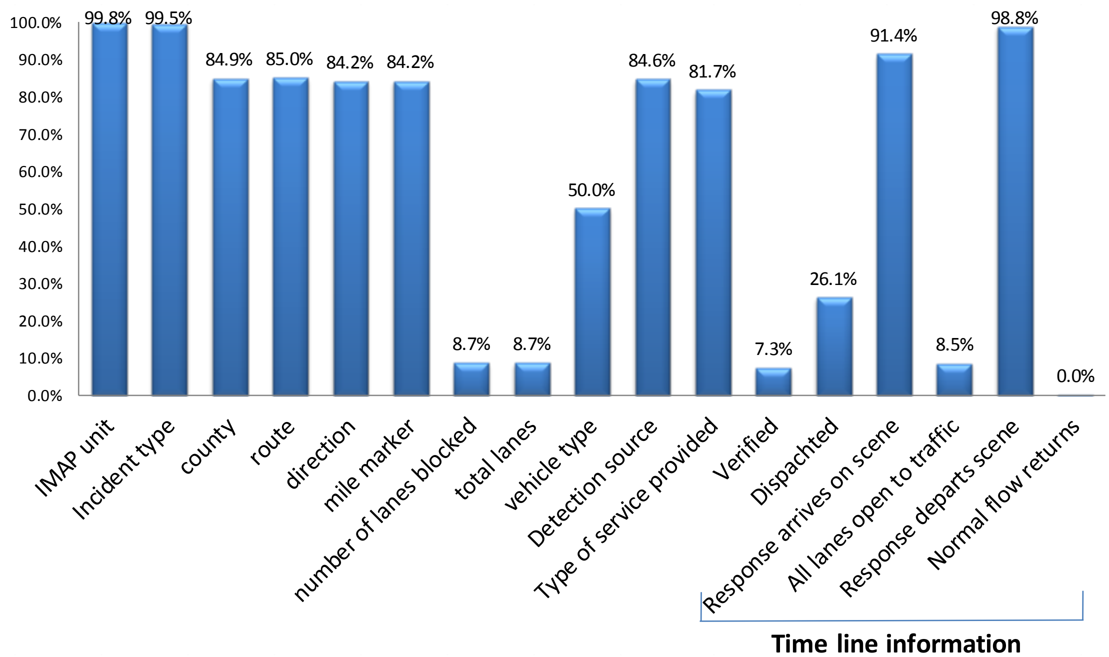


Figure 3-2 Summary of Reported Data Rates for Incident Management Log Critical Indicators (Division 5)

3.1.2. Traffic Information Management System (TIMS)

Drivers can get real time information on incident events that cause severe and unusual congestion on NCDOT maintained roadways in North Carolina through the traveler information management system (TIMS) website[1] and the NC 511 voice actuated system built on the TIMS information. Since 1998, the system has stored incident event data. In 2002, a data tool was launched that creates TIMS event data tables that include the following information: division, county, road name, road alternative, direction, mile marker, mile marker to, city name, traffic condition, start/end time, incident type, reason, severity (low, middle, and high), lane(s) closed by incident, total of lanes on the road, and event name. Further detailed on the TIMS database is also provided in Appendix F.

[1] tims.ncdot.gov/tims/default.aspx

Figure 3-3 depicts changes over time in TIMS incident and crash frequencies. Incident frequency rose steadily in the first 8 years, then rose sharply beginning in 2005, and reached a peak in 2010. Incident frequency than dropped off sharply in 2011 and 2012, and levelled out in 2012 to 2014. Crash frequency on the other hand demonstrated a linear increase through about 2009 from where it curved upward rapidly reaching a peak in 2013 with a small drop in 2014. Based on these trends and changes, the project team conducted an investigation to see if there were identifiable factors that could help explain the evolution of TIMS data over the years.

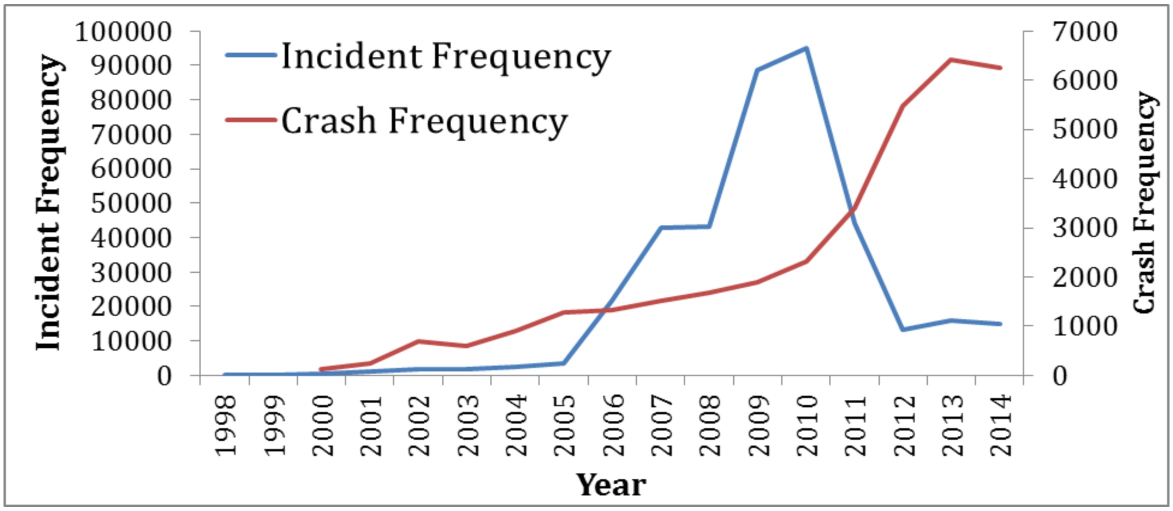


Figure 3-3 Incident Frequency in TIMS

The results of this investigation are illustrated in the following series of figures. Figure 3-4 shows incident frequency by incident type in 2010. More than 90% of the recorded 2010 incidents were classified as *automatic congestion*. The project team learned that this incident type was added as an algorithmically driven indicator based on available traffic condition data. Therefore, much of this congestion may in fact be recurring congestion that is not related to an identifiable precipitating incident. Based on this finding, the frequencies of *congestion* and *automatic congestion* over time were plotted in Figure 3-5. Figure 3-5 shows *automatic congestion* from 2006 to 2011 has similar pattern with the incident frequency plotted in Figure 3-3, and that this incident type is not present before 2007 nor after 2011. A similar though shorter pattern is seen for the *congestion* incident type with events of this type only being recorded in 2006 and 2007. Based on this result, the project team decided to exclude the *congestion* and *automatic congestion* event records from incident data analysis.

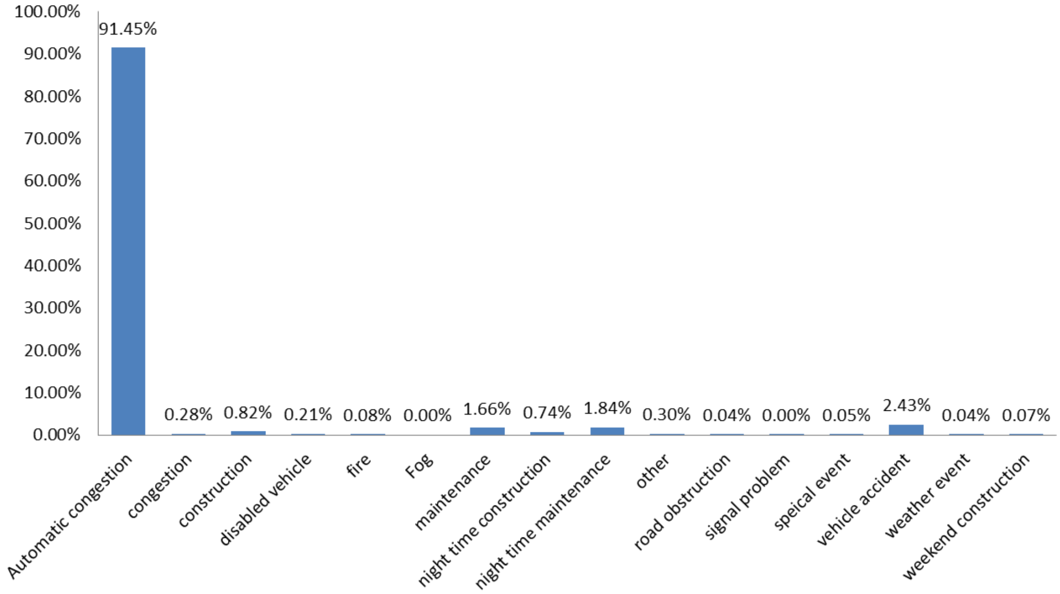


Figure 3-4 Incident Frequency by Incident Types in 2010

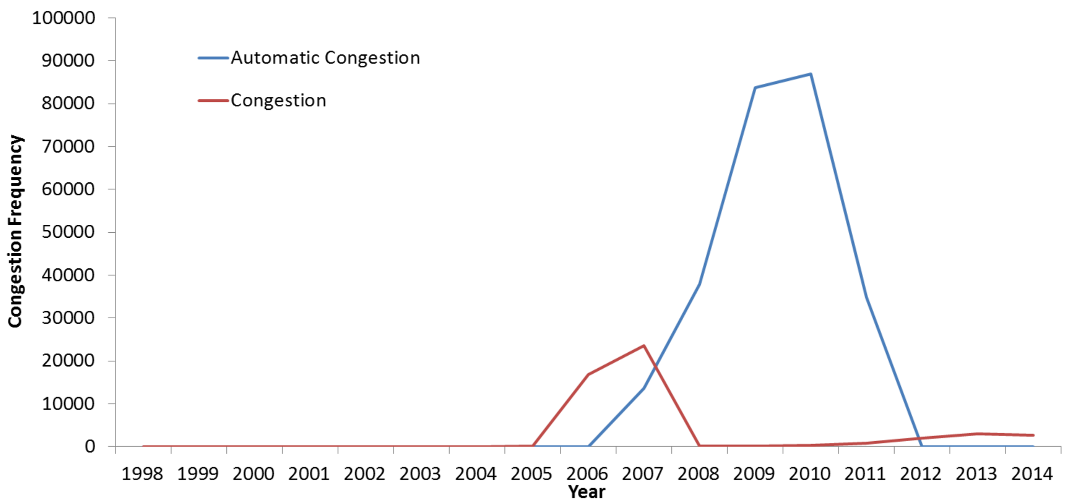


Figure 3-5 Congestion and Automatic Congestion Frequency by Year

Figure 3-6 shows that the plotted crash frequency and incident frequency have similar patterns when the *automatic congestion* and *congestion* events are excluded from the raw TIMS data.

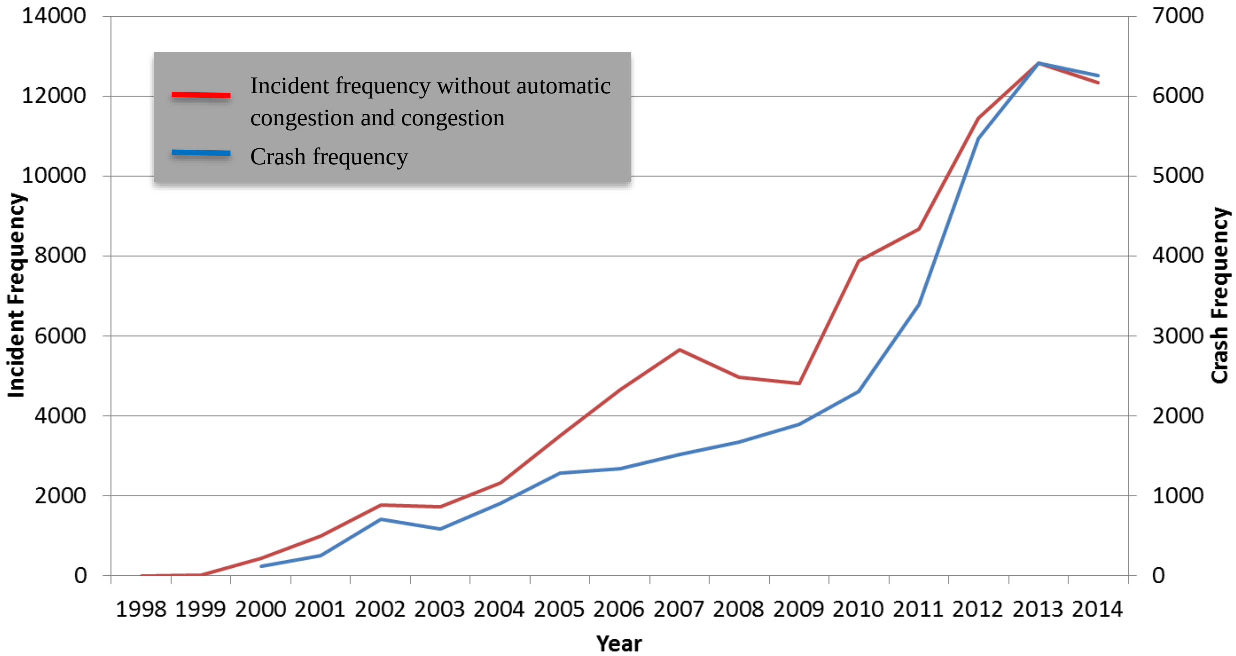


Figure 3-6 Incident Frequency (*Automatic Congestion* and *Congestion* Excluded) and Crash Frequency

Approximately 400,000 records on North Carolina's maintained Interstate and US roads in 18 sheet files downloaded from TIMS database have been filtered to obtain key statistics for an assessment of the data quality. Figure 3-7 illustrates the comparison data record completeness for data recorded in the period of 1998 to 2014.

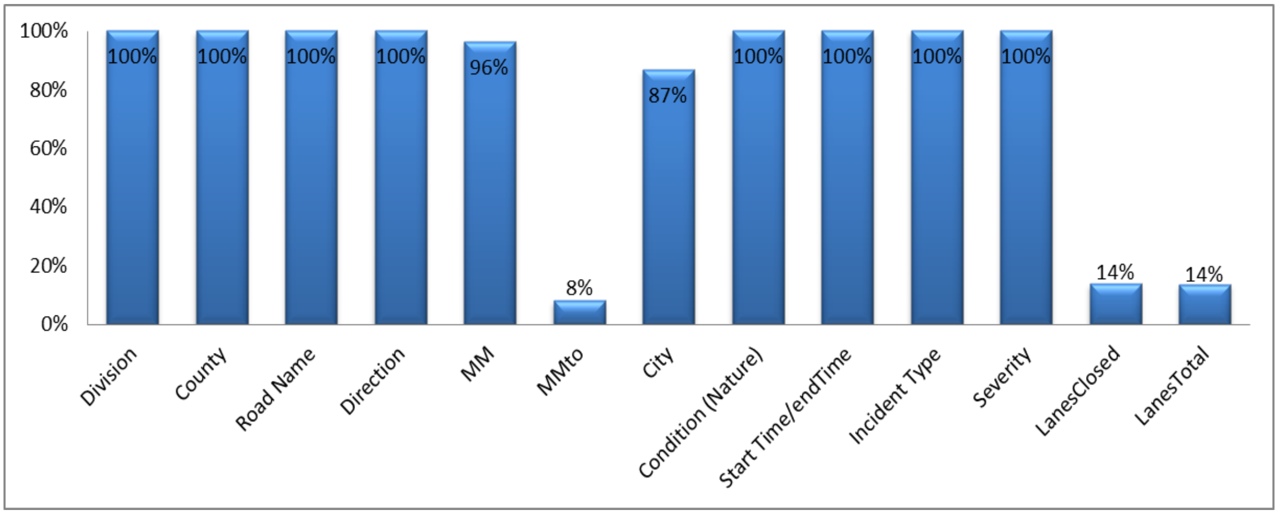


Figure 3-7 Summary of Data Reporting Rates for Critical TIMS Record Fields (1998-2014)

As shown in Figure 3-7, most indicators, which include division, start/end time, and so forth, were recorded for all TIMS records. About 96% of Mile Marker (MM) fields were completed, and only 8% of Mile Marker to (MMto), which indicates the limits of incident impact, were reported in TIMS. Only 14% of the total lanes and lane(s) closed fields were reported.

3.1.3. Traffic Engineering Accident Analysis Systems (TEAAS)

NCDOT maintains data on traffic crashes in the Traffic Engineering Accident Analysis Systems (TEAAS). Records in the TEAAS database include: injury severity, roadway characteristics, crash characteristics and location, and environmental characteristics in terms of a set of pre-specified categories.

The Geovisual Analytics and Decision Management Group (GADA) at Institute for Transportation Research and Education is in a multi-year effort for NCDOT to capture TEAAS data into a GIS data tool for the purpose of truck crash analysis. These TEAAS crash data have additional information including latitude and longitude information as well as temporal information. At the time that the project team conducted its assessment of crash data in the GADA GIS, data were available only on interstate roads in NC through 2010 and 2013. Data for 62,077 crashes were reported in the database. For the recorded interstate crashes, the only missing data were direction of travel under which the crashes occurred. Even when direction was recorded, the GIS shapefile for the TEAAS data geospatially located all crashes all in the direction of increasing county milepost. For example, all of crash data along I-40 were geo-located in eastbound direction within the shapefile even for crashes labeled to have occurred in the westbound direction.

Table 3-2 depicts crashes reported by direction in 2010-2013 TEAAS data. Dominate directions on each road are readily apparent. For instance, most crashes were located in eastbound (E) and westbound (W) of I-40 while in northbound (N) and southbound (S) of I-95.

Table 3-2 Crashes Reported by Direction in 2010-2013 TEAAS

Route	Direction									Total
	E	W	N	S	NE	NW	SE	SW	N/A	
I-140	**33**	**46**	0	2	0	0	0	1	7	89
I-240	**317**	**406**	14	13	8	4	2	9	196	969
I-26	**452**	**487**	191	196	3	87	84	6	211	1717
I-277	**39**	**59**	35	27	8	6	3	6	95	278
I-40	**8025**	**8050**	503	485	45	123	117	34	2326	19708
I-40 BUS	**45**	**40**	0	0	0	0	0	0	6	91
I-440	**1095**	**1094**	335	313	43	69	33	72	266	3320
I-540	**682**	**804**	51	79	16	9	10	20	209	1880
I-74	**121**	**147**	36	38	2	24	27	0	62	457
I-73	5	7	**74**	**80**	2	2	0	1	30	201
I-77	12	18	**3459**	**3720**	8	5	1	10	574	7807
I-795	4	4	**136**	**142**	0	1	0	0	14	301
I-840	5	9	10	18	0	0	0	0	5	47
I-85	876	880	**4741**	**4525**	325	39	37	272	1252	12947
I-85 BUS	11	10	49	35	21	0	0	19	24	169
I-95	8	6	**2202**	**2118**	6	1	5	9	563	4918
I-95 BUS			**1**	**1**						2
I-485	691	685	700	604	28	37	49	25	269	3088

A total of 35,988 crashes labeled in the obvious directions (**bold numbers)** on each road through 2010-2013 was then applied to this project. At the time of this analysis, the crash data for November and December of 2013 had not yet been incorporated in the GADA GIS database.

3.2. Contextual Data Sources

In addition to incident characteristics data sources, there are several key contextual data sources. The first is historical speed data which is used as a key source for IMAP route consideration. Second, a link shapefile including link attributes is required since a GIS-based link classification is processed for the screening analysis. Third, traffic characteristics information should be located into each segment that involves a link code. A discussion of available IMAP cost data, value of time, and type of area follow the discussion of speed data and statewide network.

3.2.1. RITIS for Historical Speed Data

INRIX.com is the source of the link based speed data and travel time data employed in the project. Near the end of the project period, NCDOT changed its primary data provider from INRIX to HERE. The frameworks and processes developed for the INRIX data can be applied to the HERE data with no modification needed. The primary difference will be that fewer TMC segments will be tracked and analyzed un the HERE data environment because HERE does not classify the short segments interior to interchanges (between off and on ramps) as separate segments.

INRIX.com uses GPS enabled probe cars to collect their speed information. Geocoding is based on freeway and arterial NAVTEQ Traffic Message Change (TMC) codes, as defined by Tele Atlas and NAVTEQ. Each NAVTEQ TMC code corresponds to a directional roadway segment with a geo-located beginning and end point. INRIX reports average travel time, average speeds, reference speeds, C-scores, and C-values by time of day and day of week. The C-value is a measure of the confidence attributable to the real time data. The C-score indicates if the speed data point is based on historical data, real time data, or a blend of the two.

These link speed data can be downloaded from the Regional Integrated Transportation Information System (RITIS) Vehicle Probe Project (VPP) suite that includes tools for generating performance measures, dashboard analysis, and visual analytics. Figure 3-8 depicts a screenshot of the RITIS Massive Data Downloader tool. Users can submit a data request by region, data range, day of week, time of day, data source, downloaded format, and data aggregation interval from one minute up to one hour. A total of 2,287 NAVTEQ TMC links were identified by a request for data on Interstates in North Carolina.

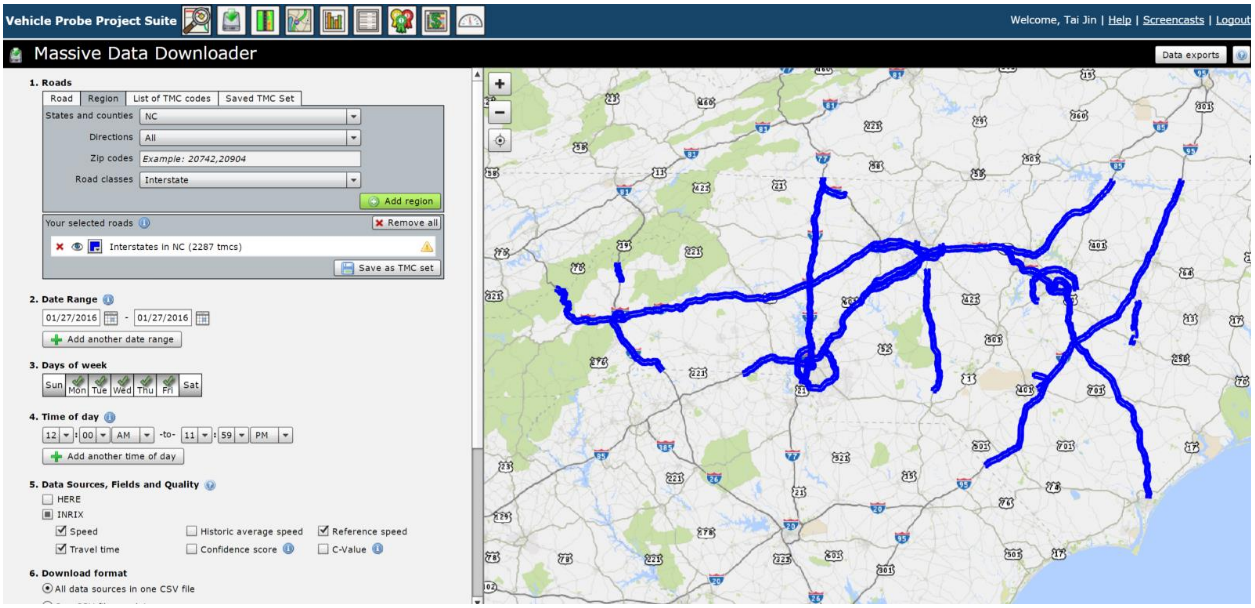


Figure 3-8 Screenshot of RITIS Webpage

3.2.2. GIS for NAVTEQ Link Attributes

A shapefile of 2009 NAVTEQ TMC link data was obtained from NCDOT and applied to the analysis for IMAP route consideration. The shapefile covers arterial links as well as freeway links and include information only for physical lengths of links and NAVTEQ TMC link code (originally called as TMC code). Figure 3-9 shows a screenshot of the NAVTEQ TMC link GIS map with total 20,293 NAVTEQ TMC links. All information to be used in this project should be located and archived into each NAVTEQ TMC link in the shapefile. Since this project focuses on IMAP operation, freeways, especially primary routes are only considered as candidate IMAP route alternatives. This project defined primary segments as Interstate and US road segments with a poster speed limit of greater than or equal to 55 miles per hour. As mentioned earlier, only length and link code are included in the shapefile, and therefore extracting primary routes required joining NAVTEQ TMC link information for route name and road direction (which can directly downloaded through RITIS.org) with NAVTEQ TMC link GIS data.

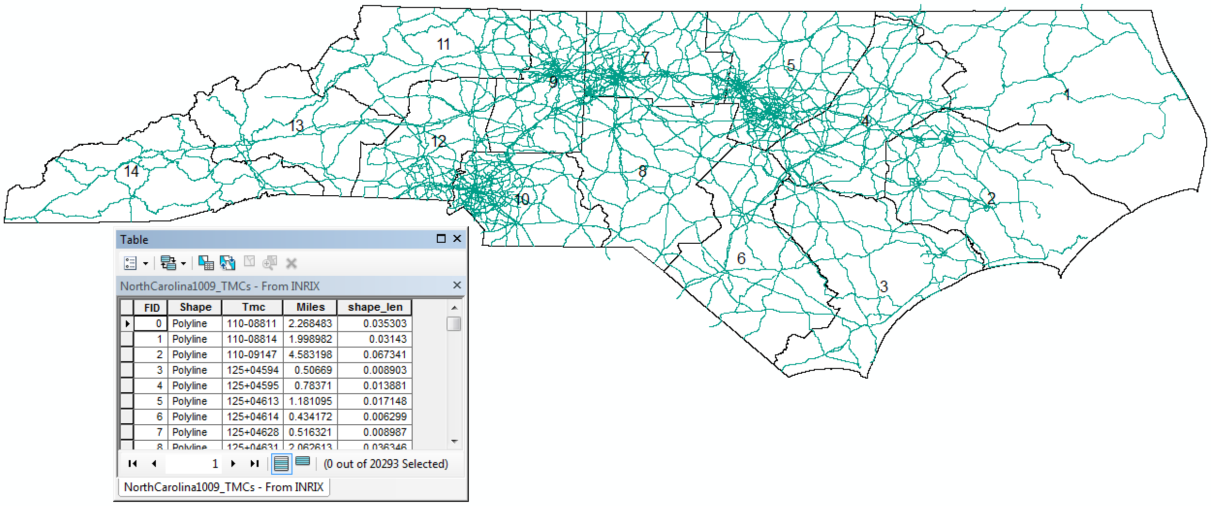


Figure 3-9 A Screenshot of GIS-NAVTEQ TMC link Attribute Map

A total of 8,037 NAVTEQ TMC links on primary routes was selected in North Carolina within 2009 NAVTEQ TMC link GIS data as presented in Table 3-3. Division 5 was the division with the highest number of links on primary routes, while Division 2 and Division 3 were the divisions with the lowest number of links. Before applying these GIS data, the project team compared the 2009 GIS data to the current NAVTEQ TMC links downloaded from RITIS.org. Table 3-4 shows the difference between the number of links by division. The current NAVTEQ TMC links (as of 2015) obtained from RITIS.org has 459 more links on primary routes in North Carolina.

Table 3-3 Total NAVTEQ TMC links on Interstate or Primary Routes

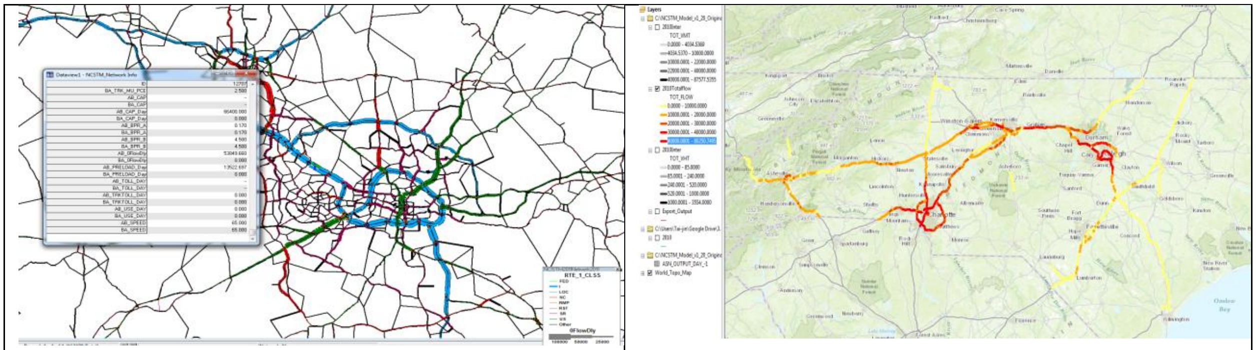
Division	Interstate	Primary routes	Division	Interstate	Primary routes
1	11	396	8	110	621
2	0	381	9	270	699
3	60	339	10	331	700
4	160	722	11	56	416
5	350	1055	12	173	485
6	124	466	13	204	557
7	273	684	14	57	516
A total of NAVTEQ TMC links on Interstate routes	2179		A total of NAVTEQ TMC links on Primary routes	8037	

Table 3-4 Difference Between Previous and Current Number of NAVTEQ TMC links

NAVTEQ TMC links GIS map (2009 NAVTEQ TMC link data)					RITIS.org (2015 TMC data)			
Division	**Interstate**	**US**	**Total**		**Division**	**Interstate**	**US**	**Total**
5	350	705	1055		5	363	750	1113
10	331	369	700		10	348	379	727
14	57	459	516		14	57	472	529
Statewide	2179	5858	8037		Statewide	2323	6164	8487

3.2.3. North Carolina Statewide Transportation Model

Traffic characteristics information for current and future statewide road networks is needed for IMAP screening and prioritization. NCDOT developed the North Carolina Statewide Transportation Model (NCSTM) Gen 1.0 for statewide planning/programming, freight analysis, economic analysis, environmental impact studies, project/corridor appraisal with professional judgement needed. The model's socio-economic data is based on 2010 census data and InfoUSA employment data. There are two scenarios in the current model: the base model (2010) and year 2040. Therefore, to get information in a year within the range from 2010 to 2040, the project team estimated values by interpolating between 2010 and 2040. The NCSTM provides various traffic characteristics information from road network link fields, such as posted speed limit and street name, and daily assignment results such as AADT plus other information of both current and future road networks. The project team selected the NCSTM as the GIS-based link classification for future IMAP route consideration. The NCSTM highway network link fields provide the following information use in this research: street name, posted speed limit data, and number of lanes. The NCSTM AADT data were used to classify NAVTEQ TMC links on the basis of travel demand level. The required elements were extracted as a shape-file from the TransCAD-based NCSTM as shown in Figure 3-10.



(a) In TransCAD (b) In GIS

Figure 3-10 NCSTM Model (2010)

The shapefile extracted from the NCSTM is based on TransCAD ID and therefore a "spatial join" was conducted to impose the NCSTM data onto the NAVTEQ TMC links.

3.2.4. Available IMAP Cost Data

All available IMAP cost data were obtained from NCDOT. The IMAP cost data include:

- Truck cost: $30/hour
- Employee salaries: $15/hour
- Number of trucks operated: number of trucks can be classified by a route and a division
- Operation hours: operation hours can be identified by a route
- Operation days: annual days of operation on a route
- Miles driven: miles driven of IMAP trucks on a division
- Total length of IMAP routes on a division

3.2.5. Value of Time

Value of time is an estimate of the average cost for the additional travel time caused by the congestion. Value of time is classified by purpose of travel: personal travel versus commercial travel. In terms of personal travel, value of time can be defined as the sum of driver's perceived value of time plus the cost of extra fuel consumption in congested state conditions. In contrast, for commercial travel the value of time is the operating costs plus the wage rate of the driver.

Value of time both for passenger cars and trucks is employed for estimating delay savings in terms of dollars saved multiply by the hours of delay savings. In this project, the 2016 value of time determined by the Texas Transportation Institute and provided by RITIS.org was used, namely:

- Passenger: $16.79
- Commercial: $86.81

3.2.6. Area Type

A shapefile of Urbanized Boundaries from the 2010 Census downloaded from NCDOT was applied to distinguish classify segments as urban versus rural. The file includes three classifications: urbanized areas, urban clusters, and rural areas. The project team classified segments falling within the urbanized area and urban cluster regions as urban and all other segments as rural area. This classification is illustrated in Figure 3-11.

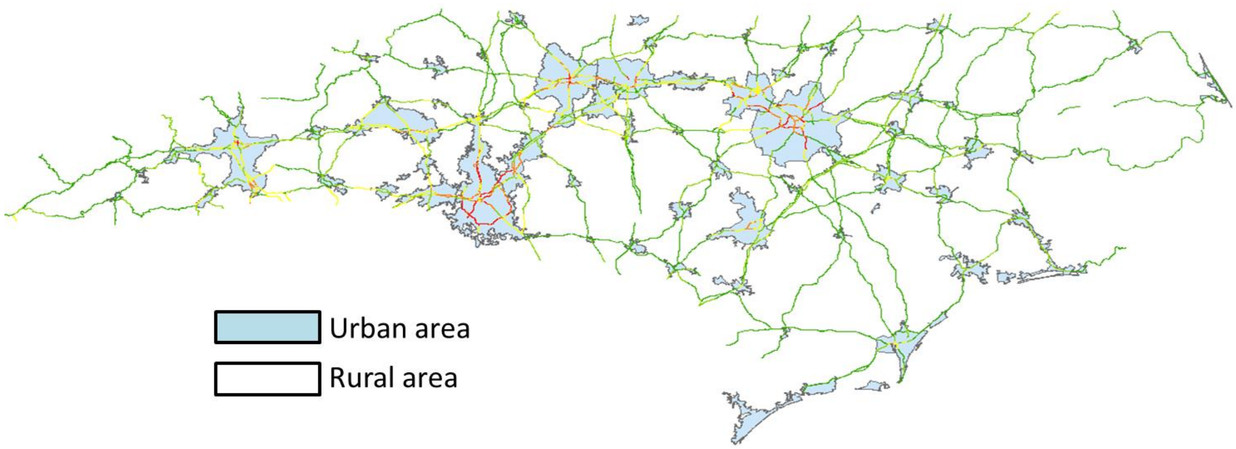


Figure 3-11 Urban Versus Rural Areas in NC

3.3. Summary

Based on the identification and the assessment of the quality of relevant data sources, the data sources to be applied to the project objectives were selected. Table 3-5 summarizes the characteristics of the incident-related data sources.

Table 3-5 Characteristics of Available Incident Data Sources

Data availability	Incident management log	TIMS	TEAAS
Temporal	Aug. 2013 – Dec. 2014	1999-current	2010-2013
Spatial	Current IMAP locations	I, US, NC, and SR	Interstate
Incident or crash	Incident that were served by IMAP	Incident that caused non-recurrent congestion	Crashes occurred
Timeline information	Start time, duration, end time	Start time, end time	Start time

The incident management log was the richest data source in the sense that it records all incidents that are served by IMAP truck drivers from minor to severe. However, application of the incident management log to before-and-after analysis was hampered by the fact that the log data were available only for one and half years prior to the project analysis. In addition, no incident data on locations not served by IMAP patrols are available, and thereby a with-and-without study cannot be enhanced by using incident management log data.

TIMS makes us possible conduct a before-and-after study by virtue of its 10 year span. In addition, a key parameter to estimate delay savings is incident duration, which can be calculated from TIMS using the recorded start and end time. Therefore, TIMS is an appropriate data source for before-and-after study of IMAP benefit. However, TIMS does not include all incidents.

TEAAS crash data geo-located in the GADA GIS are only the data that include latitude and longitude information for crashes. Thus, these data can be applied to the classification of secondary collisions. In addition, it is possible apply these data to a before-and-after study for locations where IMAP was implemented between 2011 and 2012.

In terms of contextual data sources, the most important issue is the necessity to incorporate all data sources needed for this research into the NAVTEQ TMC link GIS attributes. For example, the developed secondary collision classification methodology requires that collision data be geo-located in terms of NAVTEQ TMC links and that each collision record be labeled with its corresponding NAVTEQ TMC link code. As mentioned above, the TEAAS crash data from the GADA GIS can be located on NAVTEQ TMC links because they include latitude and longitude information for each collision.

4. Criteria for IMAP Deployment Consideration

In the previous IMAP planning tool [26], crash rate and average annual daily traffic (AADT) were used as the indicators of traffic safety and demand characteristics. GIS software was used to map these indicators to determine the highest-ranking facilities along roadway links and to illustrate the locations of existing IMAP coverage. Building on this prior work, the research team conducted an extension analysis of the previous planning level method as a foundation for developing a GIS-based screening framework with more realistic and impact sensitive criteria to identify locations with a potential for significant IMAP operational benefits. Statewide planning analysis is enabled through the integration of all input data into the statewide NAVTEQ TMC link-based GIS database. A GIS based screening and identification of candidate NAVTEQ TMC link segments is conducted by classifying TMC links based on travel demand level, congestion, and safety. Travel demand and congestion frequency are considered to be suitable as criteria for urban area roadways, while safety-based criteria are relevant for both rural or urban area roadways. The screening results are displayed graphically, thereby allowing users to spatially observe concentrations of candidate links. Clusters of candidate segments indicate routes where IMAP deployments warrant further consideration.

4.1. Statewide GIS Based Link Classification

Figure 4-1 describes the flow diagram of processing statewide link classification for IMAP route consideration. The first step is to collect available data source for the classification. First, Average Annual Daily Traffic (AADT) data are extracted from the NCSTM. Second, link-based speed data are downloaded from RITIS.org. Finally, interstate crash data are inserted from the TEAAS data in the GADA GIS database. The first processing step involves calculation of the Average Historic Congestion Index (AHCI) and crash classification by congestion type. These processes are carried out by the congestion contour and collision classification tool. The AHCI and collision classification are introduced in subsequent report chapters. Detailed information for the classification tool is also provided in Appendix E. These sourced and derived link and collision attributes are integrated into the statewide TMC link-based GIS database.

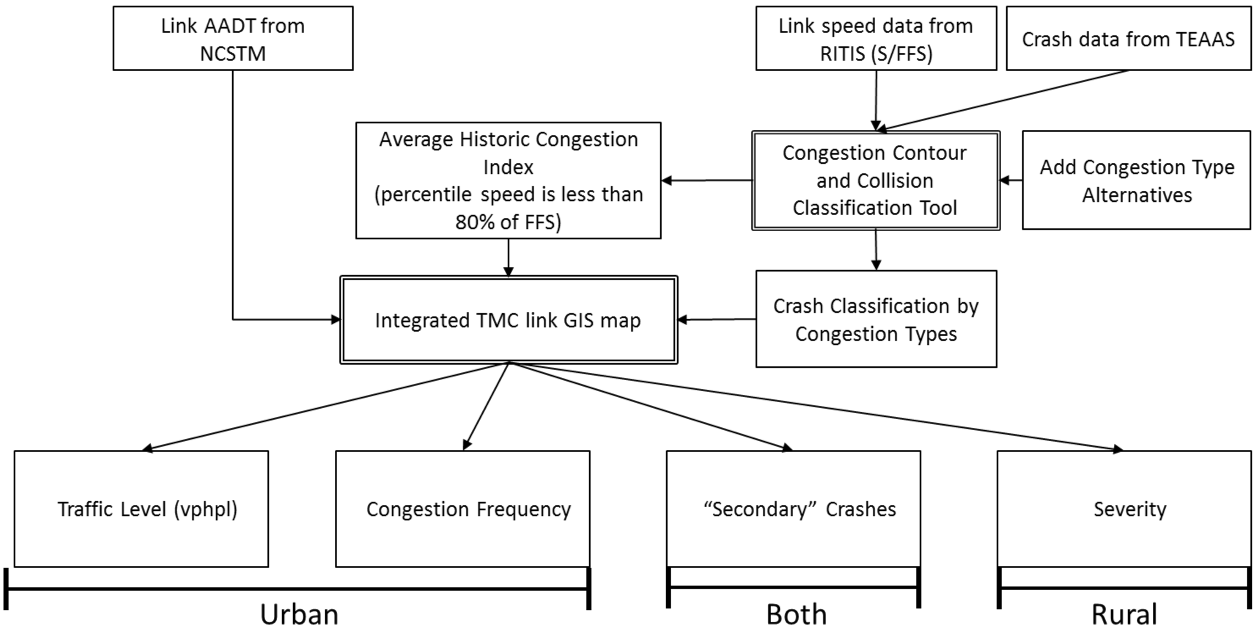


Figure 4-1 The Flow Diagram of NAVTEQ TMC link Classification

4.1.1. Traffic Level

In this study, traffic (travel demand) level is estimated and forecasted based on the NCSTM. The NCSTM AADT values are converted to an estimated peak hour volume per lane. The AADT values from NCSTM Gen1.0 were used for this purpose. The NCSTM Gen1.0 model provides daily traffic flow for both current and future transportation networks by simulating travel inside and outside of NC. The model provides 2010 and 2040 traffic assignment data. Therefore, as mentioned earlier, linear interpolation is used to estimate the AADT for intervening years, such as 2020 or 2025. The interpolated AADT values are then integrated into the NAVTEQ TMC link-based GIS. For a given analysis year, the peak hour volume per lane is estimated with the following equation:

$$VpL = \left(AADT \times \alpha\right) / N \qquad \textbf{Equation 4-1}$$

Where, *AADT*: Annual Average Daily Traffic for the analysis year

α: proportion of daily traffic during the peak hour (0.1, default value in this study)

N: number of lanes on a link

The process for classifying NAVTEQ TMC links by traffic volume per lane is shown in Figure 4-2.

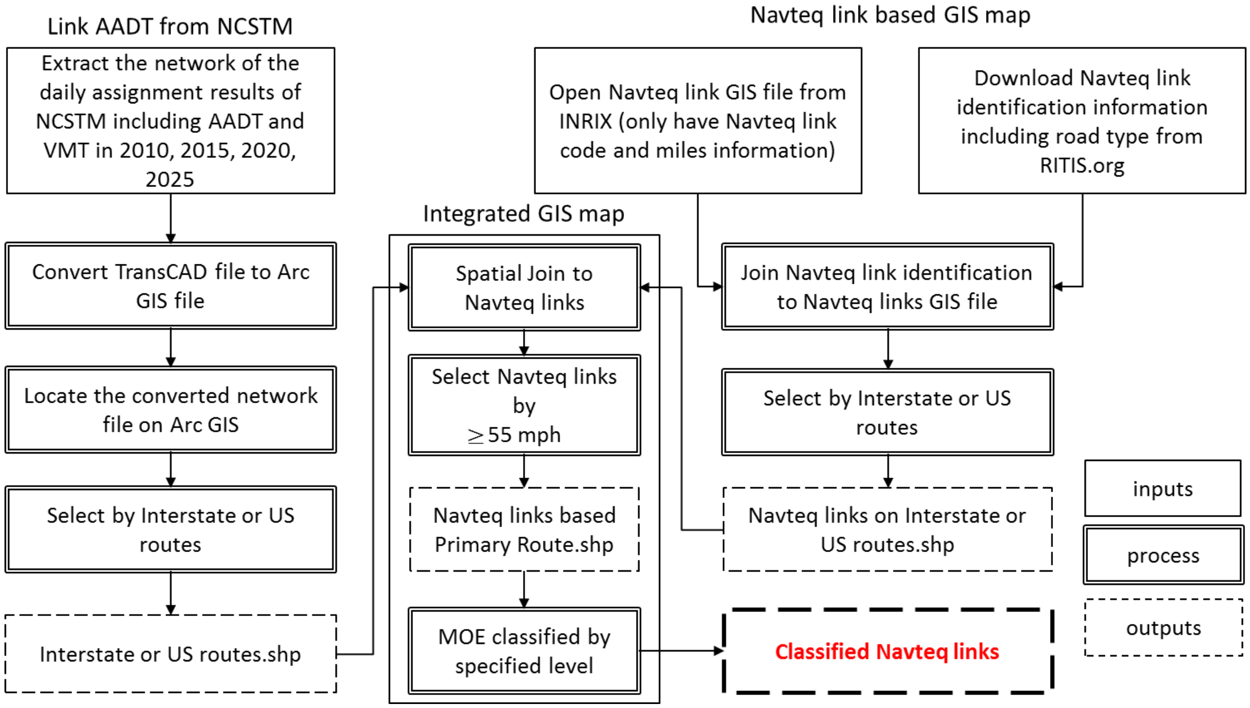


Figure 4-2 The Flow Chart of Travel Level based NAVTEQ TMC link Classification

4.1.2. Congestion Frequency

Congestion frequency presents a measure of travel time reliability and is defined as the average congestion in a weekday or weekend over one year at TMC segment *i*. To estimate congestion frequency, a four-step methodology was employed.

In Step 1, this study uses a segment and time interval congestion value, $C_{d\ or\ w}(i,t,m)$, which is the prevailing measured speed divided by the posted speed limit on the segment *i* at time *t*. If $C_{d\ or\ w}(i,t,m)$ is below a specified threshold, the segment is classified as being congested at time *t*. This metric can be downloaded from RITIS.org and is calculated with the following equation:

$$C_{d\,or\,w}(i,t,m) = \frac{MS(i,t,m)}{SPDLMT(i)} \times 100\% \qquad \textbf{Equation 4-2}$$

Where, *i*: NAVTEQ TMC segment,

t: specified time interval in a day (e.g., 8:00-8:15, 15 min); typically *t* will vary from 1 to 96 for a single day,

m: index for a day in the study period,

d: weekday $\in$ (Monday, Tuesday, Wednesday, Thursday, Friday),

w: weekend $\in$ (Saturday, Sunday),

$MS(i,t,m)$: measured speed (mi/h),

SPDLMT (*i*): posted speed limit (mi/h), and

$C_{d\,or\,w}(i,t,m)$: congestion value for segment (*i*) at time (*t*).

Figure 4-3 depicts sample of congestion value data obtained directly from RITIS.org. The NAVTEQ segment is shown on the vertical axis and time on the horizontal axis. Congestion values are shown in the cells. Traffic flow direction is from bottom to top from NAVTEQ TMC segment 125-10218 to NAVTEQ TMC segment 125N04645 along I-85.

Congestion for I-85 between Statesville Ave/Exit 39 and Kannap
Southbound June 11, 2014

NAVTEQ	NAME	MILES	3:00 PM	3:15 PM	3:30 PM	3:45 PM	4:00 PM	4:15 PM	4:30 PM	4:45 PM	5:00 PM	5:15 PM	5:30 PM
125N04645	W Mallard Creek Church Rd/Exit 46	0.60	100%	100%	100%	100%	100%	100%	100%	100%	94%	92%	91%
125-04645	W Mallard Creek Church Rd/Exit 46	1.08	100%	100%	94%	96%	93%	94%	97%	93%	92%	98%	92%
125N04646	I-485/Exit 48	0.35	100%	79%	40%	42%	58%	41%	52%	41%	42%	38%	52%
125-04646	I-485/Exit 48	0.94	100%	75%	17%	11%	17%	15%	21%	15%	35%	32%	41%
125N04647	Speedway Blvd/Exit 49	0.73	100%	100%	78%	18%	9%	12%	15%	15%	34%	40%	57%
125-04647	Speedway Blvd/Exit 49	1.82	100%	100%	100%	71%	32%	15%	10%	8%	20%	49%	99%
125N04648	Poplar Tent Rd/Exit 52	0.53	100%	100%	100%	99%	100%	99%	72%	13%	13%	59%	100%
125-04648	Poplar Tent Rd/Exit 52	1.32	100%	100%	100%	100%	100%	99%	100%	83%	35%	74%	100%
125N10218	Kannapolis Pkwy/Exit 54	0.70	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
125-10218	Kannapolis Pkwy/Exit 54	0.83	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure 4-3 Contour of Congestion Value

In Step 2, a binary congestion index, $CI_{d\,or\,w}(i,t,m)$, based on $C_{d\,or\,w}(i,t,m)$, is introduced to denote whether or not segment *i* was congested at time *t* during a day *m*, as illustrated in Figure 4-4. For this purpose, the ratio of the measured speed on the segment *i* at time *t* to the posted speed limit of that segment is determined. If this ratio is below a specified threshold, the segment is classified as being congested at time *t*. In this study, a threshold value of 80% was used as to identify congestion. This value is consistent with the ratio of speed at capacity to free flow speed in the latest version of the FHWA's *Highway Capacity Manual*.

Therefore, the congestion index can be formally defined as:

$$CI_{d\,or\,w}(i,t,m) = \begin{cases} 1 \; if \; C_{d\,or\,w}(i,t,m) < 0.8 \\ 0 \; otherwise \end{cases} \qquad \textbf{Equation 4-3}$$

Where,

$CI_{d\,or\,w}(i,t,m)$: Congestion Index at a spatiotemporal cell (i,t).

Congestion for I-85 between Statesville Ave/Exit 39 and K Southbound June 11, 2014													
NAVTEQ	NAME	MILES	3:00 PM	3:15 PM	3:30 PM	3:45 PM	4:00 PM	4:15 PM	4:30 PM	4:45 PM	5:00 PM	5:15 PM	5:30 PM
125N04645	W Mallard Creek Church Rd/Exit 46	0.60	0	0	0	0	0	0	0	0	0	0	0
125-04645	W Mallard Creek Church Rd/Exit 46	1.08	0	0	0	0	0	0	0	0	0	0	0
125N04646	I-485/Exit 48	0.35	0	1	1	1	1	1	1	1	1	1	1
125-04646	I-485/Exit 48	0.94	0	1	1	1	1	1	1	1	1	1	1
125N04647	Speedway Blvd/Exit 49	0.73	0	0	1	1	1	1	1	1	1	1	1
125-04647	Speedway Blvd/Exit 49	1.82	0	0	0	1	1	1	1	1	1	1	0
125N04648	Poplar Tent Rd/Exit 52	0.53	0	0	0	0	0	0	1	1	1	1	0
125-04648	Poplar Tent Rd/Exit 52	1.32	0	0	0	0	0	0	0	0	1	1	0
125N10218	Kannapolis Pkwy/Exit 54	0.70	0	0	0	0	0	0	0	0	0	0	0
125-10218	Kannapolis Pkwy/Exit 54	0.83	0	0	0	0	0	0	0	0	0	0	0

Figure 4-4 Congestion Index Contour

In Step 3, The Average Historic Congestion Index, $AHCI_{d\,or\,w}(i,t)$, is calculated. The AHCI is defined as the fraction of days (can be calculated for weekdays or all days) in the study period T (typically one or two years) for which segment i was congested at time t, based on the specified congestion index ($CI_{d\,or\,w}(i,t,m)$). Figure 4-5 shows a schematic AHCI contour map. It denotes the probability that segment i was congested at time t and is calculated as shown below:

$$AHCI_{d\,ow\,w}(i,t) = \frac{\sum_{m=1}^{M} CI_{d\,or\,w}(i,t,m)}{M} \times 100\% \qquad \textbf{Equation 4-4}$$

Where,

M: the number of days in the study period,

$AHCI_{d\,or\,w}(i,t)$: Average Historic Congestion Index at for segment i at time t (index d for weekdays and index w for weekend days)

FID	TMC	road	direction	county	Link_len	SPDLimit	Order	2:15 PM	2:30 PM	2:45 PM	3:00 PM	3:15 PM	3:30 PM	3:45 PM	4:00 PM	4:15 PM	4:30 PM	4:45 PM	5:00 PM	5:15 PM	5:30 PM	5:45 PM	6:00 PM	6:15 PM	6:30 PM	6:45 PM	7:00 PM	7:15 PM	7:30 PM
401	125+04648	I-85	NORTHBOUND	CABARRU	1.96224	65	131972	1%	1%	3%	0%	2%	3%	4%	4%	4%	4%	5%	3%	5%	5%	4%	4%	4%	2%	3%	2%	2%	2%
6576	125P04647	I-85	NORTHBOUND	CABARRU	0.60643	65	131971	1%	1%	1%	0%	2%	3%	3%	6%	5%	6%	5%	5%	6%	5%	6%	6%	6%	5%	4%	2%	2%	1%
296	125+04647	I-85	NORTHBOUND	CABARRU	1.13514	65	131970	12%	17%	27%	34%	35%	41%	59%	71%	75%	77%	75%	75%	74%	76%	83%	78%	82%	69%	59%	34%	20%	7%
7908	125P04646	I-85	NORTHBOUND	MECKLEN	0.56557	65	131969	14%	24%	36%	38%	44%	56%	78%	88%	89%	93%	94%	95%	94%	95%	95%	96%	95%	91%	79%	43%	21%	9%
9	125+04646	I-85	NORTHBOUND	MECKLEN	0.73833	65	131968	12%	17%	24%	31%	34%	46%	68%	85%	87%	92%	93%	95%	96%	95%	95%	96%	95%	88%	70%	37%	15%	6%
6575	125P04645	I-85	NORTHBOUND	MECKLEN	0.58359	65	131967	10%	11%	15%	22%	28%	36%	53%	73%	83%	89%	91%	95%	96%	96%	95%	96%	92%	82%	62%	31%	12%	5%
8	125+04645	I-85	NORTHBOUND	MECKLEN	0.97976	65	131966	4%	4%	4%	6%	7%	10%	25%	37%	50%	69%	79%	88%	94%	95%	94%	92%	82%	66%	35%	16%	5%	2%
6594	125P04644	I-85	NORTHBOUND	MECKLEN	0.70244	65	131965	1%	0%	0%	0%	1%	1%	3%	5%	9%	16%	29%	48%	66%	80%	73%	65%	46%	25%	13%	3%	0%	0%
295	125+04644	I-85	NORTHBOUND	MECKLEN	0.87926	65	131964	0%	0%	0%	0%	0%	0%	0%	0%	1%	3%	5%	9%	21%	29%	30%	22%	14%	6%	3%	0%	0%	0%
7885	125P09616	I-85	NORTHBOUND	MECKLEN	0.63244	65	131963	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	4%	11%	12%	11%	6%	3%	1%	0%	0%	0%

Figure 4-5 Schematic Average Historic Congestion Index (AHCI) for I-85 Northbound

In Step 4, congestion frequency, CF_i, is calculated. CF_i is defined as the average proportion of time congested in weekdays or weekend days over one year at segment *i*. This research used the following equation to estimate congestion frequency at segment *i*:

$$CF_i = \frac{\sum_{t=1}^{T} AHCI_{d\,or\,w}(i,t)}{T} \qquad \textbf{Equation 4-5}$$

Where,

$AHCI_d\,(i,t)$ and $AHCI_w\,(i,t)$: as defined for Equation 4-4

T: number of 15-minute intervals in analysis day (96 intervals for 24 hour analysis),

CF_i: congestion frequency at segment *i* over one year.

The process flow chart for calculating congestion frequency is provided in Figure 4-6. Congestion frequency at segment *i* is joined onto NAVTEQ TMC links, and then classification by congestion frequency can be applied.

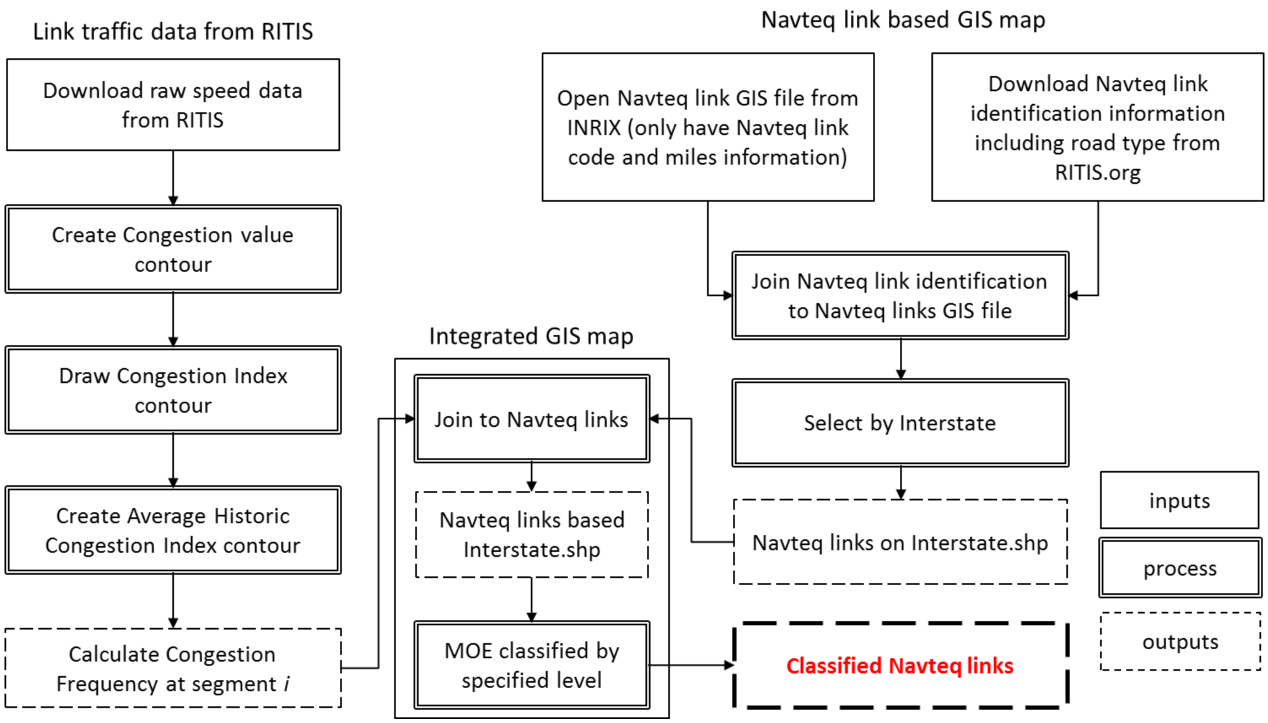


Figure 4-6 The Flow Chart of Congestion Frequency based NAVTEQ TMC link Classification

4.1.3. Bottleneck Identification

Early in the research, the project team recognized the value of categorizing collisions based on whether or not they occurred in a congestion queue that was created by a prior non-recurring incident. The resulting collision classification process is discussed in the following report section. However, as a necessary preliminary step to the collision classification methodology, recurring bottleneck locations that were active during the collision analysis period must be identified. This section provides a brief description of the bottleneck identification procedure that was developed for and implemented in the research.

4.1.3.1. Spatial Patterns of AHCI

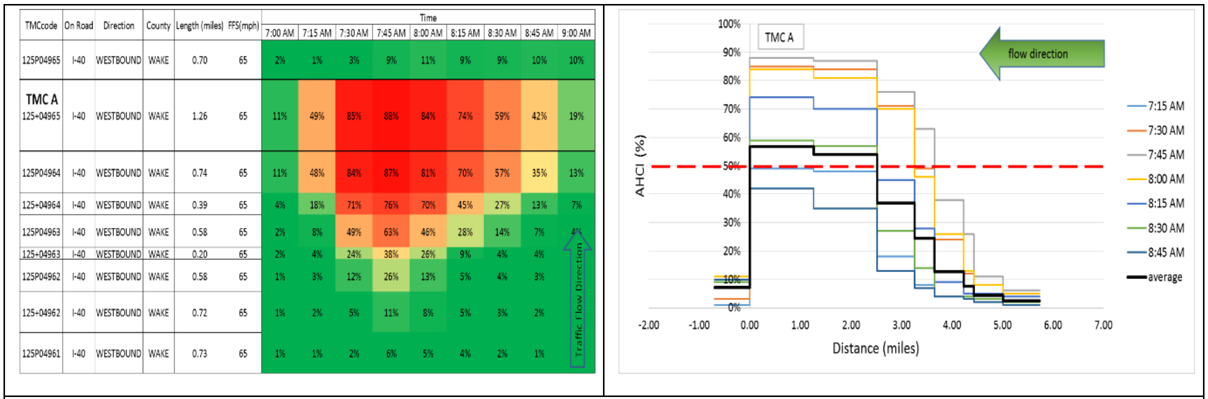
Stated simply, the developed bottleneck identification method identifies recurrent bottlenecks based on the AHCI contour map. Therefore, the first step for identifying recurrent bottlenecks is to ascertain the spatiotemporal characteristics of the AHCI contour map. The question then is which TMCs should be identified as recurrent bottlenecks?

To answer the question, the project team identified three different spatial patterns observed on weekdays in 2014 on all Interstates in North Carolina. Figure 4-7 describes the patterns that are directly applicable to recurrent bottleneck identification.

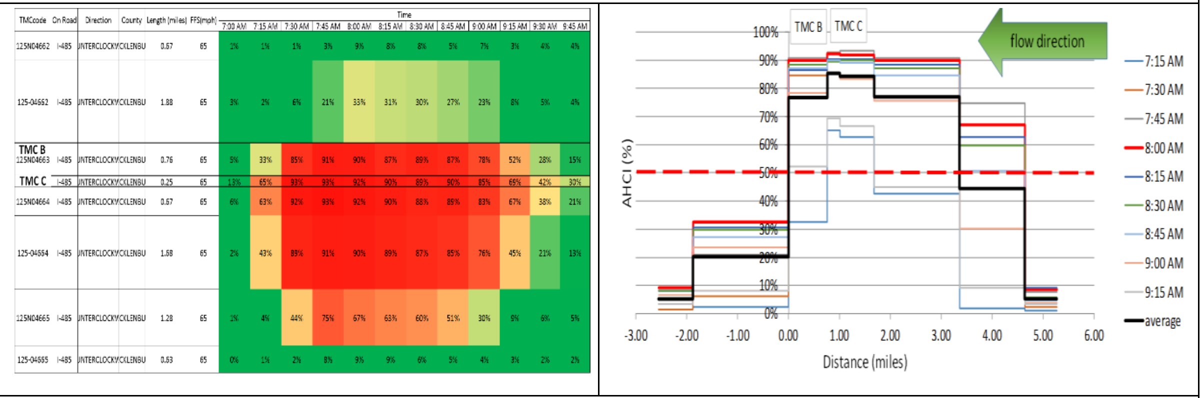
The TMCs identified as a recurrent bottleneck usually have the highest AHCI (TMC A as seen in Site 1 of Figure 4-7 (a)) and are located just upstream of a significant drop in AHCI value. Therefore, these TMCs are clearly defined as recurrent bottleneck segments and are labeled as Spatial Pattern 1 in this study.

Different spatial patterns were associated with other recurrent bottlenecks in the AHCI contour map. Site 2, shown in Figure 4-7 (b), exhibits a pattern of AHCI where the TMC with the highest AHCI value (TMC C) is not located immediately upstream of a significant drop in AHCI. In this case, TMC C and the one downstream of it (TMC B) have AHCI values greater than 90% and TMC B is located upstream of a significant drop in AHCI. Therefore, TMC C is also part of the bottleneck and this pattern is called as Spatial Pattern 2. If the “physical” recurrent bottlenecks are located nearly at the end of TMC B and adjacent downstream of TMC C, the TMC B may report a travel speed based on mixed traffic flow. In this case, the AHCI value at TMC B may be lower than that at TMC C.

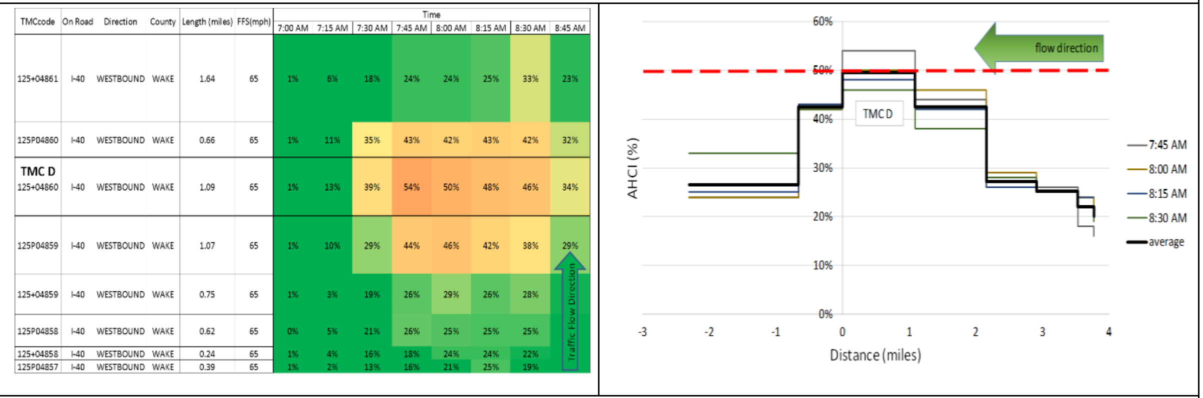
In Figure 4-7 (c), Site 3 describes the final spatial pattern detected in this research. No significant drop in AHCI values is observed for TMC D and the one downstream of it. If TMCs with AHCI greater than β % (e.g. 50% is for Figure 4-7 (c)) are referred as recurrent bottlenecks, only TMC D can be included in a recurrent bottleneck. This conditions labeled Spatial Pattern 3.



(a) Spatial pattern 1 of AHCI (Site 1 - 125+04965 on I-40 Westbound in Wake County, NC)



(b) Spatial pattern 2 of AHCI (Site 2 - 125N04663 on I-485 Counterclockwise in Mecklenburg County, NC)

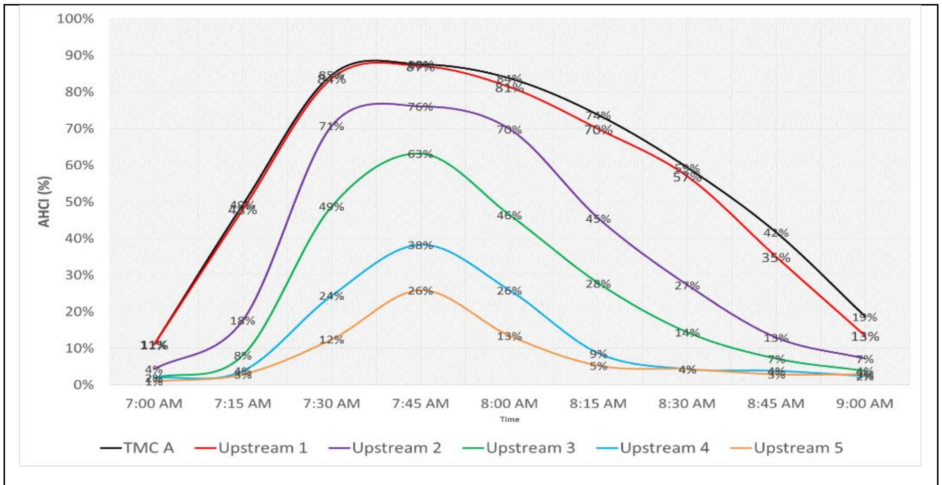


(c) Spatial pattern 3 of AHCI (Site 3 - 125+04860 on I-40 Westbound in Wake County, NC)

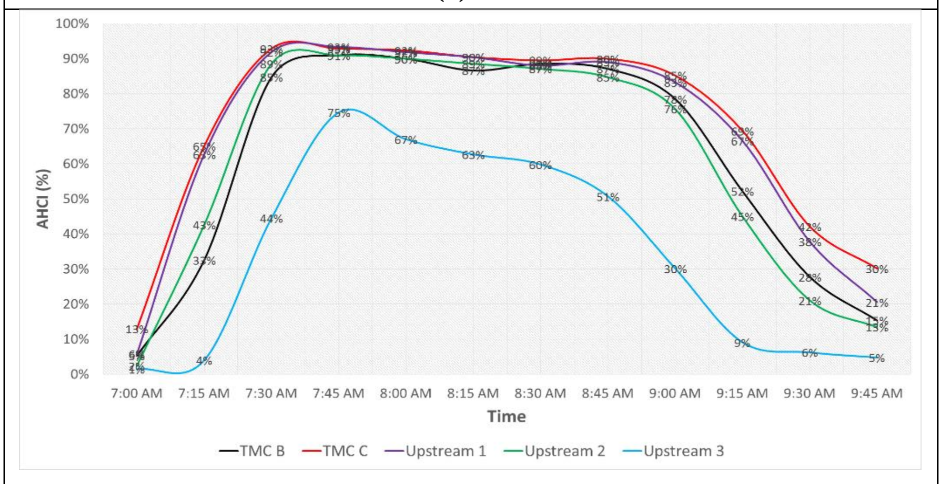
Figure 4-7 Spatial Patterns of AHCI in 2014

4.1.3.2. Temporal Patterns of AHCI

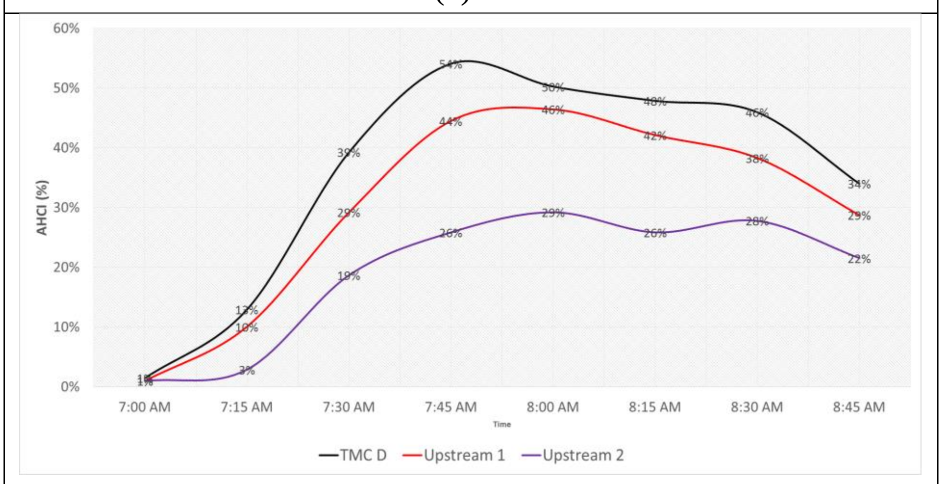
Another objective of this study is to identify the historical time span of bottleneck activation. Figure 4-8 depicts AHCI values over time on TMCs in the recurrent bottleneck impact area corresponding to Figure 4-7. Figure 4-8 (a) shows AHCI values exhibiting a bell shape curve over time. AHCIs' at 7:45 AM were at the highest values during congested conditions, then decreased gradually over time. This trend is labeled Temporal Pattern 1. Figure 4-8 (b) shows a slightly different temporal pattern. Several TMCs had AHCI values greater than 80% for 90 minutes, and then decreased sharply and this pattern is labeled Temporal Pattern 2. In Figure 4-8 (c) AHCI values on TMCs increased and then decreased slowly without any significant drop. However, the AHCI values where TMCs have greater than 50% appear similar to Temporal Pattern 1. It indicates that no difference between (a) and (c) of Figure 4-8 was found. Therefore, two temporal patterns were finally identified for the three bottleneck areas shown Figure 4-8.



(a) Site 1



(b) Site 2



(c) Site 3

Figure 4-8 Temporal Patterns of AHCI across Multiple TMC's

4.1.3.3. Recurrent Bottleneck Identification

This project defines a "recurrent bottleneck" as a location having a *spatiotemporal congestion pattern observed regularly over a specified study period*. The Recurrent Bottleneck Identification (RBI) methodology explained later employs an exhaustive search algorithm to identify where, when, and how often congestion occurs at a bottleneck. Two constraints are imposed on the search. The first step searches recurrent for bottleneck locations on a continuous sequences of TMC's, and the following step processes the data for identified recurrent bottleneck locations to determine the historical time span of bottleneck activations.

4.1.3.3.1. Identification of Recurrent Bottleneck Locations

The Recurrent Bottleneck Location Identification (RBLI) methodology employs an exhaustive search algorithm to identify the recurrent bottleneck locations. A TMC segment must have an AHCI value exceeding β %. Secondly a recurrent bottleneck location can include at most two contiguous TMCs by the spatial pattern 2 of AHCI. Finally, those TMCs satisfied by above two constraints can be included in a recurrent bottleneck area if the AHCI of the first or second TMCs is greater than γ times the AHCI value of its downstream two TMCs. The parameter γ is defined as the threshold of spatial congestion difference in AHCI. The proposed location identification algorithm is represented by the following pseudo code:

For all each spatiotemporal $AHCI_{d\ or\ w}(i,t)$

If $AHCI_{d\,or\,w}(i,t) \geq \beta\%,\ \ 0 \leq \beta < 100,\ \gamma > 1$

$y_1 = AHCI_{d\,or\,w}(i,t) - \gamma \cdot AHCI_{d\,or\,w}(i+1,t)$: spatial pattern 1 and 3

$y_2 = AHCI_{d\,or\,w}(i,t) - \gamma \cdot AHCI_{d\,or\,w}(i+2,t)$: spatial pattern 2

$y_3 = AHCI_{d\,or\,w}(i,t) - AHCI_{d\,or\,w}(i+1,t)$: spatial pattern 2

$if\ \ y_3 \geq 0\ \ \&\&\ \ if\ \ y_1 \geq 0 \,\|\, y_2 \geq 0$

Then TMC (i) possibly as bottleneck

4.1.3.3.2. Identification of Historical Time Span of Recurrent Bottleneck Activations

A simple heuristic approach for the Recurrent Bottleneck Time span Identification (RBTI) is introduced. The time span starts at a TMC with an $AHCI_{d\ or\ w}(i,t)$ exceeding δ % on a recurrent bottleneck. The $AHCI_{d\ or\ w}(i,t)$ is then compared to the $AHCI_{d\ or\ w}(i,t+1)$, $AHCI_{d\ or\ w}(i,t+2)$, $\cdots$, $AHCI_{d\ or\ w}(i,t+n)$ over time. If a TMC with $AHCI_{d\ or\ w}(i,t+n)$ equals to or less than δ % and n is greater than 1, the cell with $AHCI_{d\ or\ w}(i,t+n-1)$ is referred as the last time of the time span of the recurrent bottleneck. Pseudo code representing the proposed algorithm for identifying time span of a recurrent bottleneck is as follows:

For all bottleneck cell (i,t)

  for t=1:P (96=maximum t value)

   if $AHCI_{d\ or\ w}(i,t) > \delta\%$

    Stop if $AHCI_{d\ or\ w}(i,t+n) \leq \delta\%$

     if $n > 1$

Then the TMCs at the cell (i,t), (i,t+*1*)…(i,t+n-1) *are referred as activation time of the recurrent bottleneck*

4.1.4. Secondary Crashes

One of the important goals of traffic incident management, is to reduce secondary crashes that can in turn exacerbate the congestion from precipitating primary events. FSP services can assist this goal by minimizing congestion from precipitating events by expediting incident clearance. Previous research has noted that it is becoming increasingly difficult to ignore reduction in secondary crashes as a criterion for IMAP deployment consideration. In this study, crashes which occur at locations and during times not known for recurring congestion were classified as having occurred in non-recurring congestion and are proposed as a surrogate for secondary crashes. This definition approximates that of the secondary crash definition found in the relevant literature. An advantage of this approach is that it better serves NCDOT's incident management mission by allowing classification of all collisions without the need for identifying a precipitating collision or incident. The definition of crashes occurring in non-recurring congestion also expands upon a secondary crash definition that requires the primary event to be a collision. In the classification developed for this project, the precipitating event may be any congestion-producing incident.

Therefore, this study classified collisions into one of three types based on the traffic congestion conditions at crash time.

- Crash occurred in uncongested NAVTEQ TMC link segment
- Crash occurred in recurrent congestion NAVTEQ TMC link segment
- Crash occurred in non-recurrent congestion NAVTEQ TMC link segment (surrogate for secondary crashes)

The project team proposes that this classification system can be useful to NCDOT for tracking safety over time and for segregating crashes into categories that are helpful in identifying which NCDOT operating units have primary responsibility for addressing potentially correctable situations. For example, crashes that occur on a segment when the segment is not congested are most likely primary collisions and a high concentration of such incidents may indicate a location that should be evaluated by the Traffic Safety Unit. Crashes occurring in recurrent congestion are also considered likely to be primary collisions. However, if there are a relatively high number of such collisions and the congestion is considered to be a significant contribution factor, NCDOT units that program and plan improvement project may need to consider a targeted bottleneck improvement project of a major expansion of capacity. Finally, the crashes that occur in non-recurrent congestion are the classification type that is most likely to be mitigated by improved incident management, including new or upgraded IMAP service, as a means of expediting incident clearance and minimizing the resultant congestion.

A four-step crash classification methodology was developed in this study. The classification process is depicted in Figure 4-9. In Step 1, both mobility and crash data are added to the attributes for the directional NAVTEQ TMC link segments. In Step 2, using this information, crashes are between those having occurred during congested or uncongested conditions. In Step 3, crashes that occurred under congested conditions are classified as to whether or not the time period of the crash is normally congested. In step 4, the crashes are analyzed further for final classification. If the *AHCI* for the time and location of the crash is greater than 60%, the crash is classified as having occurred in recurring congestion. For AHCI values between 20 and 60%, the situation at the crash site is analyzed to determine whether or not the crash occurred in a "historically consistent queue." If so, the crash is classified as having occurred in recurring congestion. If not, the crash is classified as having occurred in non-recurring congestion. In the remainder of this section, details for this proposed methodology for crash classification is described.

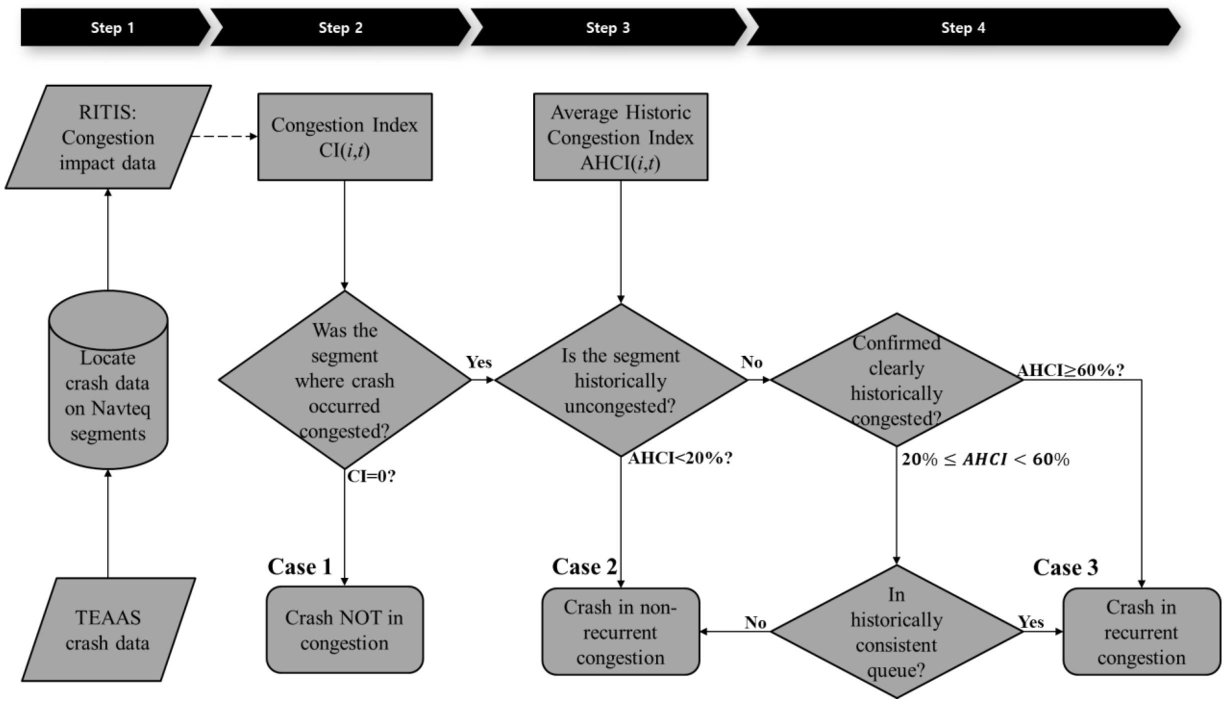


Figure 4-9 The Crash Classification Process

4.1.4.1. Locate crashes on NAVTEQ TMC links

First, the location of the crash has to be ascertained. In this step, NAVTEQ TMC link codes are associated with the crashes using the GADA TEAAS database longitude and latitude information. A link shapefile of NAVTEQ TMC links is then applied to join the two datasets. Thus, each crash becomes associated with specific NAVTEQ TMC link, which is defined as attribute "L_c" in the joined database.

4.1.4.2. Identify crashes based on congestion level

In this step, the congestion condition at the time of each crash is identified based on the Congestion Index, *CI*, as defined above. As shown in Figure 4-9, if the crash occurred on a NAVTEQ TMC link that was uncongested at the time of the crash, then the crash is labeled as "Case 1 – Crash not in congested conditions". Otherwise, it is further assessed in Step 3.

To determine the congestion status of NAVTEQ TMC link segment *i* at time of the crash *t*, two main metrics are employed: $CI_{d\ or\ w}(i,t,m)$ and $AHCI_{d\ or\ w}(i,t)$. As mentioned earlier, if $CI_{d\ or\ w}(i,t,m)=0$, then NAVTEQ TMC link *i* is considered to be uncongested at time *t* and vice versa. The next set of processes involves the historical pattern $AHCI_{d\ or\ w}(i,t)$. Two breakpoints, δ (the lower breakpoint) and γ (the upper breakpoint) are used to evaluate $AHCI_{d\ or\ w}(i,t)$. If $AHCI_{d\ or\ w}(i,t)<\delta$, then NAVTEQ TMC link *i* is considered to be historically uncongested at time *t* otherwise if $AHCI_{d\ or\ w}(i,t)\geq\gamma$ then it is historically congested. When $AHCI_{d\ or\ w}(i,t)$ falls between the two breakpoints, the additional Step 4 analysis briefly mentioned above and described in more detail later in this section is employed. Thus, in Step 2, the test performed is as follows. If $CI_{d\ or\ w}(t,m)=0$, then the crash is labeled as occurring when the segment was operating uncongested. If $CI_{d\ or\ w}(t,m)=1$, then further analysis is required, based on $AHCI_{d\ or\ w}(t)$.

The values for δ and γ were determined through a sensitivity analysis. Figure 4-10 shows the sensitivity for the number of crashes labeled as “Case 2 – Crash in non-recurrent congestion” to the upper and lower bounds on the AHCI criterion. It is clear that if the upper bound is between 50 and 70 and the lower bound is between 10 and 20, the number of Case 2 selections becomes quite stable. However, if the upper bound drops below 50 or the lower bound is increased beyond 30, the number of Case 2 classifications changes significantly. This led the study team to conclude that the upper and lower bounds given in the selection process illustrated in Figure 4-9, namely a lower threshold δ of 20% and an upper threshold γ or 60%, would provide robust classification.

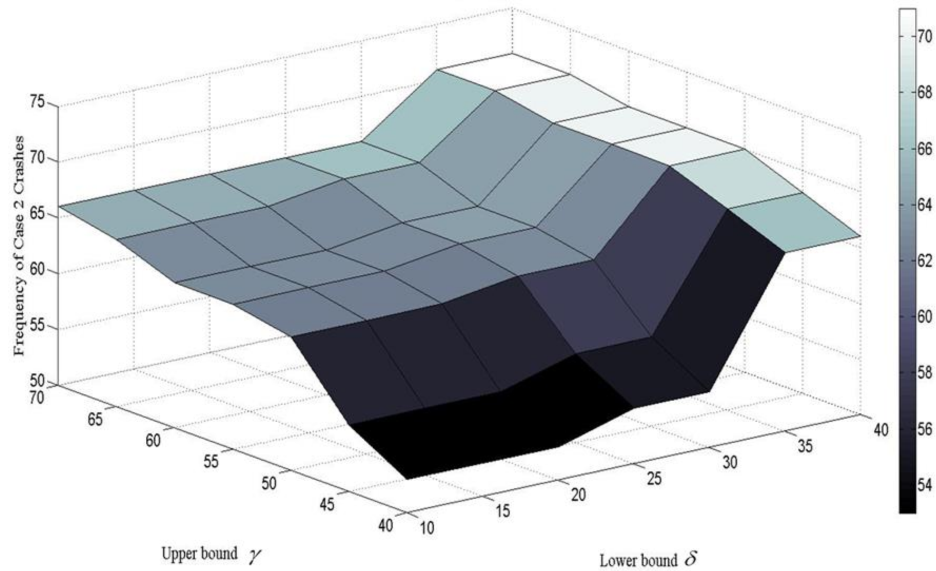


Figure 4-10 Number of Case 2 under Various Upper and Lower Bound of AHCI

Viewed from a perspective of congestion frequency, the proposed values $\delta = 20\%$ and $\gamma = 60\%$ can be interpreted as follows. If the $AHCI_{d\ or\ w}(t) < 20\%$ for the NAVTEQ TMC link *i* at the time of the crash, then historically the link is congested is less than one out or five days at time *t*. If on the other hand, the $AHCI_{d\ or\ w}(t) \geq 60\%$ for the NAVTEQ TMC link *i* at the time of the crash, then historically the link is congested at least every other day at time *t*.

4.1.4.3. Distinguish crashes in non-recurrent congestion

In Step 3, if $AHCI_{d\ or\ w}(t) < \delta$, then the crash is labeled "Case 2 – Crash in non-recurrent congestion." If not, it is passed to Step 4.

4.1.4.4. Classify any remaining crashes on congestion type (recurrent or non-recurrent)

In this step, if $AHCI_{d\ or\ w}(t) \geq \gamma$, then the crash is labeled "Case 3 – Crash in recurrent congestion". If not, which means $20\% \leq AHCI < 60\%$, then a sub-test is performed to ascertain whether there is historically consistent recurrent congestion at the time of the crash. If positive, the crash is labeled as "Case 3". If not, it is labeled "Case 2." In the area of uncertainty, i.e. $20\% \leq AHCI < 60\%$, the historical situation is evaluated to determine whether or not there is a recurrent bottleneck downstream of queue crash location and whether or not the queue from the bottleneck typically spills back into the crash location. As a precursor to this test, the TMC segment or segments associated with recurring bottlenecks must be identified as described in the previous report section. This algorithm for classifying collision that occur in congested segments that have an *AHCI* in the range defined by $20\% \leq AHCI < 60\%$ is shown below:

If L_c is in a recurrent bottleneck segment

Go to Case 3 (Crash in recurrent congestion)

Elseif L_c is not in a recurrent bottleneck segment

$$\begin{aligned} &AHCI_{Lc}(i,t) \leq AHCI_{Lc}(i+1,t) \,\&\& \\ &AHCI_{Lc}(i,t) \leq AHCI_{Lc}(i+2,t) \,\&\& \\ &\vdots \\ &AHCI_{Lc}(i,t) \leq AHCI_{Lc}(i+b,t) \end{aligned}$$

Go to Case 3 (Crash in recurrent congestion)

Else Go to Case 2 (Crash in non-recurrent congestion)

In the algorithm, $AHCI_{Lc}(i,t)$ is the *AHCI* of the TMC segment where the crash occurred, L_c, and $AHCI_{Lc}(i+b,t)$ is the *AHCI* of the nearest downstream TMC segment identified as a recurring bottleneck (the index increment *b* indicates how many TMC segments the bottleneck segment is from the TMC segment where the crash occurred, L_c). Stated simply, if the *AHCI* where the crash occurred is lower than all the downstream segment to and including an identified bottleneck segment, then the crash is considered to have occurred in a recurring bottleneck queue.

Based on the crash classification procedure, each crash is classified into one of three congestion types. The NAVTEQ TMC link codes can be identified easily with those crash data onto a link shapefile of NAVTEQ TMC links. Therefore, the number of secondary crashes can be calculated per NAVTEQ TMC link on Interstate in North Carolina. Based on the number of secondary crashes, this research calculated secondary crashes per 100 million vehicle-miles of travel (100M VMT) across NAVTEQ TMC link segments. The crash rate for secondary crashes on a NAVTEQ TMC link segment is calculated by the equation:

$$CR_{sc} = \frac{C_{sc} \times 100{,}000{,}000}{V \times 365 \times N \times L} \quad \textbf{Equation 4-6}$$

Where,

CR_{sc}: crash rate for secondary crashes by severity of K and A at segment *i* as crashes per 100 million vehicle-miles of travel,

C_{sc}: Total number of crashes including death in the study period,

V: AADT at segment *i*,

N: Number of years of data, and

L: Length of the NAVTEQ TMC link segment *i* in miles.

In addition to secondary crash rate, proportion of secondary crashes is applied as the other criterion and can be calculated by this equation:

$$P_{sc} = \frac{C_{sc}}{C_t}$$ **Equation 4-7**

Where,

P_{sc}: proportion of secondary crashes at segment *i*,

C_t: Total number of crashes at segment *i*.

With two MOEs, this study used the detailed process as shown in Figure 4-11.

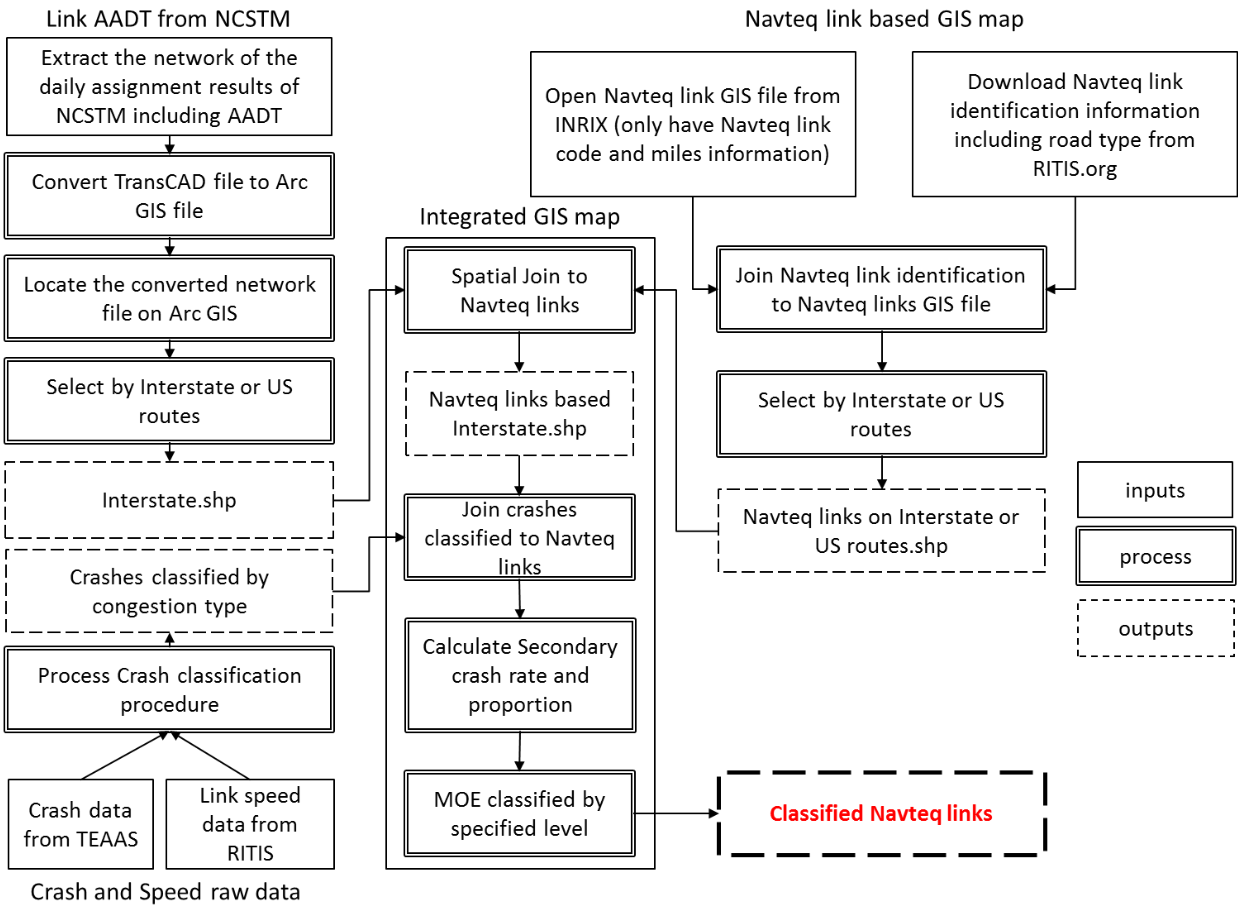


Figure 4-11 Flow Chart of Secondary Crash-Based NAVTEQ TMC Link Classification

4.1.5. Crash Severity

The crash data reported in TEAAS GIS database provided by GADA includes crash severity information. Crash severity is classified into five types:

- K (fatal): deaths occur within twelve months of the crash,
- A (disabling): injuries serious enough to prevent normal activity for at least one day such as massive loss of blood, broken bones, and so forth,
- B (evident): non-K or A injuries that are evident at the scene such as bruises, swelling, limping, and so forth,
- C (possible): no visible injury but there are complaints of pain or momentary unconsciousness, and
- O (none): no injury.

The NAVTEQ TMC link codes can be easily analyzed and screened based on the link shapefile severity information. For screening purposed, the project team focused on crashes with a K or A severity level and calculated a K and A crash rate per 100 million vehicle-miles of travel (100MVMT) across all NAVTEQ TMC link segments. The K and A crash rate for crashes on a NAVTEQ TMC link segment is calculated by the equation:

$$CR = \frac{\left(C_K + C_A\right) \times 100,000,000}{V \times 365 \times N \times L} \qquad \textbf{Equation 4-8}$$

Where,

CR: K and A crash rate for crashes by severity of K and A on a NAVTEQ TMC link segment as crashes per 100 million vehicle-miles of travel,

C_K: Total number of crashes including death in the study period,

C_A: Total number of crashes including disabling injury in the study period,

V: AADT at segment *i*,

N: Number of years of data, and

L: Length of the NAVTEQ TMC link segment *i* in miles.

The detailed flow chart of crash severity based NAVTEQ TMC link classification is shown in Figure 4-12.

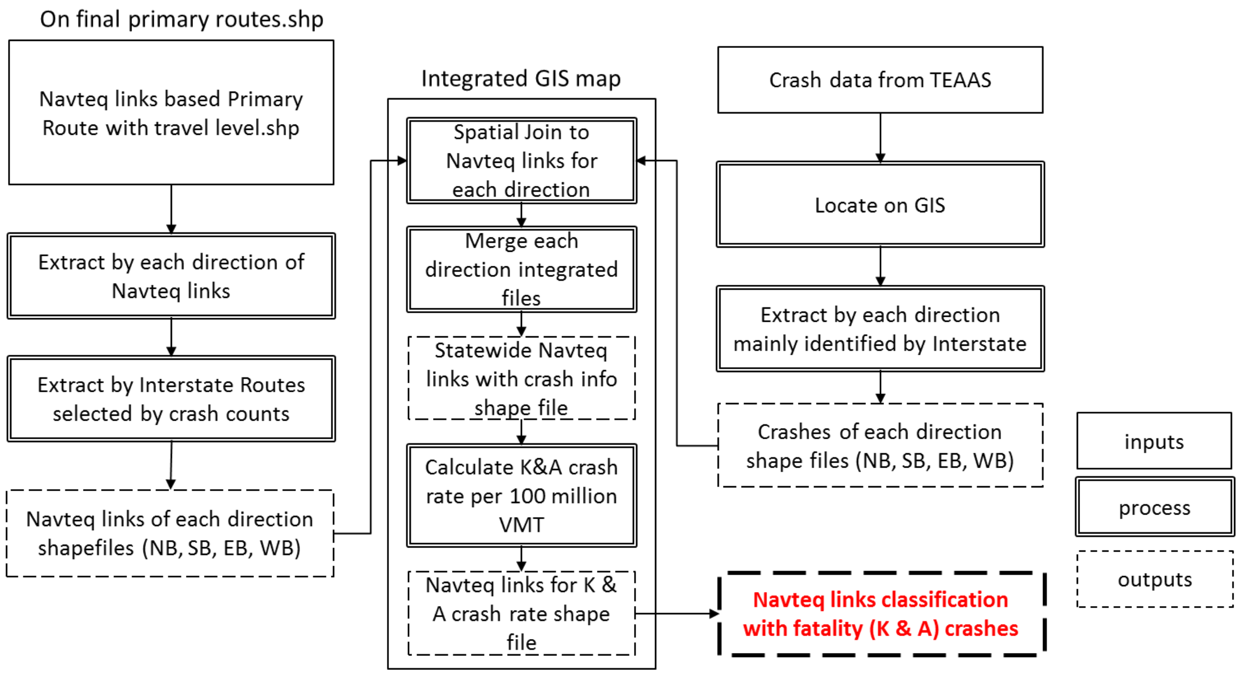


Figure 4-12 The Flow Chart of Crash Severity based NAVTEQ TMC link Classification

4.2. Visualization NAVTEQ TMC link Classification for IMAP Route Consideration

Based on the four-criteria for IMAP route consideration, this research presented a statewide map visualization of NAVTEQ TMC link classification results for IMAP route consideration because it allows spatial representation and analysis of data. This visualization capability is enabled by the enhanced GADA GIS databases and allows the criteria visually apprehended thereby provided a simple means for identifying locations with a potential for high-impact IMAP deployment.

4.2.1. Inputs for NAVTEQ TMC link Classification

As for four criteria representing travel level, congestion, and safety (secondary crash and severity), the link classification requires a rational process for cutting thresholds off for each level of each criterion. In the remainder of determination of cut-off thresholds, inputs for the link classification are then employed for the visualization.

Travel level, which is volume per lane for this research, is categorized into three levels: less than 1200, 1200 up to 1800, and greater than 1800. Those boundaries were determined by the research team's engineering judgement based on the US Highway Capacity Manual.

Congestion frequency is calculated for weekday and weekend separately since it may appear differently with the nature of commuting. To decide boundaries of level, we observed visually statewide congestion frequency to adjust the threshold for cut-off levels. As a result, congestion occurs at most 1 hour a week on most NAVTEQ TMC links on Interstate road in NC. On the other hand, a few NAVTEQ TMC links around Charlotte and Raleigh Metropolitan areas, with congestion frequency of greater than 2 hours in a day which indicates that congestion occurs on somedays greater than 2 hours but somedays are under un-congested state condition, were identified. Based on the visual analysis, eventually congestion frequency was classified into five levels: never congested, between 0 and 1 hour a week (or weekend), between 1 hour a week and 1 hour a weekday (or weekend day), between 1 hour a weekday (or weekend day) and 2 hours a weekday (or weekend day), and greater than 2 hours in a weekday (or weekend day).

The criterion for secondary crash has two MOEs (measurement of effectiveness): secondary crash rate per 100 M VMT and proportion number of secondary crashes. In order to get cut-off thresholds to be determined for those criteria, a statistical test was examined to estimate interquartile values of from Q1 (25%) to Q3 (75%) even for 90%. As seen in Figure 4-13, the distribution of secondary crash rate per 100 M VMT follows Pearson 6 (4P) and Wakeby distribution. Q1, Q2 (median), Q3 (75%), and 90% values were 16.2, 31.4, 58.6, and 106, respectively. Based on those values from the distribution, cut-off thresholds of level by secondary crash rates were determined.

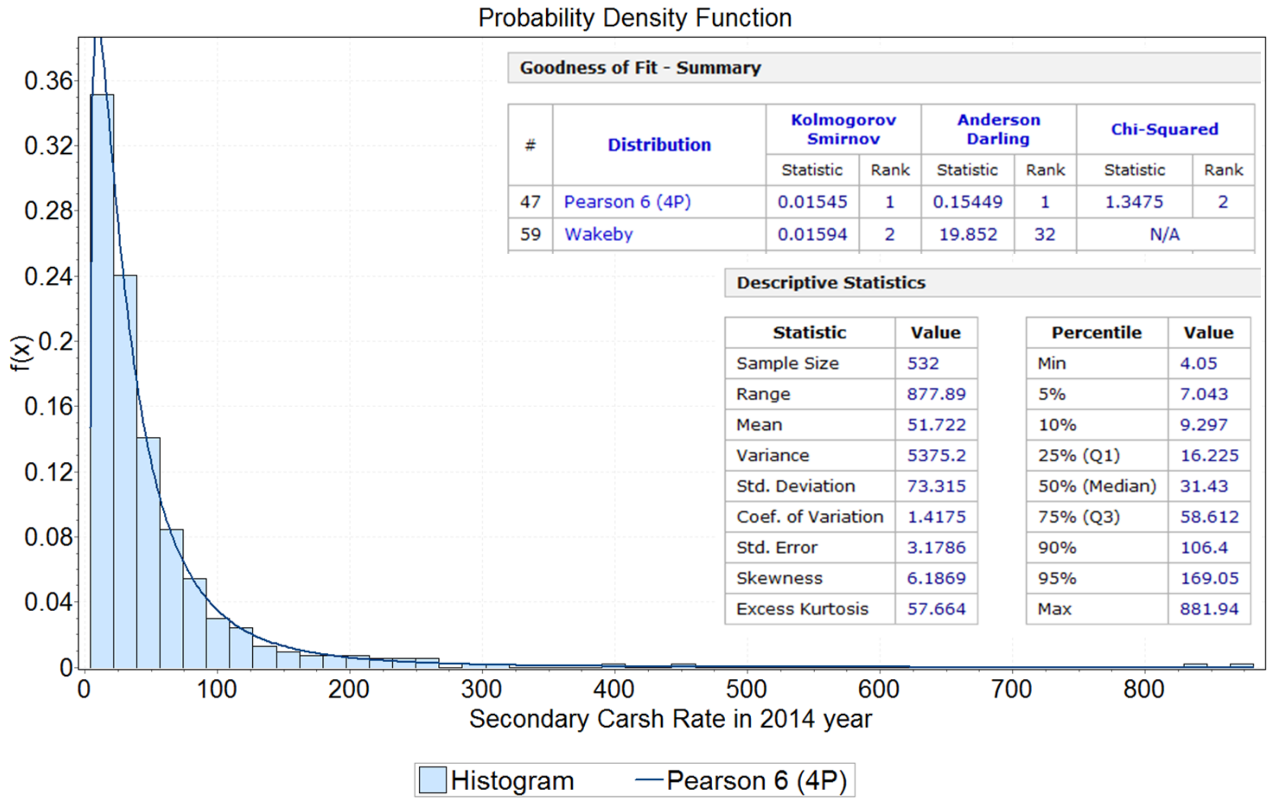


Figure 4-13 Probability Density Function of Secondary Crash Rate per 100 M VMT

To better understand and generate more meaningful levels by cut-off threshold, those values were translated based on average normal crash rate (used 209.49 of statewide crash rate in 2013 in NC). In other words, the translated value for Q1 (16.2 crash rate per 100 M VMT) was around 10% of average normal crash rate (100M VMT), which is the value of 16 of 209.49. Eventually, the five levels were divided by those thresholds: no secondary crashes, less than 15% of the average normal crash rate, 15% up to 30% of the average normal crash rate, 30% up to 60% of the average normal crash rate, and greater than 60% of the average normal crash rate.

Figure 4-14 describes the probability density function (PDF) of proportion of secondary crashes. The distribution of the proportion of secondary crashes also follows Pearson 6 (4p) distribution as well as Lognormal and Burr (4P). Q1 (25%), Median (50%), Q3 (75%), and 90% values were obtained from Pearson 6 (4P) distribution. Each threshold for proportion of secondary crashes was determined by values of Q1, Q3, and 90%. Finally, the five levels were classified by the following thresholds: 0%, less than 15%, 15% up to 30%, 30% up to 50%, and greater than 50% of total number of crashes at segment *i*.

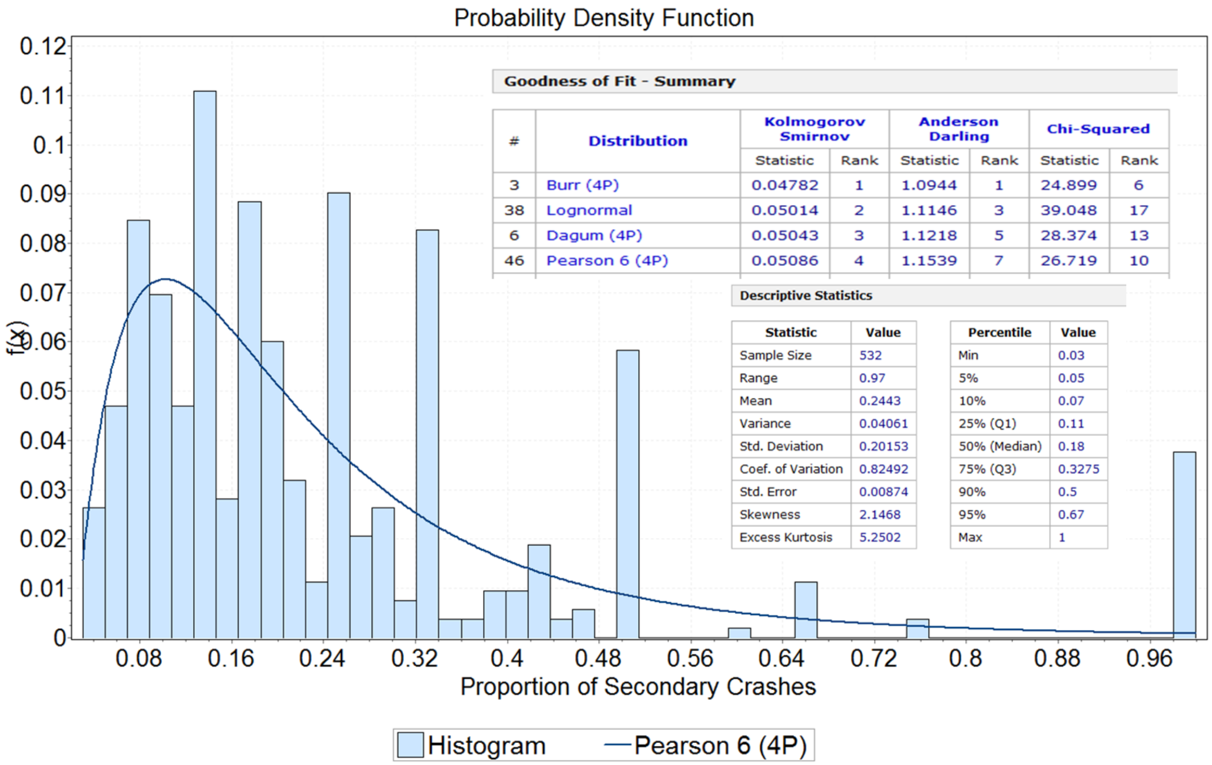


Figure 4-14 Probability Density Function of Probability of Secondary Crashes

K and A crash rate at segment *i* was calculated with 2010-2013 Interstate crash data. The approach applied for the criteria of secondary crash was applied for this crash severity criterion as well. Figure 4-15 depicts the PDF of 2010-2013 K and A crash rate per 100 M VMT. In this criterion, Q1 to Q3 values were applied for cut-off thresholds. The average K and A crash rate across NAVTEQ TMC links on Interstate in NC through 2010 and 2013 was 1.71 per 100 M VMT. Based on the average K and A crash rate, five levels were determined by values of percentile which were translated as follows: no K and A crashes, less than 1 times average crash rate, 1 up to 2 times average crash rate, 2 times up to 4 times average crash rate, and greater than 4 times average crash rate which means greater than 3rd quartile value (Q3).

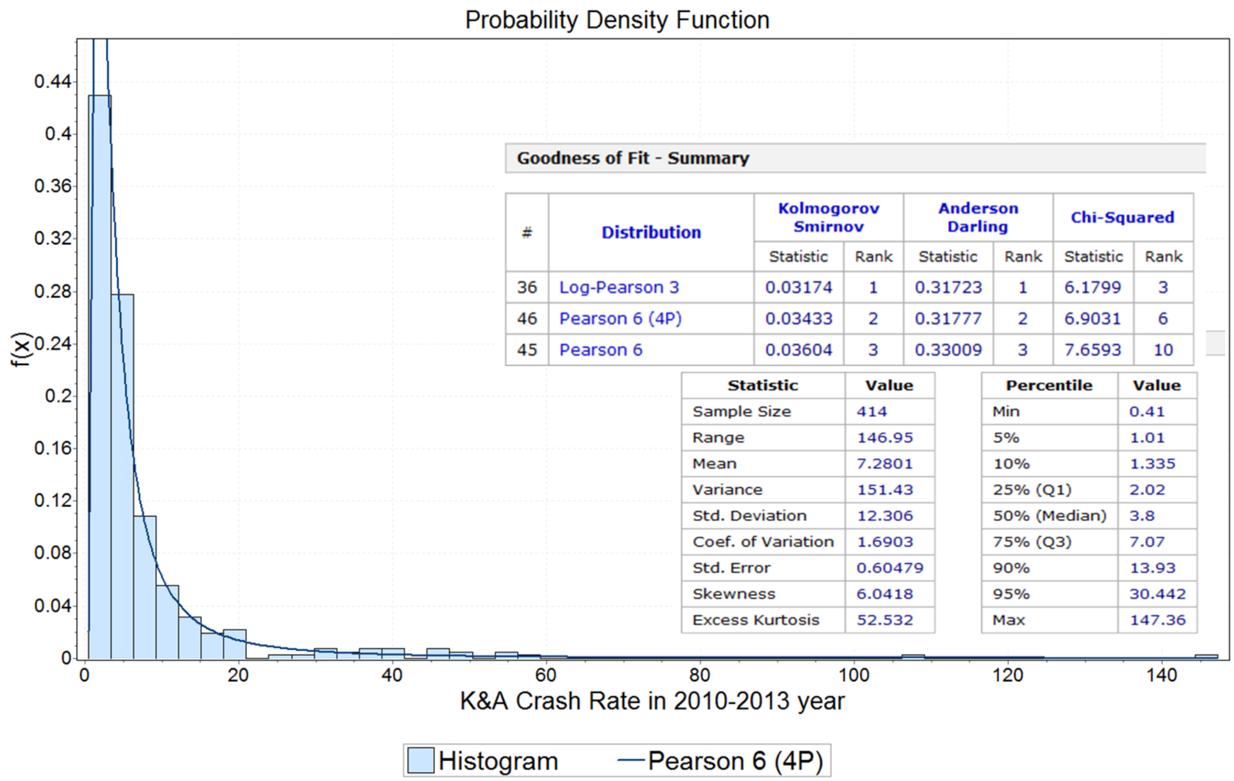


Figure 4-15 2010-2013 Probability Density Function of K and A Crash Rate per 100 M VMT

Table 4-1 presents the final inputs for statewide GIS-based link classification visualization for IMAP route consideration.

Table 4-1 Inputs for IMAP Route Consideration

Criteria	Detailed criteria	Year	Road	Number of links	Level
Travel level	Volume per lane	2010	Primary (Inter and US)	8037	➢ Less than 1200 ➢ 1200 up to 1800 ➢ Greater than 1800
Congestion frequency	Average congestion a weekday (or weekend) over 1 year at segment *i*	2014	Interstate	2147	➢ Never congested ➢ Between 0 and 1 hour a week (weekend) ➢ Between 1 hour a week and 1 hour a work weekday (weekend) ➢ Between 1 hour a work weekday (weekend day) and 2 hours a work weekday (weekend day) ➢ Greater than 2 hours a work weekday (weekend day)
Secondary crashes	Secondary crashes rate per 100 M VMT	2012	Interstate	2077	➢ No secondary crashes ➢ Less than 15% of average crash rate ➢ 15% up to 30% of average crash rate

					➢ 30% up to 60% of average crash rate ➢ Greater than 60% of average crash rate
	Number of secondary crashes / number of total crashes	2012	Interstate	2077	➢ No secondary crashes ➢ Less than 0.11 ➢ 0.11 up to 0.18 ➢ 0.18 up to 0.33 ➢ 0.33 up to 1.00
Crash severity	K and A crash rate per 100 M VMT	2010-2013	Interstate	2077	➢ No crashes ➢ Less than 1 times average crash rate ➢ 1 up to 2 times average crash rate ➢ 2 up to 4 times average crash rate ➢ Greater than 4 times average crash rate

4.2.2. NAVTEQ TMC link classification results for IMAP route selection

The GIS-based identification of candidate NAVTEQ TMC link segments was processed to classify high-impact links on travel level, congestion, and safety. The GIS map visualization result for each criterion was described in the following chapter.

4.2.2.1. Travel Level

The previous IMAP study in fact involved this index as one of criteria for prioritizing IMAP route alternatives. Also, current IMAP trucks may be deployed and operated on heavy traffic volume area. Therefore, a research hypothesis is that the IMAP trucks are now being deployed and operated on the links identified as heavy traffic volume areas. To verify this hypothesis, this research located and integrated 2013 IMAP locations obtained from NCDOT based on NAVTEQ TMC link into the GIS database in order to compare the relationship between current heavy traffic area during peak time and IMAP operation locations.

Figure 4-16 shows the classified NAVTEQ TMC links by three different travel levels. Table 4-2 and Table 4-3 present number of NAVTEQ TMC links by volume per lane of greater than 1800 and greater than 1200 for each division, respectively. These results indicate that most IMAP trucks are currently deployed on the heaviest traffic volume (greater than 1800) areas on the primary routes. In the case of level 2 (volume per lane of greater than 1200), there are several NAVTEQ TMC links where IMAP have not deployed yet. These links can be considered as potential IMAP route alternatives in terms of urban area as depicted in Figure 4-17.

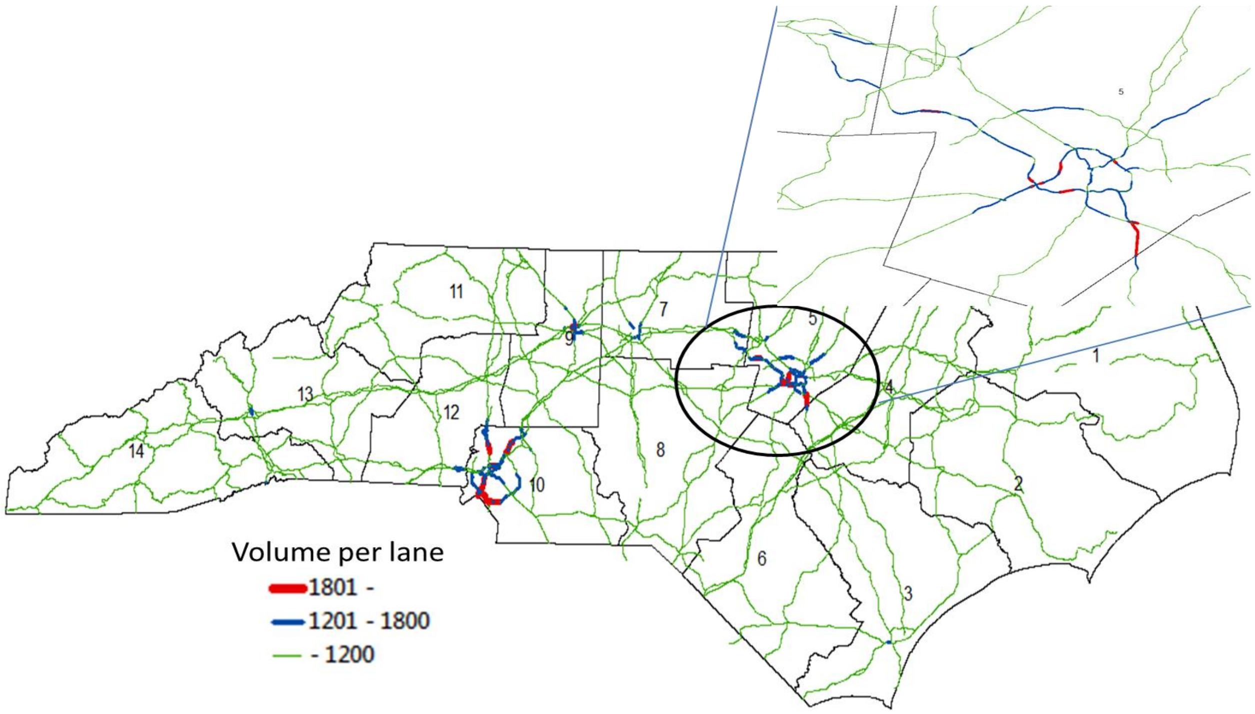


Figure 4-16 NAVTEQ TMC link Classification Result – Travel Level

Table 4-2 Number of NAVTEQ TMC links by Volume per Lane Greater than 1800 for Each Division

Division	Interstate	Primary Routes	IMAP Routes		Division	Interstate	Primary Routes	IMAP Routes
1	0	0	0		8	0	0	0
2	0	0	0		9	1	6	5
3	0	0	0		10	40	46	42
4	2	2	2		11	0	0	0
5	14	16	15		12	0	0	0
6	0	0	0		13	0	0	0
7	0	0	0		14	0	0	0
Total NAVTEQ TMC links						57	70	64

Table 4-3 Number of NAVTEQ TMC links by Volume per Lane Greater Than 1200 for Each Division

Division	Interstate	Primary Routes	IMAP Routes		Division	Interstate	Primary Routes	IMAP Routes
1	0	0	0		8	0	0	0
2	0	0	0		9	32	114	109
3	0	2	2		10	179	256	185
4	6	6	6		11	0	0	0
5	137	234	153		12	4	8	4
6	0	0	0		13	7	17	10

7	8	52	32		14	0	2	2
Total NAVTEQ TMC links						373	691	501

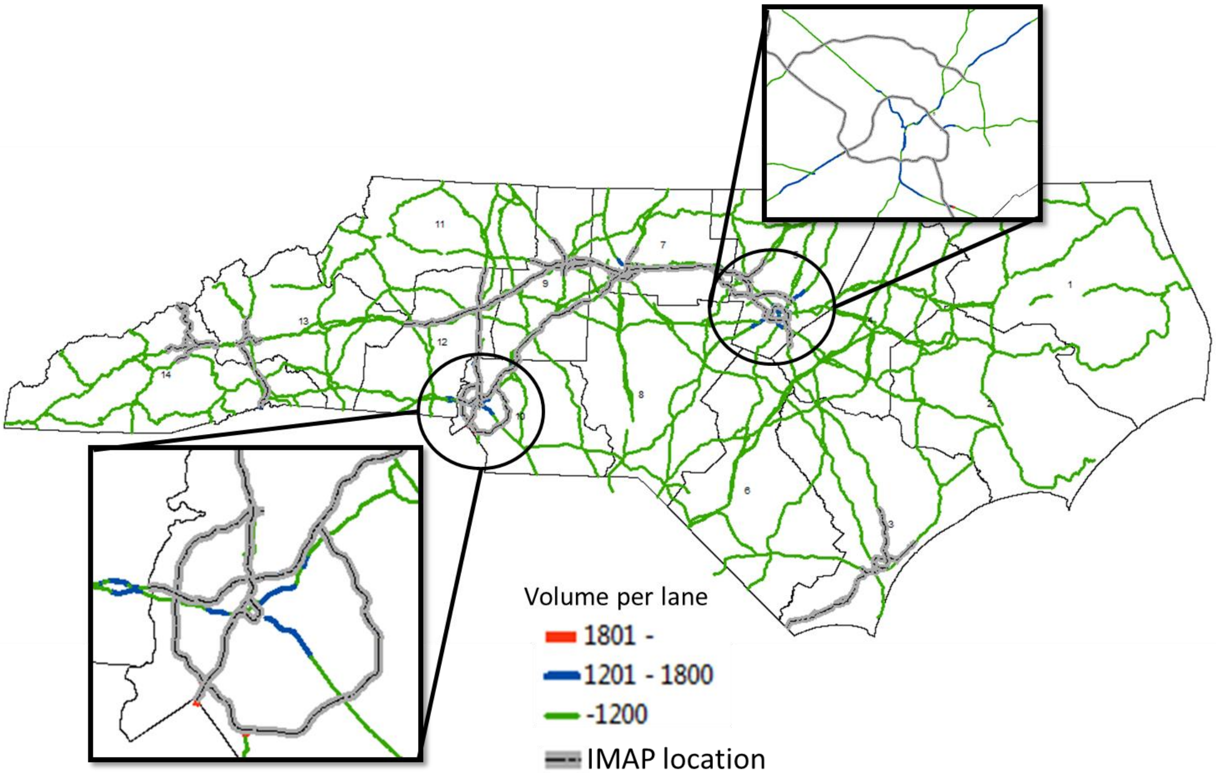


Figure 4-17 NAVTEQ TMC link Classification Result without IMAP – Travel Level

4.2.2.2. Congestion frequency

Visualization for congestion frequency was conducted for weekday and weekend separately due to the fact that congestion occurs with different patterns in terms of day of week on the nature of commuting in the state. Figure 4-18 depicts link the classification result for congestion frequency on weekday in 2014. The visualization was excluded for primary routes because most primary routes have no congestion frequency as well as the lowest level (less than 1200 volume per lane) of travel level. Most NAVTEQ TMC links, where congestion frequency is greater than 2 hours a work weekday, were identified in Charlotte and Raleigh-Durham metropolitan areas. In other words, those links identified were the links with heavy travel level greater than 1200 volume per lane. However, additional notable results were also identified compared to visualization for the travel level analysis. First, some links where "no congestion" occurs were identified. Second, several links, which are not located on IMAP locations (see Figure 4-19) were highlighted as links with significant noticeable congestion frequency levels (greater than between 1 hour in a week and 1 hour in a work weekday) on I-95 in division 4.

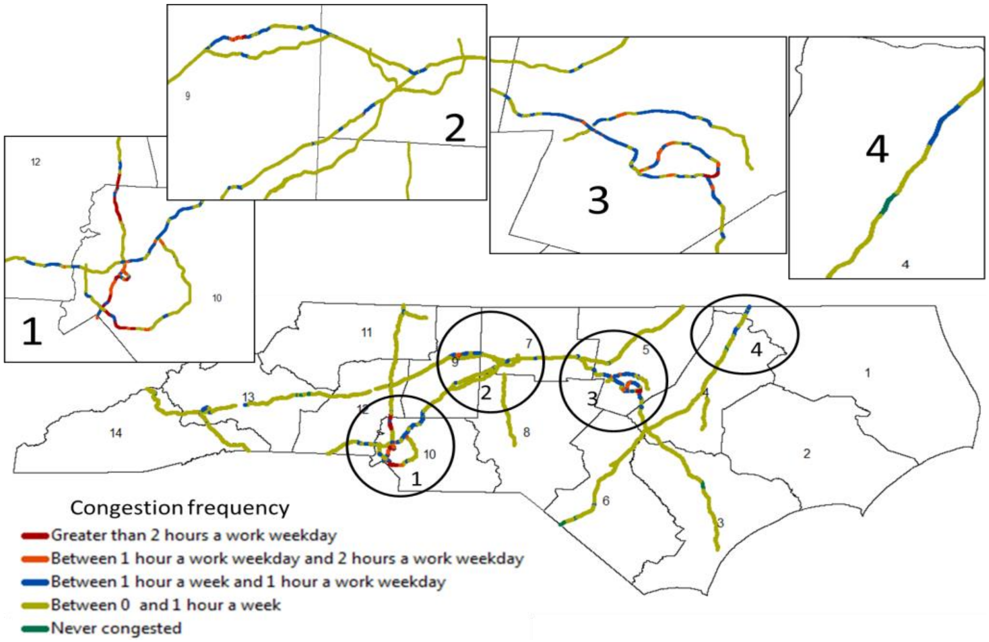


Figure 4-18 NAVTEQ TMC link Classification Result – Congestion Frequency on Weekday

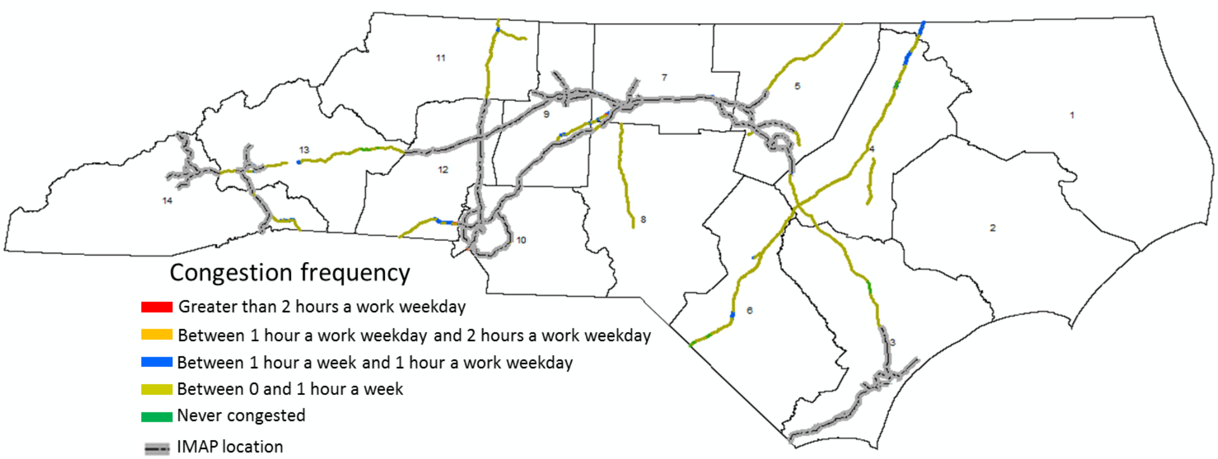


Figure 4-19 NAVTEQ TMC link Classification Result – Congestion Frequency on Weekday without IMAP

Figure 4-20 shows the link classification result for congestion frequency on weekend. This map visualization denoted different congestion pattern significantly with the weekday analysis. Especially, more "never congested" links were identified than the congestion frequency map on weekday throughout Interstate roads. The most notable result on the weekend analysis were the links identified of where congestion frequency is between 1 hour in a weekend and 1 hour in a weekend day on I-85 in division 5.

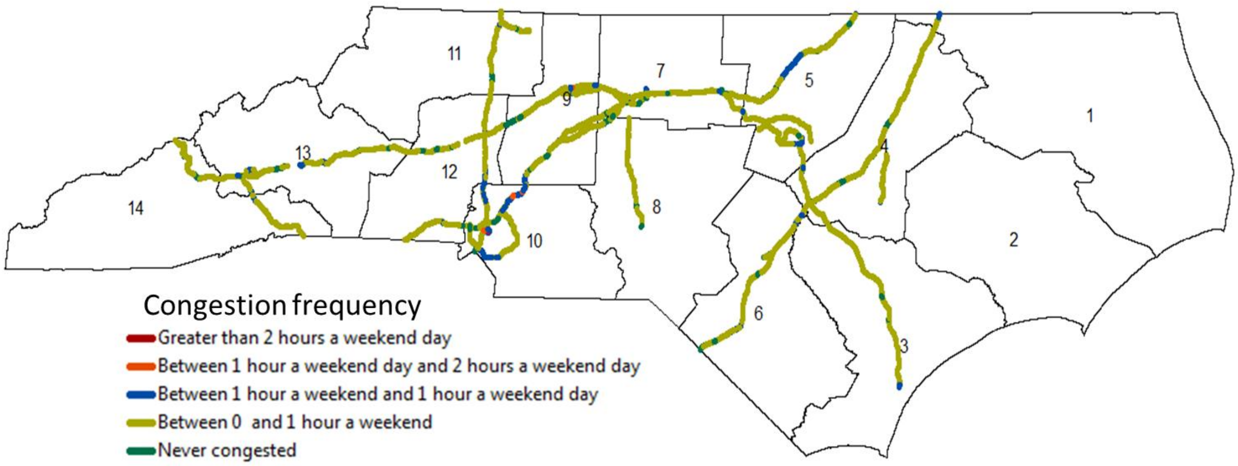


Figure 4-20 NAVTEQ TMC link Classification Result – Congestion Frequency on Weekend

4.2.2.3. Secondary crash

In the literature, most previous FSP studies were corroborative of which FSP service plays a role in reduction in number of secondary crashes. As such, the research team also assumed that IMAP service contributes to reduction in number of secondary crashes. Figure 4-21 describes link classification result for secondary crash rate per 100M VMT. It indicates that considerable links with higher secondary crash rate lie in on Charlotte and Raleigh Metropolitan areas as well. Especially, several links with higher secondary crash rate on I-95 across North Carolina and on I-85 in division 5 were identified in rural area. However, 2013 IMAP services have not covered on those links in the rural area as shown in Figure 4-22.

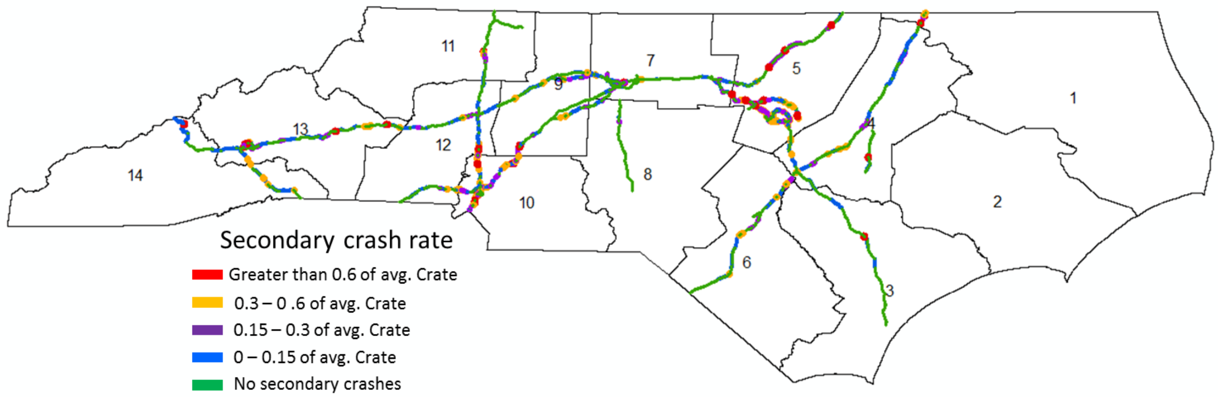


Figure 4-21 NAVTEQ TMC link Classification Result – Secondary Crash Rate

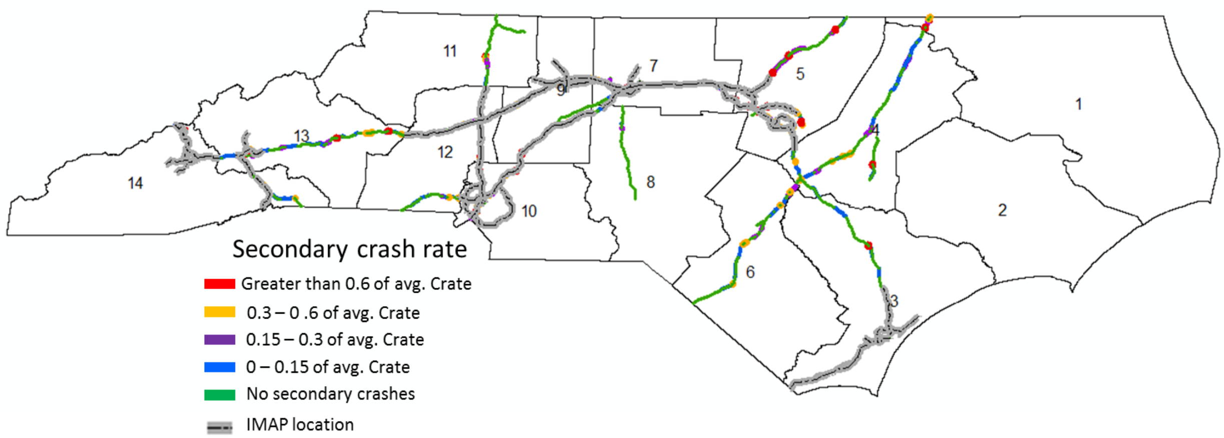


Figure 4-22 NAVTEQ TMC link Classification Result – Secondary Crash Rate without IMAP

Given that secondary crash rate connotes where the most exposure links of secondary crashes lie in, proportion of secondary crashes is the indicator to acquire hot-spots where are higher likelihood of secondary crashes relatively than other crashes. Figure 4-23 presents links classification result for proportion of secondary crashes. This statewide map depicted similar visualization result with the secondary crash rate map. Figure 4-24 depicts link classification result for proportion of secondary crashes without IMAP.

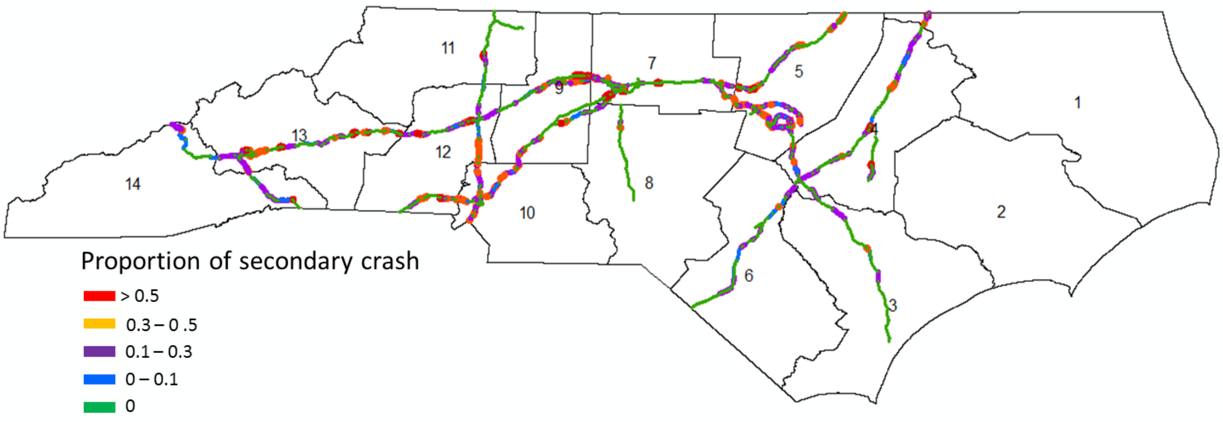


Figure 4-23 NAVTEQ TMC link Classification Result – Proportion of Secondary Crash

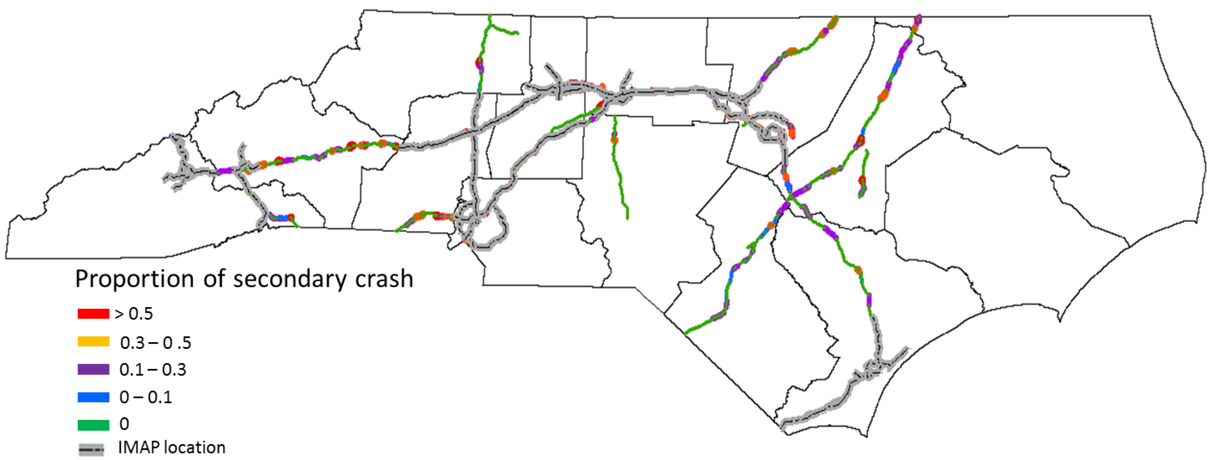


Figure 4-24 NAVTEQ TMC link Classification Result – Proportion of Secondary Crash without IMAP

Both indices for secondary crashes may have limitation on link-based visualization. That is, secondary crash rate may be overestimated in the case crashes occurred along with a very short link (i.e. 0.1 mile). Whereas, proportion of secondary crashes may be overestimated in the case few total crashes occurred along with a link. For instance, a secondary crash and two total crashes occurred on a link, the proportion of secondary crashes to the total crashes is 0.5.

In order to get better index to be applied to the IMAP route consideration, the research team used a combination index of secondary crash rate and proportion of secondary crashes. This index was generated using each median value as the cut-off threshold and was classified into four levels: above median values both, below median secondary crash rate but above median proportion of secondary crashes, above median secondary crash rate but below median proportion of secondary crashes, and below median values both. Figure 4-25 depicts the Naveteq link classification result for combination index of secondary crash rate and proportion of secondary crashes. This visualization was consistent with the visualization result for both indices for secondary crashes, but it provided more precise result in that most links were identified red (above median values above) or green (below median values both) level. Figure 4-26 shows the classification result of the combination index without IMAP.

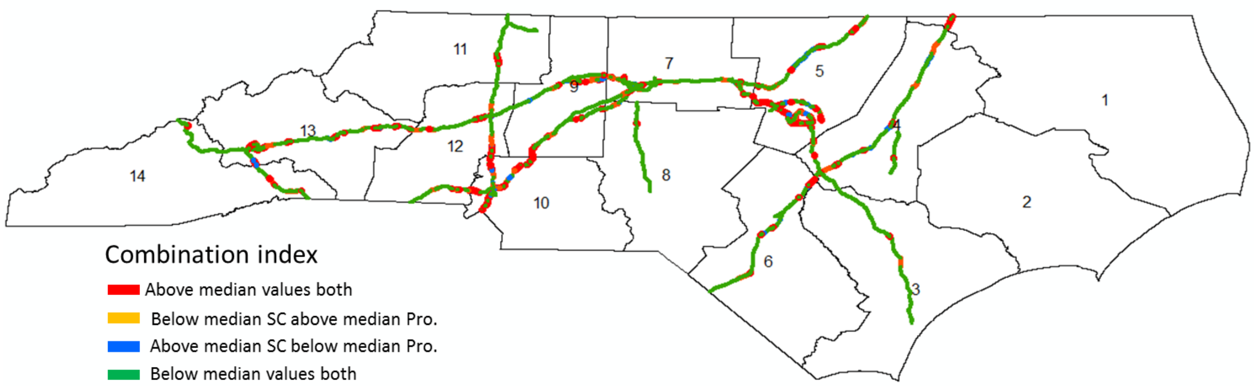


Figure 4-25 NAVTEQ TMC link Classification Result – Combination Index of Secondary Crash Rate and Proportion of Secondary Crashes

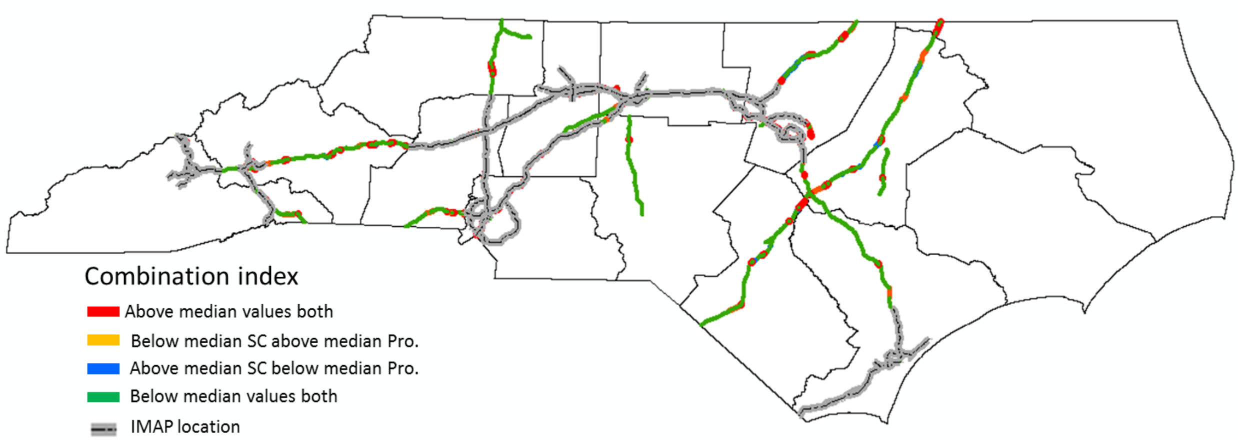


Figure 4-26 NAVTEQ TMC link Classification Result – Combination Index of Secondary Crash Rate and Proportion of Secondary Crash without IMAP

4.2.2.4. Crash severity

Crash severity was considered as a criterion for IMAP route consideration in rural area. Figure 4-27 depicts the link classification result by crash severity. Unlike other criteria, a lot of links with higher crash severity were located in rural area than in urban area. The most interesting finding was that considerable links on I-95 across NC involved K and A crash rate greater than 1 – 2 times average crash rate, especially in north area in division 4 and throughout division 6. Also, some links in central area of I-85 in division 5 and on I-77 in division 11 and 12 were identified as the links higher K and A crash rate relatively than other locations. Figure 4-28 presents the link classification result by crash rate without IMAP service. This map visualization conveyed vital information where should be served by IMAP operation to response rapidly for an event including K and A crashes.

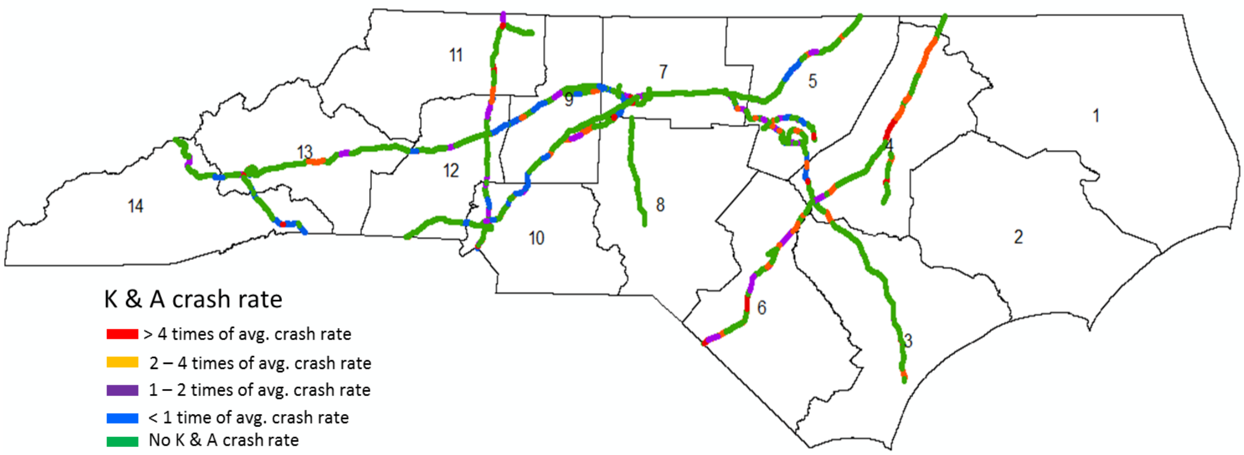


Figure 4-27 NAVTEQ TMC link Classification Result – Crash Severity

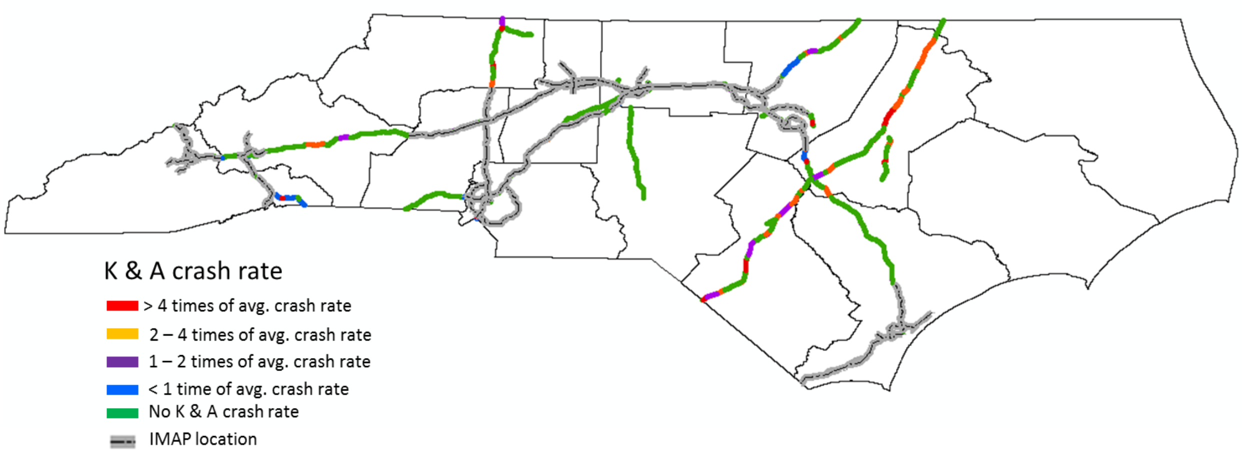


Figure 4-28 NAVTEQ TMC link Classification Result – Crash Severity without IMAP

4.2.2.5. Comprehensive screening score

The GIS map visualization results enable users to quickly ascertain where the high-impacted locations lie in by each criterion. However, in order to prioritize potential IMAP routes consideration and current IMAP locations, there is a need to develop a comprehensive screening index reflecting all of the four criteria. As a means of illustrating the potential of a composite screening score, the project team developed a simple score method that is based on translating each criterion's raw score into a categorical score that ranges from 0 to 4 as illustrated in Table 4-4. The weighting factors that follow and the results that are presented in Appendix D are provide as illustrative examples only. NCDOT mobility managers will need to develop weighting schemes that represent current operational priorities, and these weightings are likely to evolve over time.

Table 4-4 Score for each level of each criterion

Criteria	Level	Score
Travel level	➢ Less than 1200 ➢ 1200 up to 1800 ➢ Greater than 1800	➢ 0 ➢ 2 ➢ 4
Congestion frequency	➢ Never congested ➢ Between 0 and 1 hour a week ➢ Between 1 hour a week and 1 hour a work weekday ➢ Between 1 hour a work weekday and 2 hours a work weekday ➢ Greater than 2 hours a work weekday	➢ 0 ➢ 1 ➢ 2 ➢ 3 ➢ 4
Secondary crashes	➢ Above median values both ➢ Below median SCRate and above median proportion of SC and vice versa ➢ Below median values both	➢ 0 ➢ 2 ➢ 4
Crash severity	➢ No crashes ➢ Less than 1 times average crash rate ➢ 1 up to 2 times average crash rate ➢ 2 up to 4 times average crash rate ➢ Greater than 4 times average crash rate	➢ 0 ➢ 1 ➢ 2 ➢ 3 ➢ 4

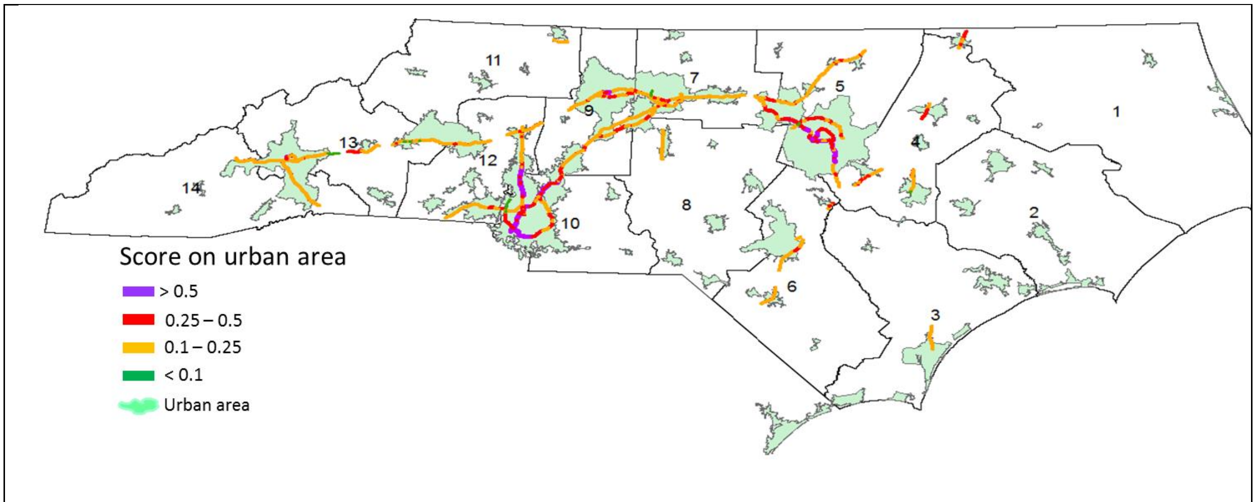
Five levels of congestion frequency and crash severity can be directly scored from 0 to 4. With respect to criteria for travel level and secondary crashes, each level scored 0, 2, and 4 since they both consist of three levels.

As demonstrated above, most high-impacted segments for travel level and congestion frequency both were located on urban area. On the other hand, high-impacted segments for crash severity were mainly located on rural area. The visualization result vis-à-vis secondary crashes covered the whole interstates in NC. These results call for evaluating urban and rural areas separately. Accordingly, this project developed weighting schemes for that are appropriate for the specific urban and rural contexts. On urban area, the scores of travel level and congestion frequency of a segment multiply by two and others continue to use original values. On rural area, the score only for crash severity of a segment multiplies by two and others continue to use original values. The comprehensive screening index is then calculated by summing all weighted values on each segment by types of area, respectively. Finally, the comprehensive screening index of a segment is normalized to compare easily to that of other segments and is equated as follows:

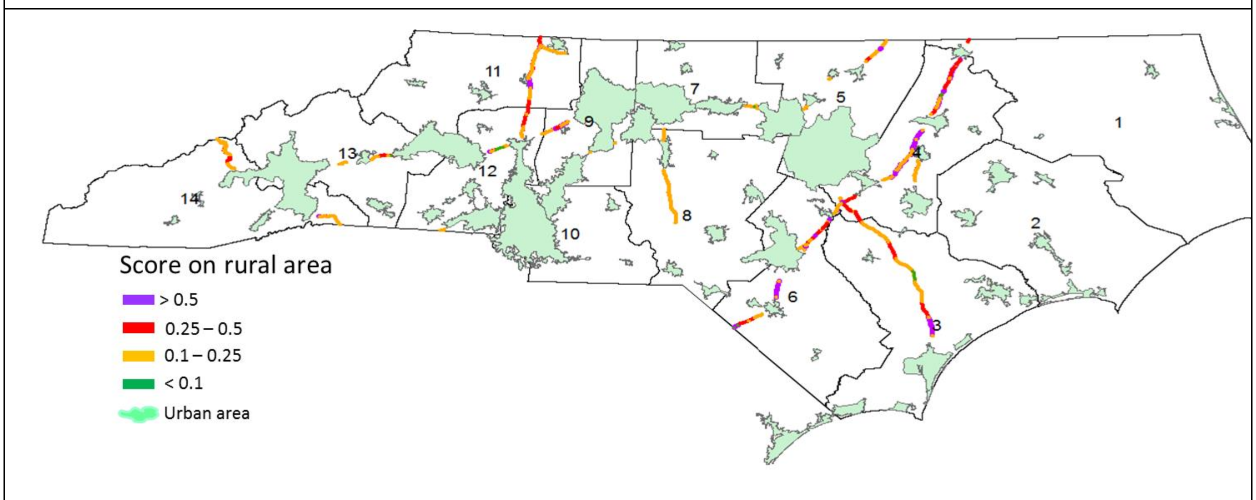
- Urban area: $\frac{2 \times VpLs_i + 2 \times CFs_i + SFs_i + CSs_i}{8+8+4+4}$
- Rural area: $\frac{VpLs_i + CFs_i + SFs_i + 2 \times CSs_i}{4+4+4+8}$

Figure 4-29 shows the results of the GIS map visualization of the comprehensive screening index on segments by types of area. Part (a) of Figure 4-29 depicts the index of segments on urban area, while part (b) illustrates that on rural area. In case of on urban area, most segments with the index greater than 0.5 were within Charlotte and Raleigh-Durham metropolitan areas. Those are locations where IMAP trucks are roaming as of 2013.

All roads not on urban area are referred as rural area as seen in part (b) of Figure 4-29. This illustration conveys information that high impacted segments with the index greater than 0.25 were mainly located on I-95. This indicates that I-95 is next potential IMAP route.



(a) Urban Areas



(b) Rural Areas

Figure 4-29 Comprehensive Screening Index by Types of Area

4.2.3. Summary

Based on the link classification visualization for the four-criteria for candidate IMAP deployment, several key findings and summaries have emerged that will assist decision makers to select IMAP deployment locations and prioritization, the following findings and summaries were found without IMAP locations:

- Travel level:
  - No more links with heavy traffic level on Interstate

  - Few links on US road identified as primary routes in Charlotte and Raleigh Metropolitan areas
- Congestion frequency
  - A few links with high congestion frequency on I-95 across division 4 on weekday
  - Several links with high congestion frequency on I-85 across division 5 on weekend
  - More links with congestion never occurs on weekend than on weekday
- Secondary crash
  - Several links with relatively high secondary crash rate and proportion of secondary crashes on I-95 across NC
  - Several links with relatively high secondary crash rate in central area on I-85 in division 5
- Crash severity
  - Considerable links with relatively high K and A crash rate on I-95 across NC
  - Several links with relatively high K and A crash rate on I-77 in north area in division 12 and division 11

These findings and summaries are promising that next recommended IMAP deployment locations are primary roads in urban area and one or two routes connected with links which have high values for those criteria on I-95 in rural area.

5. Develop IMAP Benefit and Cost Estimation Methods

IMAP benefit and cost analysis estimates potential for benefits before and after IMAPs as well as the costs in case IMAPs are implemented.

5.1. Benefit Estimation

The IMAP program has served a variety of types of service at various types of incident event. These services, which involve traffic control, extinguish fire, first aid, removed debris, jump start, flat tire, and any other services, may be beneficial to delay savings, reduction in number of crashes, especially secondary crashes, reduced wasted fuel and emissions to public and traffic operators directly and/or indirectly. In the literature, there are three major benefits for the FSP operation benefit/cost estimation analysis: delay savings, reduction in secondary crashes, reduction in fuel consumption and emissions. This chapter, therefore, unveils which benefits by IMAP operation can be estimated in case of North Carolina first. In the benefit analysis, the most important key parameters are to ascertain inputs to estimate those benefits. So, inputs which are employed to the analysis should be identified.

As such, this project started from justification of these statements for the IMAP benefit estimation and guided quantification for justified benefits. As stated in Chapter 3, TIMS incident data are plentiful if a benefit estimation is based on with-and-without IMAP (spatial difference, same time since 2010). However, to justify them, a before-and-after study (same location, temporal difference) is more suitable study rather than a with-and-without study. This is because most current IMAP beat areas are located in urban area as shown in Chapter 4. In other words, if a benefit estimation is processed based on a with-and-without study, it is likely that the analysis causes biased results for area type (urban versus rural area). Thus, a before-and-after study was used for this benefit estimation.

5.1.1. Reduction in Crash Rate

Justification that IMAP operation reduces in crash rate, especially secondary crash rate started from answering the following two questions. The first question is “Do any monthly and/or seasonal impacts affect crash rate at segment *i* in North Carolina?” This is because if monthly and/or seasonal impacts affect crash rate, our proposed benefit method should reflect those impacts. The second question is "Is there any evidence that crash rate is different between before and after IMAP operation?" This tells an answer for the justification.

The first step to answer those questions is to ascertain suitable study sites where include a significant crash data set for the before-and-after IMAP study. As stated in Chapter 3, both TEAAS and TIMS crash data since 2010 can be utilized only for the justification due to their limitation of sample size. Insofar as using the crash data, the study sites should be locations where IMAPs have implemented since 2010. Table 5-1 presents locations of where IMAP services have implemented since 2010 in North Carolina. Of these candidate locations, I-40 in division 3, I-540 in division 5, I-40 in division 13 were excluded for the analysis because of the limitation of data availability such as few crash rate (less than 10 crashes) and short route length (2 miles on I-40 in division 13).

Table 5-1 Locations IMAP Implemented after 2010

Division	Road name	IMAP implemented	Route	Operation hours
3	I-40	Summer 2013	398-420	7:30-20:30
5	I-540	June 2010	1-16	5:30-20:30
7	I-85	November 2010	163-170	5:30-21:30
9	I-40	November 2010	162-181	5:30-21:30
	I-85	November 2010	81-108	5:30-21:30
13	I-240	2012	5-9	7:00-18:30
	I-40	2012	53-55	7:00-18:30
14	I-40	January 2011	20-37	24/7
	I-26	January 211	Buncombe county to 54	10:30-18:30

This project confirmed which crash data source is more reliable and suitable prior to conducting for investigating difference in crash rate before and after IMAP operation. The process resulted in that TEAAS has more reliable. Table 5-2 shows the results for comparison between number of crashes reported by TIMS and TEAAS on the links of I-85 in division 9. Crashes reported from TIMS increased sharply in 2011, while different pattern was found from that of TEAAS. Also, more number of crashes were reported from TEAAS.

Table 5-2 Comparison between number of crashes reported by TIMS and TEAAS

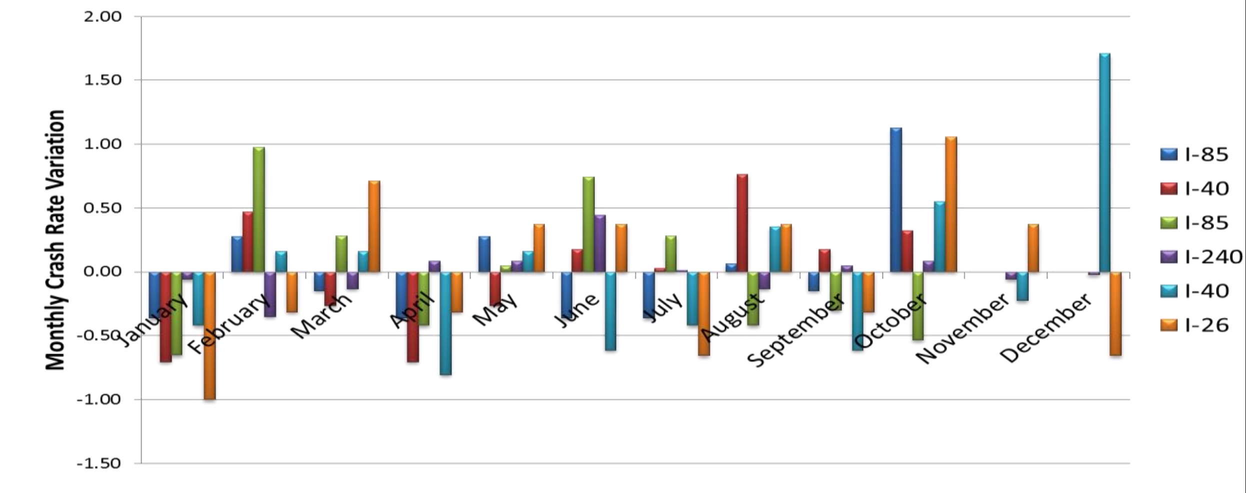
Division 9	Crashes Reported (TIMS)	TEAAS Crashes Reported
2008	16	NA
2009	29	NA
2010	**19**	**171**
2011	**68**	**197**
2012	**82**	**190**
2013	**92**	**171**

Therefore, the justification was then conducted using 2010-2013 TEAAS crash data. The data were classified into before or after the implantation of IMAP. IMAPs have implemented since November 2010 on three study sites in Table 5-1. At least one year data are needed for comparison of a before-and-after study. Therefore, average monthly number of crashes from January to October of 2010 was filled as number of crashes in November and December of 2010. Each one year data was employed in the before and after study.

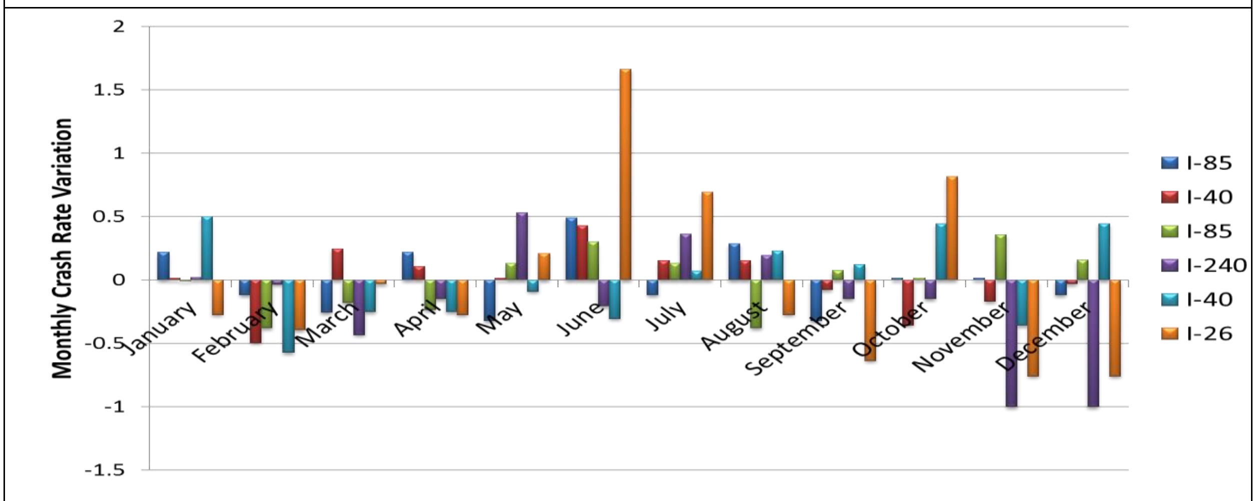
To answer whether monthly and/or seasonal impacts are effective in crash rate changes or not, crash rate variation was applied to the analysis and calculated by the following equation:

$$Crash\,Rate Variation = \frac{Monthly\,Crash\,Rate - Avg.Crash\,Rate}{Avg.Crash\,Rate}$$ **Equation 5-1**

Due to insufficient sample size, it was difficult to conduct a statistical analysis to test hypothesis for the justification. Therefore, based on the variation, this project conducted a comparison for monthly crash rate before and after IMAP operation as seen in Figure 5-1. The variations in January and April of before IMAP implementation were negative on most study sites. However, the variation in February of after IMAP were only negative on most study sites, not in January and April. In addition to this analysis, no reasonable previous studies were found. An annual incident report documented by Kansas DOT [68] illustrated the relationship of incident types to the time of year. The report just discussed that weather and seasonal, school session may contribute number of incidents from the result of visual analysis. This still calls for conducting a statistical process to answer the question. Therefore, this study finally concluded to that the answer is “no”, which means there is no evidence that monthly and/or seasonal impacts affect crash rate. To this research, it also indicated that annual crash rate can be applied for the IMAP benefit estimation.



(a) Before IMAP operation



(b) After IMAP operation

Figure 5-1 Comparison for Monthly Crash Rate Variation

To answer the second question in this chapter, this project compared crash rate before and after IMAP operation. Figure 5-2 describes crash rates per 100 M VMT on the case study sites before and after the implementation of IMAP. This graph provided information that there is no significant evidence that crash rate is difference between before and after IMAP operation. Therefore, the research team concluded that it is difficult to apply for reduction in crash rate, even for secondary crashes, and thereby reduction in crash rate by IMAP operation cannot be applied for our proposed benefit estimation method.

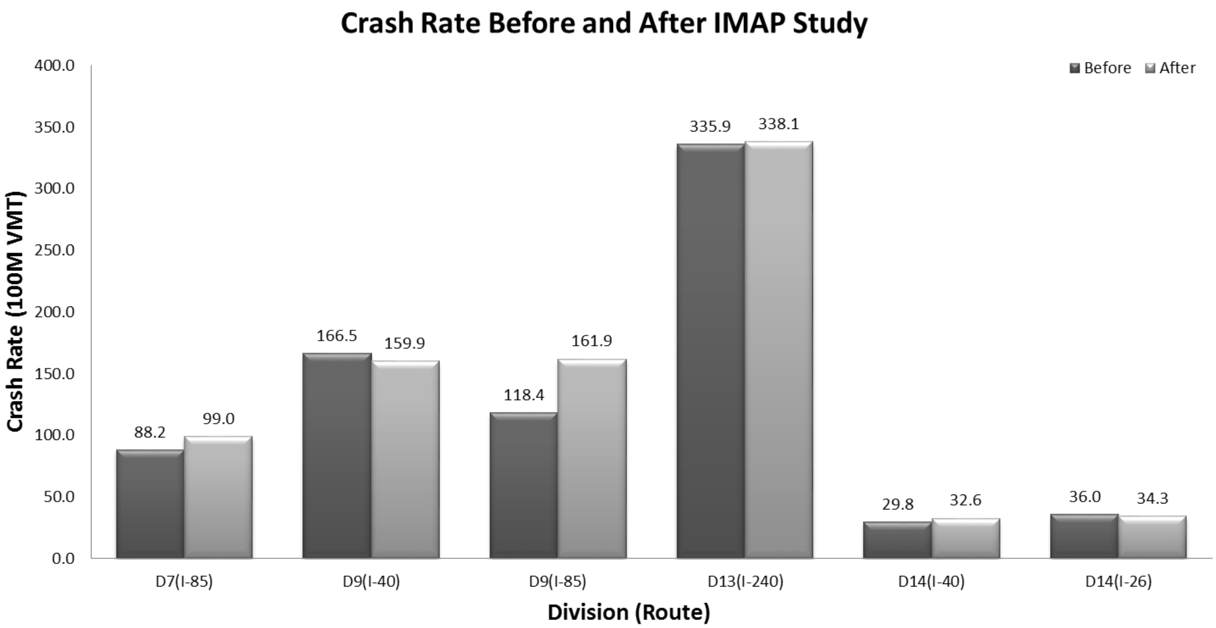


Figure 5-2 Crash rate per 100 M VMT before and after IMAP

5.1.2. Reduction in Incident Duration

Faster the incident response and clearance time for incidents may be the most effective strategy for mitigating non-recurrent congestion. Also, minimizing the incident duration time especially for crashes may be the best suitable strategy for crashes occurring outside of recurrent congestion periods. Therefore, it would definitely affect delay savings, reduction in number of the crashes.

IMAP programs play a vital role in coping with shortening the incident duration time on freeways. As such, reduction in incident duration by IMAP services was regarded as one of major factors on the proposed benefit estimation approach. Quantification for reduction in the incident duration by IMAP operation was conducted for the estimation. Necessary data for the analysis included incident severity and duration characteristics before and after IMAP. Table 5-3 depicts statistics for the incident characteristics on the specified study sites before and after IMAP operation. As seen in Table 5-3, proportion of reduction in incident duration denoted that most locations where IMAP implemented among the sites have had reduction effects in average and standard deviation of incident duration.

Table 5-3 Statistics for Incident Characteristics

Division		**D7**	**D9**	**D9**	**D13**	**D14**	**D14**
Route		I-85 (MM163-MM170)	I-40 (MM162-MM181)	I-85 (MM81-MM108)	I-240 (MM5-MM9)	I-40 MM20-MM37)	I-26 (MM40-MM54)
Operation hours		5:30–21:30	5:30–21:30	5:30–21:30	7:00–18:30	24/7	10:30–18:30
IMAP implemented		November, 2010	November, 2010	November, 2010	2012	January, 2011	January, 2011
Before	Number of incidents reported	13	18	66	2	61	4
	Avg. incident duration (min)	52.47	97.14	104.76	90.36	244.19	176.72
	Stdev. Incident duration (min)	36.45	117.64	118.39	42.94	225.22	1830.09
After	Number of incidents reported	43	58	223	14	112	25
	Avg. incident duration (min)	60.57	77.66	66.07	41.74	207.34	83.02
	Stdev. Incident duration (min)	40.66	80.08	90.40	23.19	234.52	52.37
Proportion of reduction in incident duration		15%	-20%	-37%	-54%	-15%	-53%

To justify the reduction effect clearly, the research team drew probability density function and cumulative density function of incident duration on the study sites as shown in Figure 5-3. The black line is CDF of before IMAP operation, while led line is that of after IMAP. Also, higher PDFs of incident duration was found in incident duration less than 60 minutes. It turns out that there is different in incident duration between before and after IMAP operation.

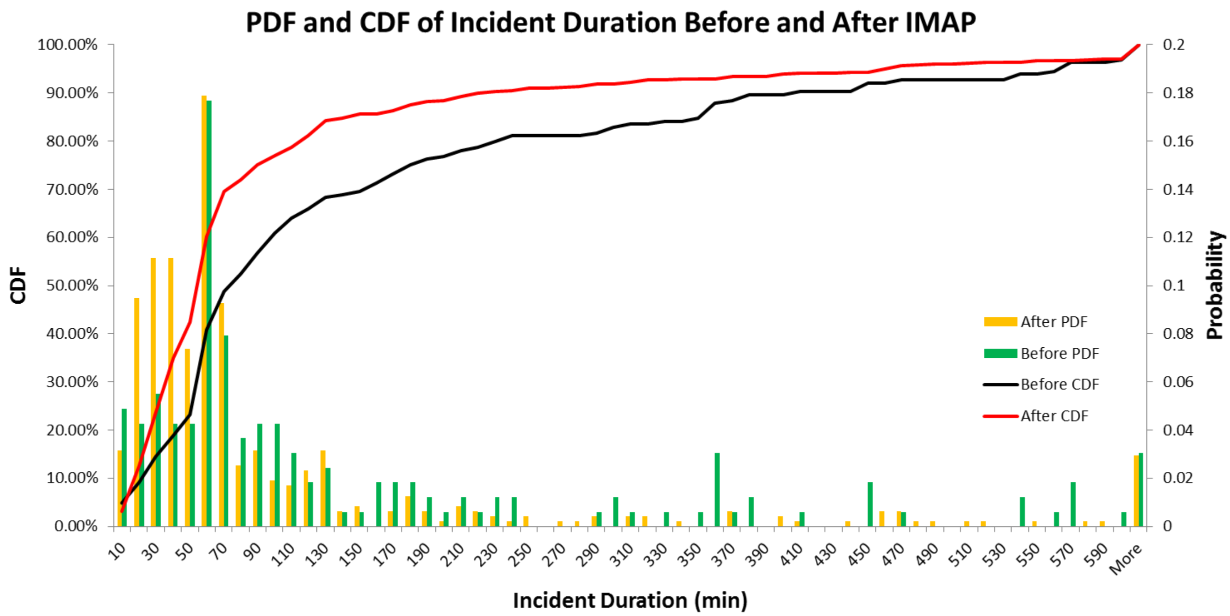


Figure 5-3 PDF and CDF of Incident Duration Before and After IMAP

In fact, incident duration is affected by incident severity (number of lane(s) blocked). So, this project considered reflecting incident duration by severity level. Figure 5-4 shows CDFs of incident duration by severity level from number of lanes 0 to 2. All CDFs of incident duration by severity level has different between before and after IMAP. Especially, a huge difference in incident duration was found on 1 lane blocked at an incident.

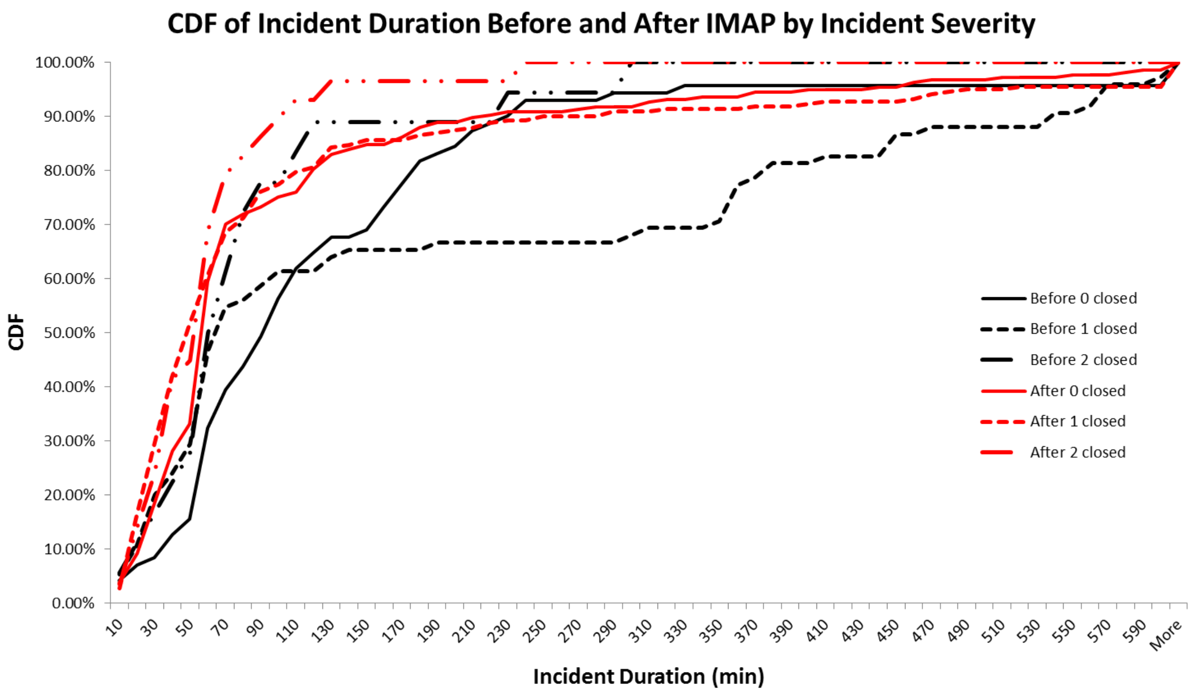


Figure 5-4 CDFs of Incident Duration Before and After IMAP by Incident Severity

As mentioned earlier, the justification that IMAP services reduce incident duration was verified through graphs visually. To justify via more scientific approach, a nonparametric Kolmogorov-Smirnov test was conducted to test of the hypothesis that there is difference in incident duration before and with IMAP. The result (D:0.1553, p-value:0.000) of the test rejected the null hypothesis that the distribution of incident duration is the same before and after IMAP, which means we are confident that there is significant difference in incident duration between before and after IMAP.

Those values identified can be employed as a major input for the IMAP benefit estimation. In fact this project conducted the before and after study with the limitation of sample size to justify the statement to justify the statement. However, one of the objectives of this chapter is to ascertain statewide impacts on reduction in incident duration. In this research, data for before IMAP on the specified study sites were only available sources in North Carolina, while statewide incident duration data with IMAP were available and can be applied to calculation of statewide incident duration by incident severity. Given the circumstance, the research team employed the data set of incident duration with IMAP to reflect statewide impacts rather than using incident duration data for after IMAP. A total of 15,254 incident duration data with IMAP in 2013 was used for setting the parameters.

Figure 5-5 depicts PDFs and CDFs of incident duration before and ***with*** IMAP. The result of a nonparametric Kolmogorov-Smirnov test appeared that there is significant difference in incident duration between before and ***with*** IMAP (D: 0.2553, p-value: 0.000).

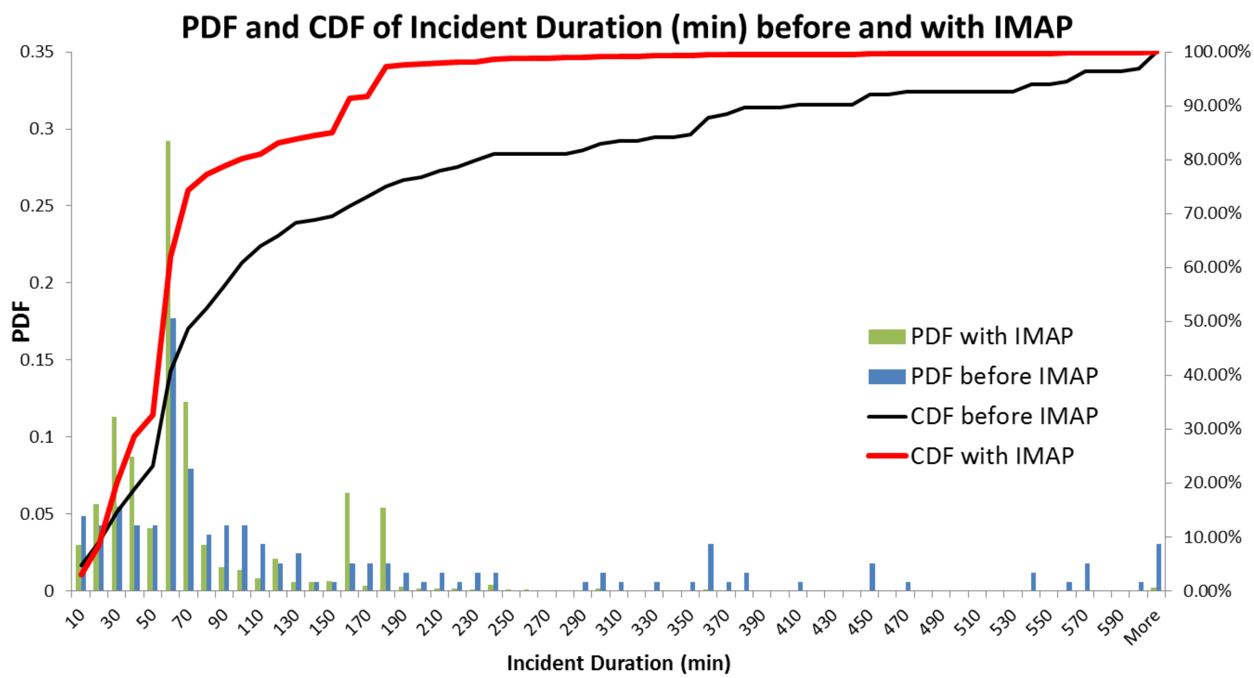


Figure 5-5 PDFs and CDFs of Incident Duration Before and *With* IMAP

This project also classified incident events by area type (urban or rural area) with the assumption that incident durations are different. Finally, the incident characteristics, which include severity and duration, were made for the benefit estimation by before and after IMAP on urban area versus rural area. Table 5-4 and Table 5-5 denote statewide incident characteristics information on urban area and rural area, respectively. In Table 5-4, on urban area, average incident duration before IMAP was 92.4 minutes and standard deviation incident duration was 91.5 minutes, while average incident duration with IMAP was 70.8 minutes and standard deviation of incident duration was 72.4 minutes. In other words, IMAP service decreases in average incident duration by 23% and in standard deviation by 21%, while no IMAP service increases in average incident duration by 31% and in standard deviation by 26%. In Table 5-5, on rural area, average incident duration before IMAP was 183.3 minutes and standard deviation incident duration was 171.5 minutes, while average incident duration with IMAP was 92.7 minutes and standard deviation incident duration 109.7 minutes. It turns out that IMAP service decreases in average incident duration by 49% and in standard deviation by 36% while no IMAP service on rural area increase in average incident duration by 97% and in standard deviation incident duration by 56%.

Table 5-4 Distribution of Incident Severity and Incident Duration – Urban Area

Study	Severity	Number of incidents (1year)	% of severity	Avg. incident duration (min)	Stdev. Incident duration (min)
Before	0	39	46.4	102.2	61.9
	1	33	39.3	89.7	124.8
	2	12	14.3	68.2	60.2
	3	0	0		
	4	0	0		
	Overall	84		92.4	91.5
With	0	7797	52.9	74.2	70.1
	1	5616	38.1	62.3	68.9
	2	1111	7.5	83.2	88.1
	3	178	1.2	91.6	87.7
	4	38	0.2	172.7	171.8
	Overall	14740		70.8	72.4
Average Difference in incident duration				-23%	-21%

Table 5-5 Distribution of Incident Severity and Incident Duration – Rural Area

Study	Severity	Number of incidents (1year)	% of severity	Avg. incident duration (min)	Stdev. Incident duration (min)
Before	0	29	39.2	110.4	79.9
	1	39	52.7	249.0	203.1
	2	6	8.1	108.9	93.8
	3	0			
	4	0			
	Overall	74		183.3	171.5
With	0	192	37.4	89.9	96.2
	1	270	52.5	91.8	116.4
	2	45	8.8	102.3	116.3
	3	7	1.4	142.0	153.4
	4	0			
	Overall	514		92.7	109.7
Average Difference in incident duration				-49%	-36%

5.1.3. Delay Savings

Traditionally, delay savings in traffic delay due to incident management systems is estimated using analytical techniques such as deterministic queueing model and shock wave analysis that assumes that the traffic arrival rate, capacity reduction, and incident duration can be identified and constant. However, these factors are not constant and may follow a specified distribution in the real world. Of these factors, incident duration is a major parameter of estimation of the impact of IMAP on non-recurrent delays as well as of stochasticity in delay. Therefore, incident duration and its statistics should be considered as a random variable for estimating those delay savings.

In this project, the proposed IMAP benefit estimation employs a new version of FREEVAL which can estimate non-recurrent delays caused by incidents, conducting a reliability analysis for the HCM. To enable a reliability analysis, the FREEVAL integrates a hybrid approach for freeway reliability scenario generation over a one-year period [69, 70]. Scenarios are generated with eight distributions including incident duration given severity, temporal distribution of incident event frequency, and other related distributions based on three core mathematical schemes which include mathematical models for demand generation, Monte Carlo simulation for incident and weather events, and an optimization used to maximize the similarities between the generated set of scenarios and population of all feasible scenarios. This project estimated delay savings using the FREEVAL engine with incident characteristics data that were collected before and after the implementation of IMAP operation or by using statewide values calculated in this research.

To explain the concept of delay estimation simply and clearly, a queuing diagram showing IMAP delay savings by reduction in incident duration is presented in Figure 5-6. The blue triangle area between the traffic flow rate (λ) and the departure curve (μ and μ_R) represents the total delay due to an incident with IMAP-assist. In other words, the total delay savings are attributed from difference in incident duration (D_i-D_n).

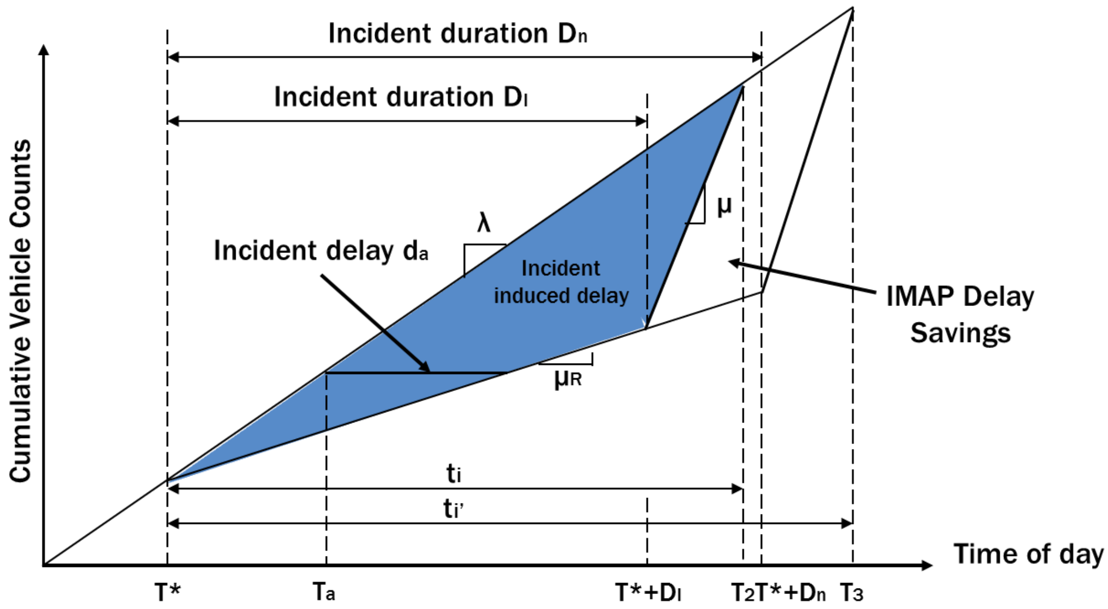


Figure 5-6 Delay Savings Due to IMAP Operation

Where, λ = traffic flow rate (vph)

μ = freeway capacity, which is also the departure rate after the incident (vph)

μ_R = reduced freeway capacity during the incident (vph)

D_a = the incident delay experienced by a vehicle that arrives at the incident spot at time t

D_i = incident duration with IMAP service

D_n = incident duration without IMAP service

T^* = the time when the incident occurs

T_2 = the time when the incident is cleared and the associated queue has dissipated with IMAP service

T_3 = the time when the incident is cleared and the associated queue has dissipated without IMAP service

t_i = duration of incident-induced congestion with IMAP service (time to normal)

t_i^* = duration of incident-induced congestion without IMAP service (time to normal)

Based on this concept, the savings in incident delays due to IMAP operation at incidents can be estimated for a long-term study period at freeway facilities with distribution of incident severity and duration. The FREEVAL runs separately for before and after study with the incident distribution data collected by field before and after implementation of IMAP operation. If site-specific data are not available, the statewide default values calculated can be utilized. Each output for before and after IMAP operation can be extracted from the FREEVAL reliability analysis running. The output file extracted includes Vehicle Hourly Delay (VHD) value for each scenario. By summing all VHDs at each scenario (e.x. 240 scenarios for weekdays over 1 year in FREEVAL), the total vehicle hourly delays are calculated from each output file. Finally delay savings (DS) in vehicle hours saved during a study period are calculated by total delay before IMAP minus total delay after IMAP. After calculating the total delay savings (vehicle hours), the monetary savings by delay reduction can be then calculated by using Equation 5-2.

$$DS_{\cos t} = DS \times P_c \times V_c + DS \times P_t \times V_t \quad \textbf{Equation 5-2}$$

Where,

DS_{cost}: incident delay savings in terms of dollars saved,

DS: incident delay savings (vehicle hourly delay without IMAP – vehicle hourly delay with IMAP)

P_c: percentage of cars in traffic, expressed as a fraction,

P_t: percentage of trucks in traffic, expressed as a fraction,

V_c: value of time for a passenger car per hour, and

V_t: value of time for a truck per hour.

5.1.4. Energy Benefits

As mentioned earlier, IMAP services play a pivotal role in reduction in incident duration caused by an incident event and thereby the length of the queue by the event is decreased. These reductions result in a decreased travel time which may decrease fuel that is used. Given these circumstances, reduction in fuel consumption by IMAP services on a facility are considered as another benefit. This project utilized fuel consumption tables by average vehicle’s speed generated categorized simply by two types of vehicle (passenger cars and trucks) exported from a simplified version of MOVES [70]. A simple statistical modeling to estimate fuel consumption was developed based on those tables for passenger and trucks. Average space mean speed is only the independent variable extracted from after running FREEVAL before and after IMAP study. Figure 5-7 depicts a plot of fuel consumptions by average speed for passenger cars with the result of the statistical modeling to be applied to our IMAP benefit estimation. Fuel consumption decreases with power distribution when speed decrease until approximately 48 mph, while fuel consumption increases steadily after the speed greater than 48 mph. Therefore, two equations were finally modeled for before and after 48mph of average speed and then applied to our benefit/cost estimation integrated tool. In the contrary, fuel consumption for trucks decreases with power distribution when speed reduces and the equation in Figure 5-8 was finally applied to the integrated tool.

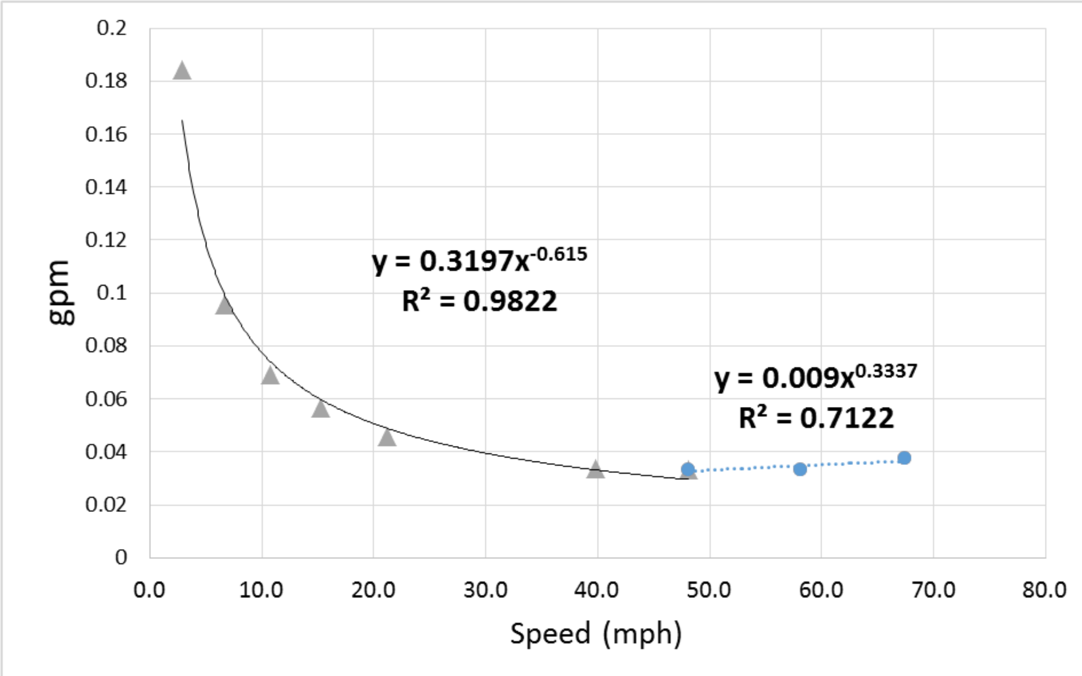


Figure 5-7 Passenger Cars' Fuel Consumption by Average Speed

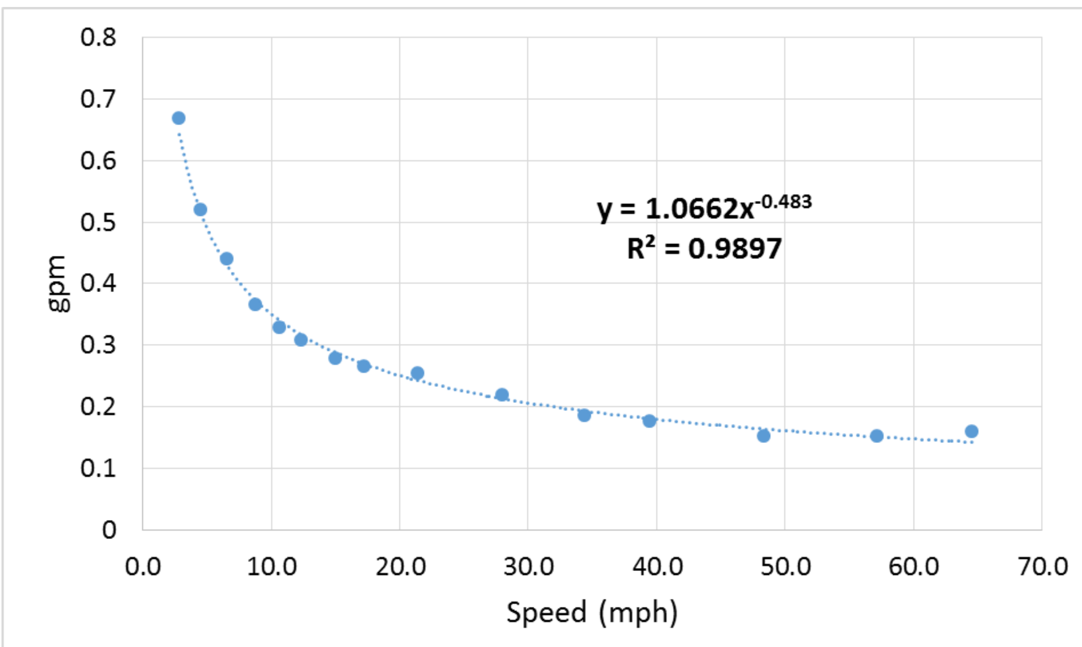


Figure 5-8 Trucks' Fuel Consumption by Average Speed

The outputs extracted from FREEVAL runs provide *P*, *VMT*, and *s* by each scenario before and after IMAP, respectively. A scenario-based estimation method for fuel consumption was developed using the outputs from FREEVAL runs. The fuel consumption of each scenario can be calculated by the following equation:

$$F_{w\ or\ wo} = VMT_c \times P_c \times G_c^s + VMT_t \times P_t \times G_t^s$$ **Equation 5-3**

where,

F: fuel consumption (gallons),

w: with IMAP

wo: without IMAP

s: average space mean speed (mi/h) at a facility,

c: car,

t: truck,

P_c: percentage of cars in traffic, expressed as a fraction,

P_t: percentage of trucks in traffic, expressed as a fraction,

VMT_c: vehicle miles of travel for cars,

VMT_t: vehicle miles of travel for trucks,

G_c^s : Gallons of gas/mile on average speed at *s*, and

G_t^s : Gallons of gas/mile on average speed at *s*.

Then, fuel changes due to IMAP operation at a facility in a specified study period can be calculated by the following equation:

$$FC = \sum_{sc=1}^{SC} F_{wo}^{sc} - \sum_{sc=1}^{SC} F_{w}^{sc}$$ **Equation 5-4**

where,

FC : fuel changes due to IMAP operation at a facility in a specified study period, and

sc: a scenario number.

Eventually, monetary benefit for fuel reduction can be calculated by the following equation:

$$E_{Benefit}(\$) = FC \times C$$ **Equation 5-5**

Where,

C: current gas price ($/gallon), and

$E_{Benefit}$: Energy benefits ($) due to IMAP operation.

5.1.5. Proposed Benefit Estimation Method

An estimation process was used to estimate the benefits by the implementation of IMAP operation shown in Figure 5-9. A four-step methodology was employed in the process. In Step 1, a potential facility for IMAP deployment should be decided by either the link classification visualization or user's request. The selected potential facility should be drawn with various inputs such as traffic, roadway characteristics, and others in FREEVAL. The other thing in the step is to download incident characteristics and frequency data from TIMS for the selected potential facility. If the analyst has few data available, statewide default values provided by this project can be used as alternative data. In Step 2, using the incident data, distribution of incident severity and duration before and after IMAP-assist can be generated. In Step 3, the reliability analysis in FREEVAL runs and generates scenarios with the distribution of incident characteristics with and without IMAP-assist. In Step 4, delay savings and energy benefit due to IMAP operation are estimated using outputs extracted from the reliability analysis.

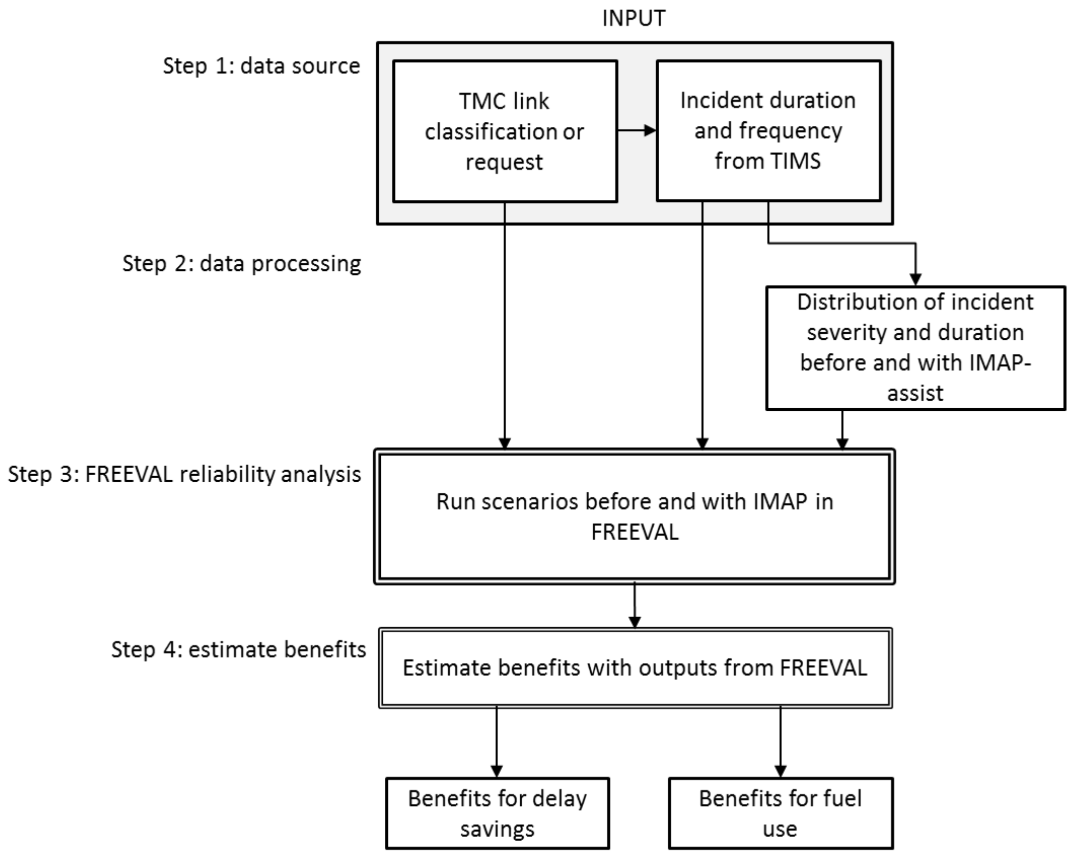


Figure 5-9 The IMAP Benefits Estimation Process

Detailed information in both Step 1 and 2 were included in the previous chapters. In this chapter, the IMAP benefits estimation process is described from Step 3. Figure 5-10 shows a screenshot of the FREEVAL. In the FREEVAL, a potential freeway facility is drawn with various inputs that are needed. As mentioned earlier, this benefit estimation utilizes a reliability analysis integrated in the FREEVAL. A reliability analysis can be run using the menu in red box as seen in Figure 5-10. To conduct a reliability analysis clicks first "Generate" button once all the information is entered for freeway facility. Further detailed information for the reliability analysis is discussed in "FREEVAL 2015e – Computational Engine User Guide" [71].

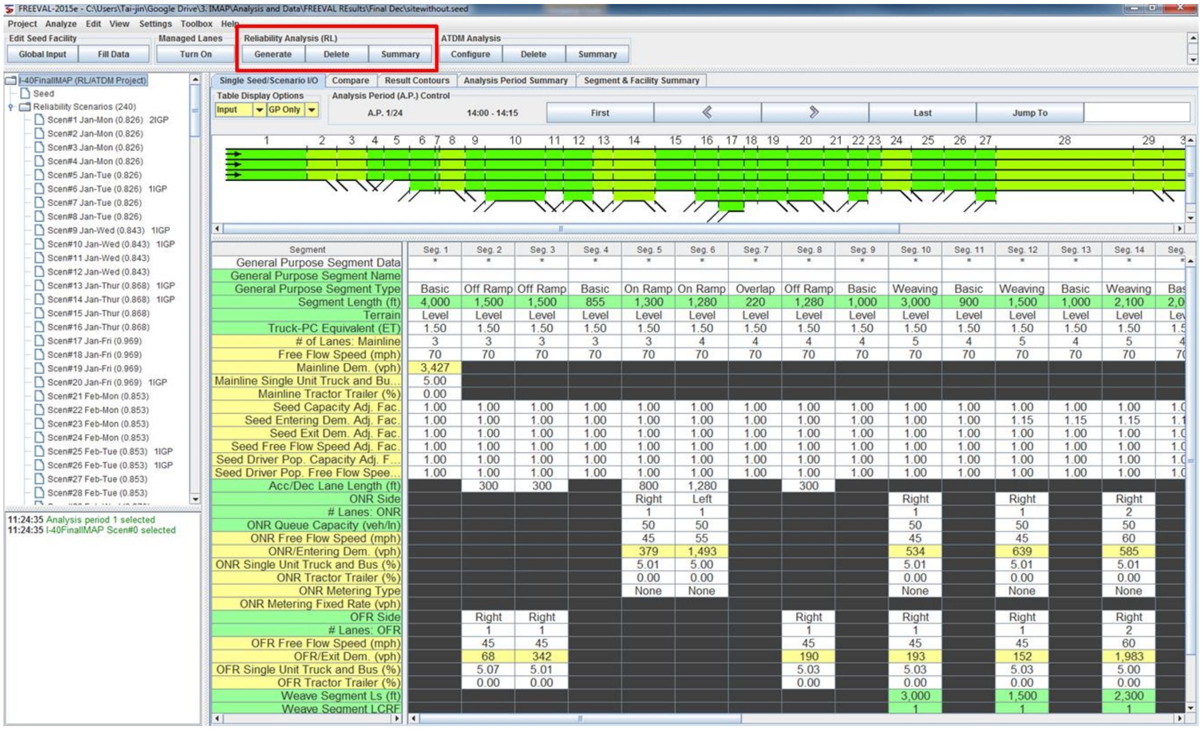


Figure 5-10 A Screenshot of FREEVAL (Exit 279 – Exit 290 of I-40 eastbound)

Each reliability analysis has a number of global properties that must be specified. The *properties* tab is divided into subsections: general properties, event type inclusion, random number generator options, and number of demand combination realizations. Figure 5-11 depicts an example of the global inputs in the properties of the reliability analysis. After setting the properties, the user can configure the daily and monthly demand adjustment factor (DAF) based on the daily and monthly variability of traffic demand for the subject facility or by using national defaults (see Figure 5-12). National defaults can used by clicking "urban or rural default values" buttons.

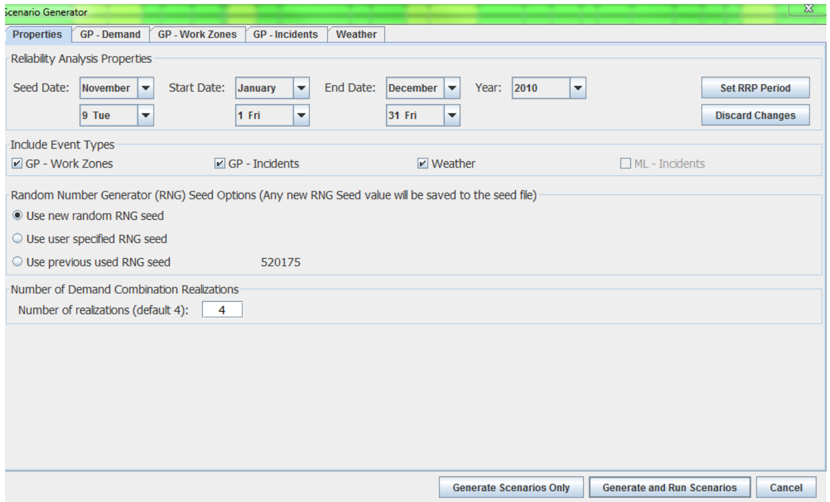


Figure 5-11 Global Reliability Analysis Properties

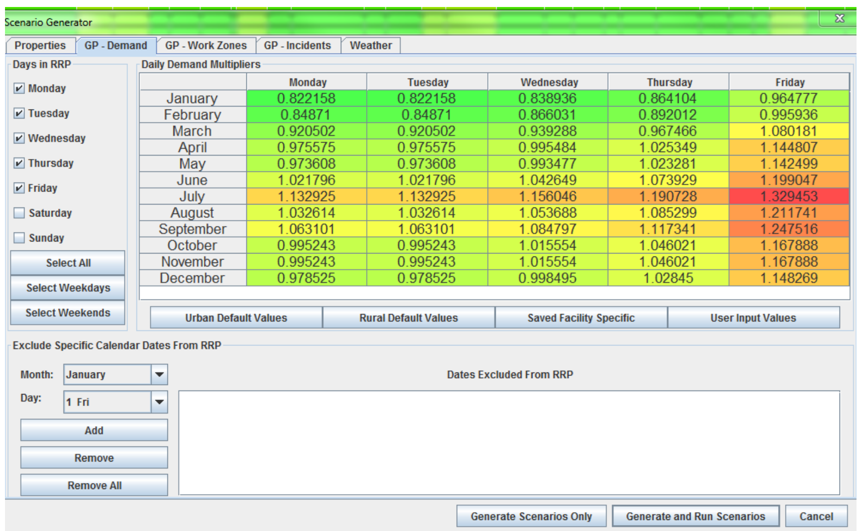


Figure 5-12 Demand Information Panel of a Reliability Analysis

After setting the demand factor, we characterize incident events in terms of probability of occurrence, duration, and severity on the freeway facility. All those information generated in Step 2 of the benefit process is applied to incident frequencies and incident durations (see Figure 5-13).

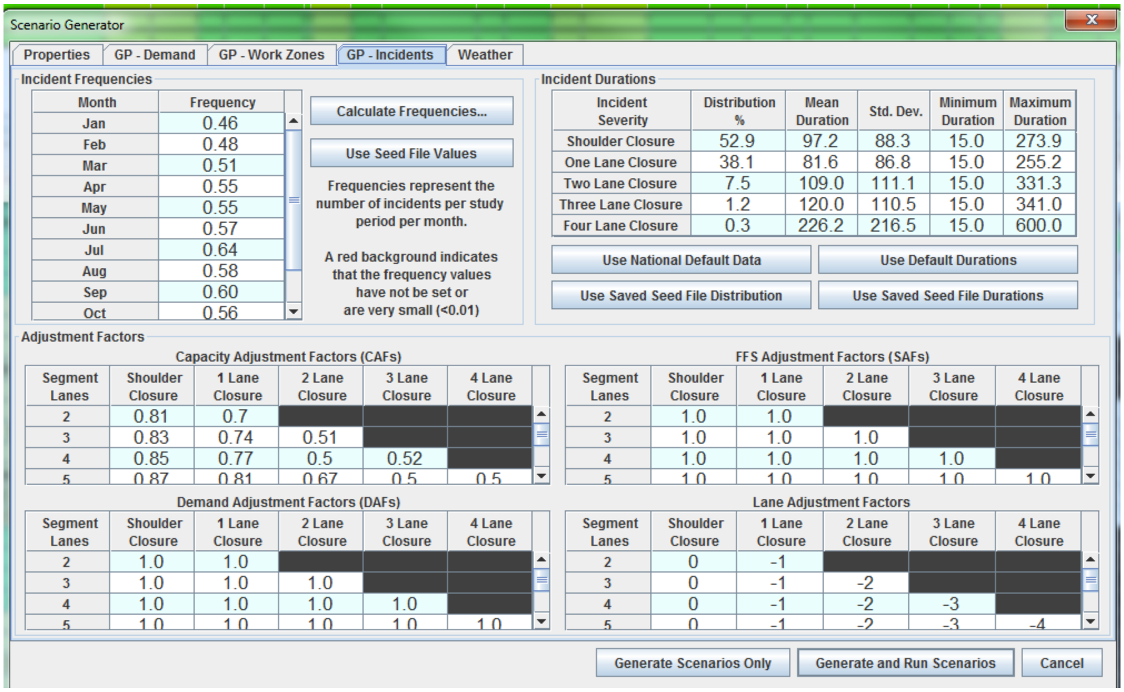


Figure 5-13 Incident Inputs of a Reliability Analysis

If incident frequencies data are not available on the freeway facility, the reliability analysis can generate the incident frequency by pressing the "Calculate Frequencies Using Incident (Crash) Rates" button instead. In case, crash rate and incident/crash ratio are only inputs to generate the incident frequency. As mentioned earlier in the reduction in crash rates, no difference in monthly crash rate was found. If the analyst has monthly crash rate information, it is better option to insert monthly crash rate. If not, annual average crash rate for monthly crash rate can be inserted as seen in Figure 5-14. Even if annual average crash rate is not available, an average statewide crash rate can be applied for the benefit estimation instead. Based on 2010-2012 North Carolina crash rates provided by NCDOT, 90 and 60 (per 100 M VMT) were selected as statewide default crash rates on Interstates in urban and rural area, respectively.

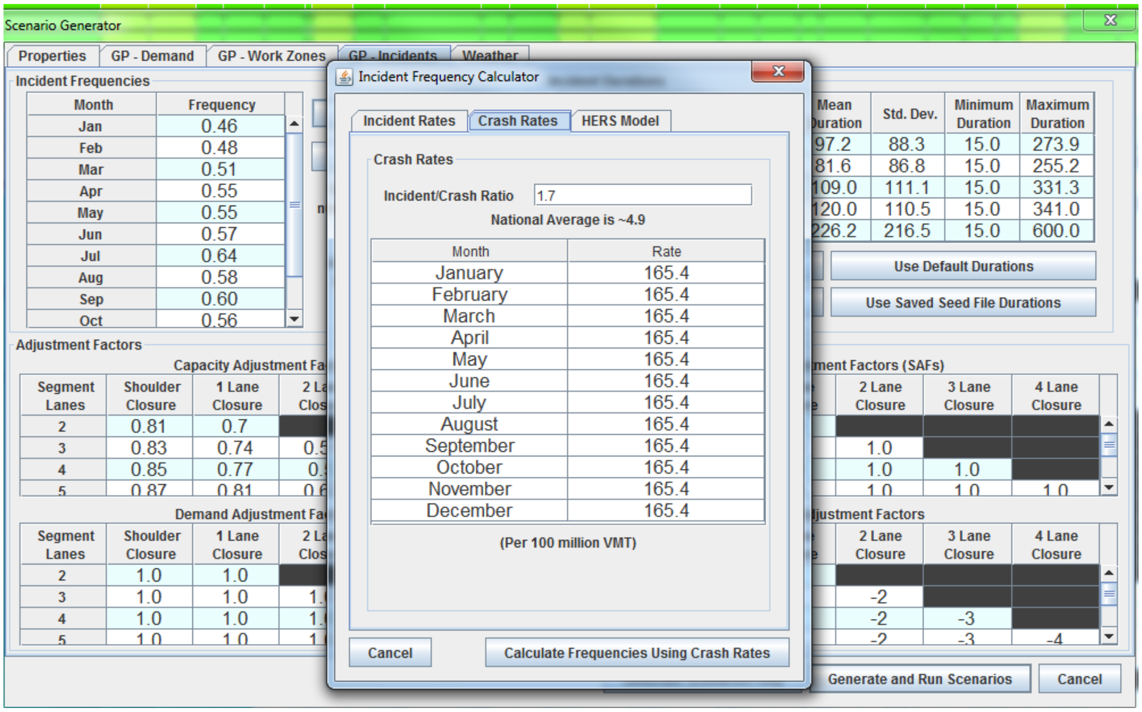


Figure 5-14 Frequency Generator Using Incident or Crash Rates

As for incident/crash ratio, the research team investigated whether there is difference in incident/crash ratio or not. The result of the investigation concluded that there is no evidence that there is a difference in incident/crash ratio between before and after the implementation of IMAP. Therefore, if both incident/crash ratios are available, then use them. If not, the analyst can use 2.0 as a statewide default value of the incident/crash ratio in North Carolina that is generated by TIMS incident data after IMAP implementation.

After setting monthly incident frequency, incident duration is then characterized. The incident duration information includes distribution of incident severity and average, standard deviation, minimum and maximum of incident duration by severity. If the incident duration information both for before and after IMAP is available from the site-specific field data, then it can be applied to the reliability analysis directly. If the incident duration information is available only for before or after IMAP, incident duration elasticity of before and after IMAP calculated in Table 5-4 for urban area and Table 5-5 for rural area can be utilized as shown in Table 5-6. For example, average and standard deviation of incident duration in a route before IMAP service are 100 minutes and 100 minutes. The average and the standard deviation of incident duration after IMAP service are 77 minutes and 79 minutes, respectively. In other words, the implementation of IMAP decreases the average incident duration by 23% and the standard deviation of incident duration by 21%.

Table 5-6 Incident Duration Elasticity of Before and the Implementation of IMAP

Regional characteristics	**Urban**		**Rural**	
Incident duration	**Average incident duration**	**Standard deviation of incident duration**	**Average incident duration**	**Standard deviation of incident duration**
Before the implementation of IMAP	Increase by 31%	Increase by 26%	Increase by 97%	Increase by 56%
After the implementation of IMAP	Decrease by 23%	Decrease by 21%	Decrease by 49%	Decrease by 36%

Minimum value of incident duration is fixed as 15 minutes (time window of the HCM) in this project. In contrast, maximum incident duration can be calculated by the following equation:

$$ID_{Max} = ID_{Avg.} + \left(2 \cdot ID_{Stdev.}\right)$$ **Equation 5-6**

Where,

ID_{Max}: maximum incident duration (minutes), 600 minutes as maximum incident duration,

$ID_{Avg.}$: average incident duration (minutes), and

$ID_{Stdev.}$: standard deviation of incident duration (minutes).

Once all the information is entered in the screens for the reliability analysis, the analyst clicks on “Generate and Run Scenarios” button. Each run is required for before and after study with different incident characteristics information. From the analysis, the analyst can export the raw results data including vehicle miles of travel for demand and service, vehicle hourly delays, average space mean speed for each scenario. In Step 4, these inputs are employed for each benefit that are discussed earlier in 5.3 and 5.4.

5.2. Cost Estimation

Most previous studies that evaluate IMAP operational impacts have developed analytic tools, given data availability. With available IMAP cost introduced in Chapter 3.2.4., this project proposes an annual based cost estimation methodology which translates into the following equation:

$$C_{IMAP} = \left(C_T + C_L\right) \times N_T \times H \times D + C_O$$ **Equation 5-7**

Where,

C_{IMAP}: IMAP operation cost ($),

C_T: cost for truck operation ($/hr),

C_L: cost for labor ($/hr),

C_O: other fixed cost ($),

N_T: number of deployed IMAP trucks,

H: hours of operation (hr), and

D: annual days of operation.

6. Develop Integrated Benefit/Cost Estimation Methodology and Associated Computation Engine

A key product of this research is the integrated benefit/cost estimation tool that incorporates the knowledge previously discussed in this report. The estimation tool was designed to be allowed easy access the outcome of this research. It also allows more realistic analysis for existing or future IMAP facilities using GIS-based link classification and the operational analysis based on the field data. The estimation tool runs by following the framework of the IMAP integrated computation engine, shown in Figure 6-1.

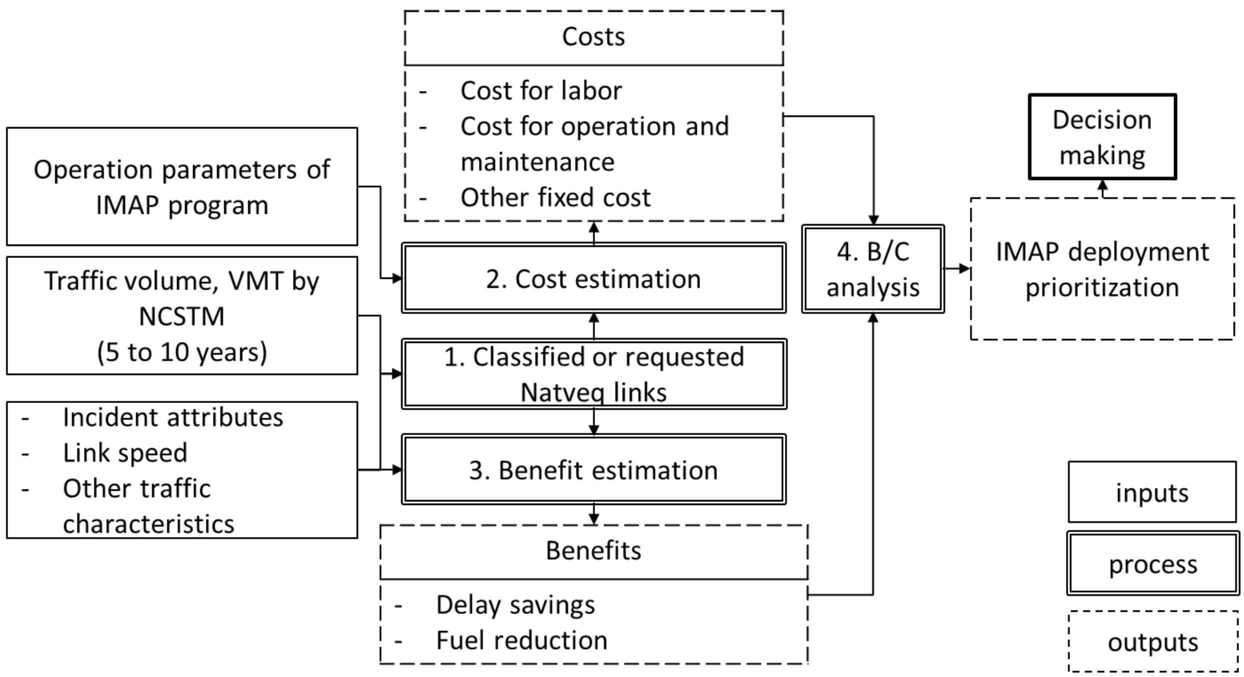


Figure 6-1 Framework of IMAP Integrated Computation Engine

The estimation tool consists of four-steps: 1) link classification, 2) IMAP operating cost estimation, 3) benefits estimation, and 4) benefit/cost ratio. In Step 1, user must select links where are being considered for IMAP installation using GIS-based link classification or by links requested. For the links selected, user should create a freeway facility file and insert inputs into FREEVAL. In Step 2, potential IMAP cost estimation is processed on the links classified or requested in the previous step. In Step 3, benefits can be estimated using outputs exported from FREEVAL runs for before and after the implementation of IMAP. In Step 4, the benefit/cost ratio is calculated by the results of cost and benefit estimation on the specified freeway facility. To inform decisions regarding where to place IMAPs, user must conduct this process on different candidate links or routes and compare the rankings of the freeway facilities along with potential benefits/costs resulting from patrol expansion. They finally encompass making decisions about IMAP implementation.

Based on this process, the IMAP estimation computation engine was developed. The following section discusses each screen in the tool. The IMAP estimation tool has multiple screens for user input. The user will enter all the information needed for the estimation in multiple steps.

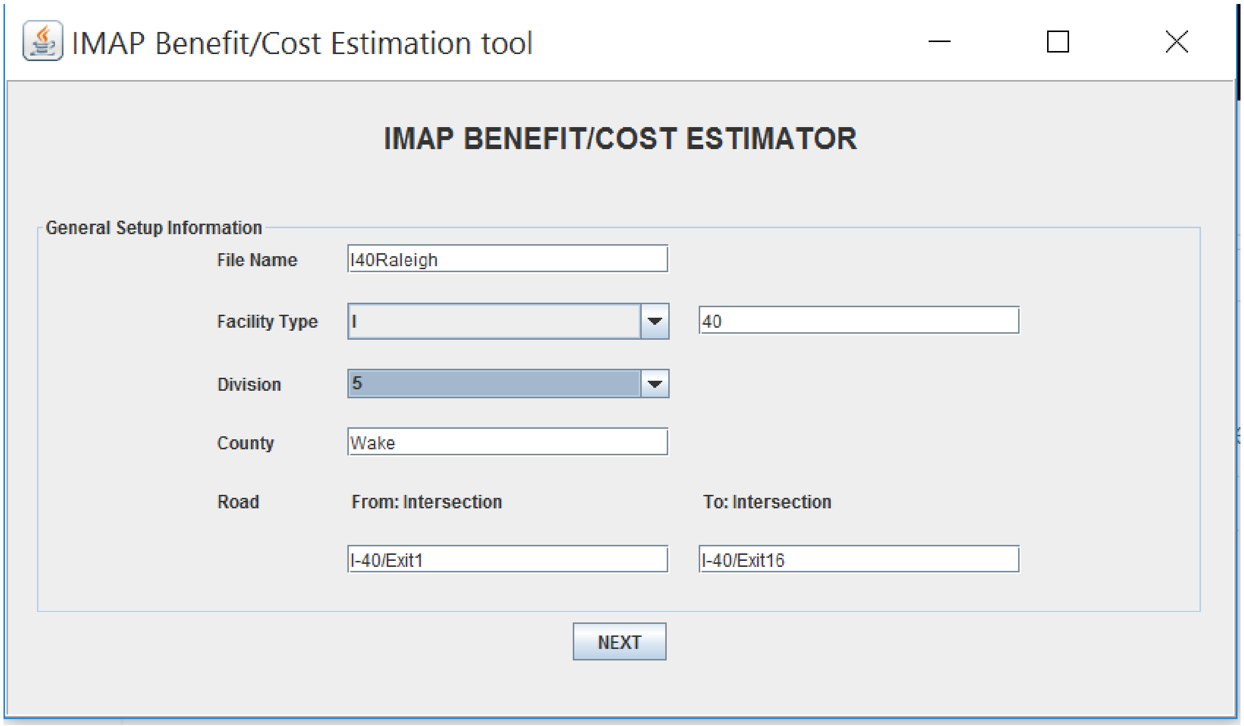


Figure 6-2 Setup Entry Screen

Figure 6-2 shows all the setup information needed for the estimation in the entry screen. The inputs include:

- File name: Enter the name of the facility that is being considered for IMAP installation. This field is needed for identifying the estimation uniquely when multiple estimations are done.
- Facility type: Select the type of facility from the pull down menu and type route number.
- Division: Select the NCDOT Division from 1 to 14.

- County: Enter the name of county where the facility is located. This field allows the user to enter in any text.
- Intersections of the Road: Enter the intersection from starting point where IMAP service is installed to ending point. This filed allows the user to enter in any text.

"NEXT" button must be pushed after all required information inserted in the entry screen. Pressing the "NEXT" button will proceed to the IMAP operational information screen, shown in Figure 6-3.

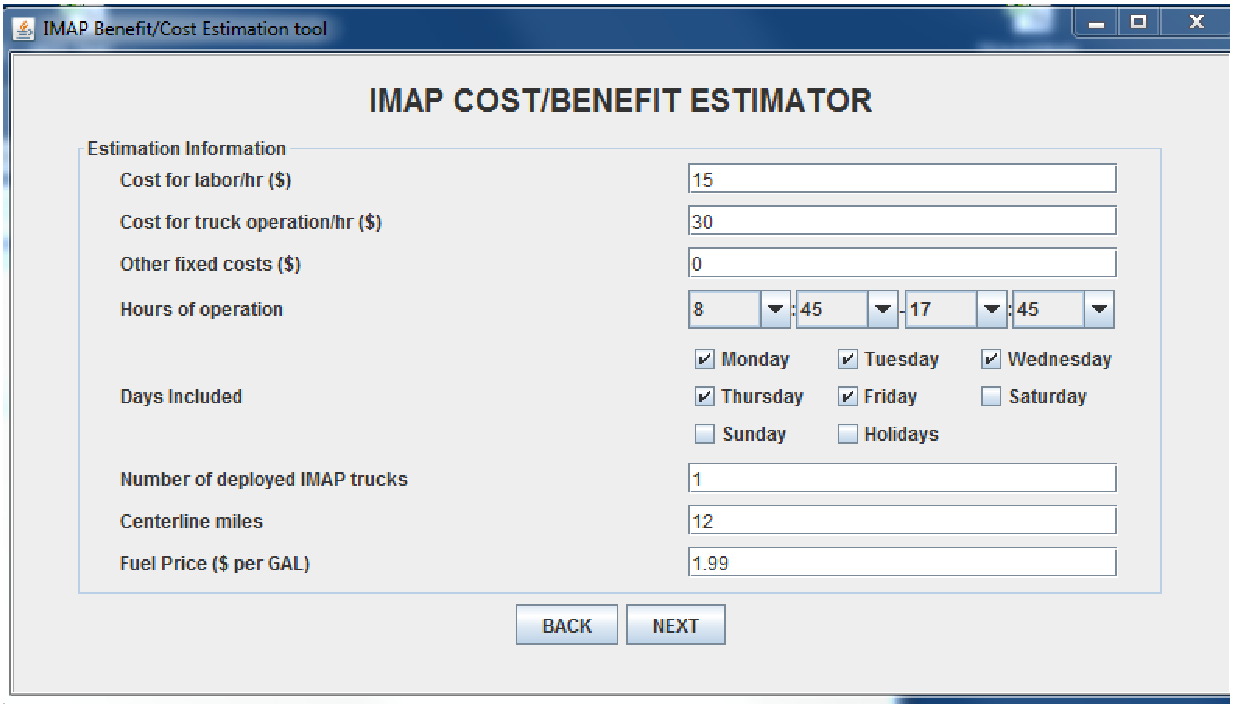


Figure 6-3 IMAP Operational Information Entry Screen

The IMAP operational information screen takes all the cost metrics for computing the cost/benefit estimation. The inputs from user include:

- Cost for labor per hour ($): Enter the hourly cost for labor on the facility that is being considered for IMAP installation. User can type the cost or use the default cost ($15) provided by NCDOT.
- Cost for truck operation per hour ($): Enter the hourly cost for truck operation on the facility that is being considered for IMAP installation. User can type the cost or use the default cost ($30) provided by NCDOT.

- Hours of operation: Enter the number of hours the IMAP program operates on an average day.
- Days Included: Select day of the week the IMAP operates over a year. At least one option must be selected to continue. Each option means day of the week and scenarios to be applied to the benefits and cost estimation in the tool, respectively. The total scenario numbers over 1 year is 336 days since FREEVAL runs 4 replications for each day of the week a month. The following examples are days calculated in the FREEVAL
  - Click a day: $1\ day \times 4\, replications \times 12\ months \approx 47 days\,(except\ \ for\, holidays)$
  - Click Holidays: 8 holidays (New year, Christmas, and others)
  - Click all possible days including holidays: 336 days
  - Click workdays (from Monday to Friday):

    $5\, day \times 4\, replications \times 12\ months - 8 holidays \approx 232 days$
  - Click workdays and Holidays: 240 days

All inputs are required to continue. Once all the inputs are entered, user will click on “NEXT” button. If any inputs in the previous screen needs to be modified, user can click on “BACK” button to go back and modify any setup information.

The next screen is for incident characteristics inputs, shown in Figure 6-4. This screen takes the incident data as input that are required to the benefit/cost estimation. The inputs required include:

- Area type: Select the general area type of the facility from the pull down menu. User can select either Urban area or Rural area.
- Study type: Select the type of study of the facility from the pull down menu. Existing deployed IMAPs are the study that evaluates current IMAPs operational effect. Future IMAP deployment is the study that evaluates benefits after the implementation of IMAP.
- Incident or crash rate (per 100 M VMT): Select the type of incident rate source of the facility that is applied to the estimate of monthly incident frequency. User selects “Site specific – incident rate” when monthly or annual incident rate are available. If crash rate and incident/crash ratio is available on the facility, user can select “Site specific – crash

rate”. Neither incident rate nor crash rate on the facility are available, then selects “Statewide default value – crash rate”.

- Incident severity and duration characteristics: Select the type of incident characteristics source of the facility that is applied to the benefit estimation as a key parameter. User selects “Site specific” when incident severity and duration are available for both before and after IMAP implementation. Once the type is selected, click on “…” button nearby and thereby click “Both” button on the top, and enter the incident characteristics data over 1 year. Although the incident characteristics information is available only for before or after IMAP implementation, user selects “Site specific” as well. Once the type is selected, click on “…” button nearby and thereby click “Only before” or “Only after” button on data availability on the top, and enter the incident characteristics data over 1 year. The tool will estimate automatically opposite incident distribution table that no available data exists in inputting the only available data by using statewide incident duration elasticity of before and after IMAP implementation. No the incident characteristics data are available on the facility before or after the implantation of IMAP, then select “Statewide”, which create automatically statewide default values calculated from the statewide incident data.

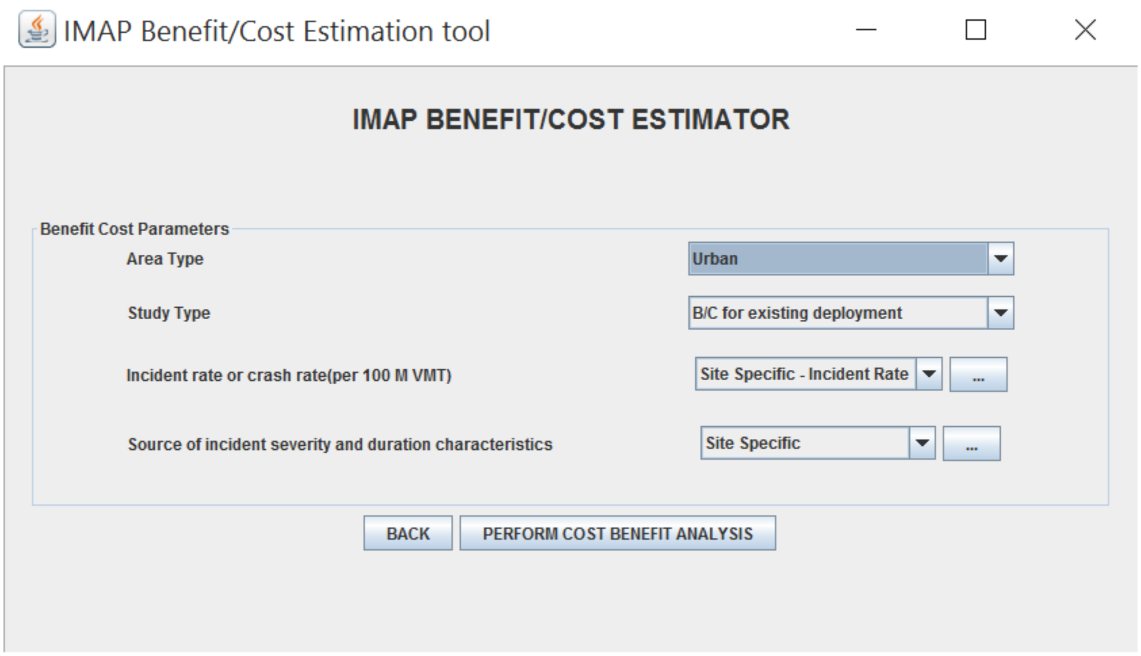


Figure 6-4 Incident Characteristics Information Entry Screen

Once all data has been entered in the incident characteristics information screen, then click on "PERFORM BENEFIT COST ANALYSIS" button. Once all the estimation information has been entered and when the "PERFORM BENEFIT COST ANALYSIS" button has been clicked, user has to select the FREEVAL seed file for the estimation. A file chooser is displayed through which user can select the FREEVAL file. Once the FREEVAL seed file has been selected, estimation analysis is performed without opening FREEVAL software program and the summary of results are displayed on the next output screen. The results include the following information:

- Facility information
- Delay savings (veh-hr) and their monetary benefit ($)
- Fuel reduction (gal/mile) and their monetary benefit ($)
- IMAP operating cost estimation ($)
- Benefit/Cost ratio

7. Evaluation: Application to a specific facility

The final step in this research is to apply the estimation tool. Presented below are the evaluation results for an existing IMAP facility. The example facility illustrated in this report involves a 12.5-mile section of I-40 eastbound in Raleigh, North Carolina, analyzed in 2010 from 14:00 to 20:00. It extends from Exit 279 to Exit 290 shown in Figure 7-1.

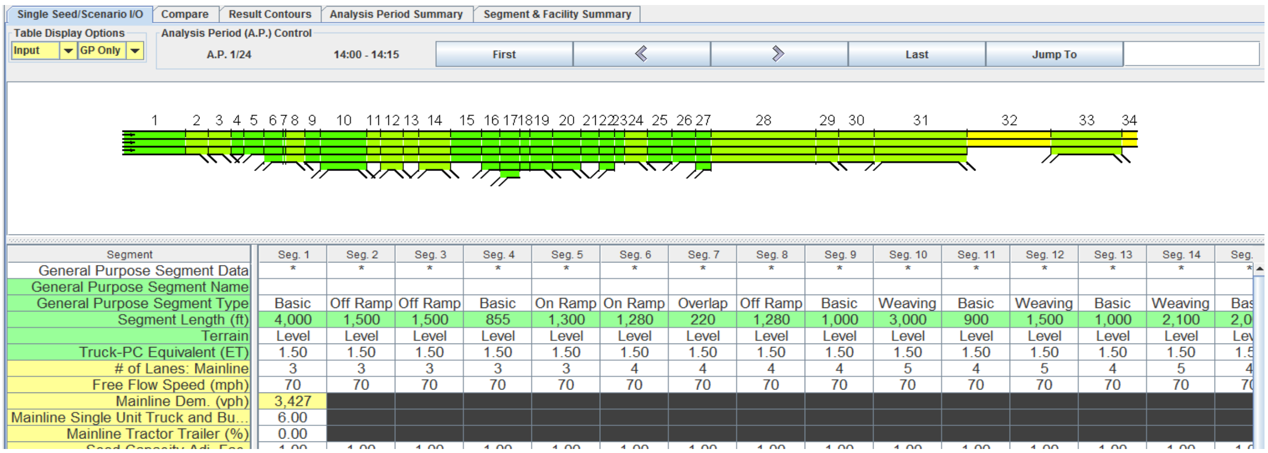


Figure 7-1 Exit 279 to Exit 290 of I-40 Eastbound in 2010

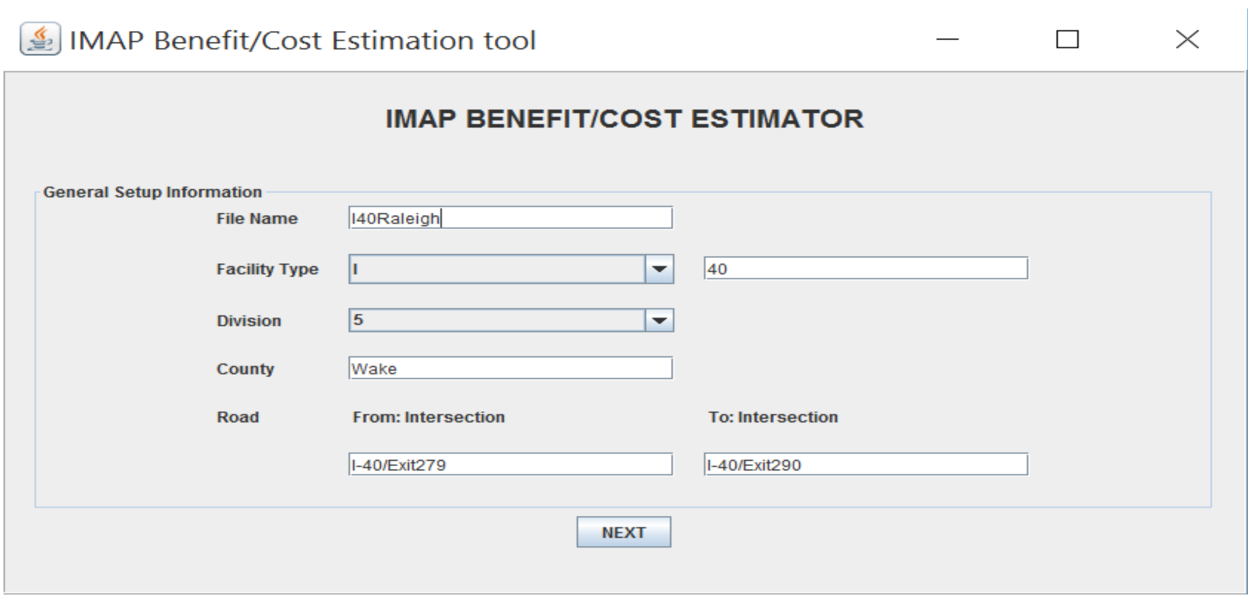


Figure 7-2 General Setup Information for the I-40 Study Facility

As the first step, inputs needed for general setup information for the facility were filled as seen in Figure 7-2. In the next step, IMAP operational information was inserted as depicted in Figure 7-3.

This tool allows user an estimation of IMAP potential benefits by hours of operation. To estimate benefits on peak-time period, hours of operation a day was selected for 14:00 to 20:00. Also, we assumed that the facility operates during workdays (from Monday to Friday) including holidays, which generate 240 scenarios over 1 year. Two IMAP trucks were roaming across the study site in 2014 by IMAP log data. The research team assumed that same trucks were operated on the study site in 2010 as well. Average gas price per gallon was 2.63 in 2010[2].

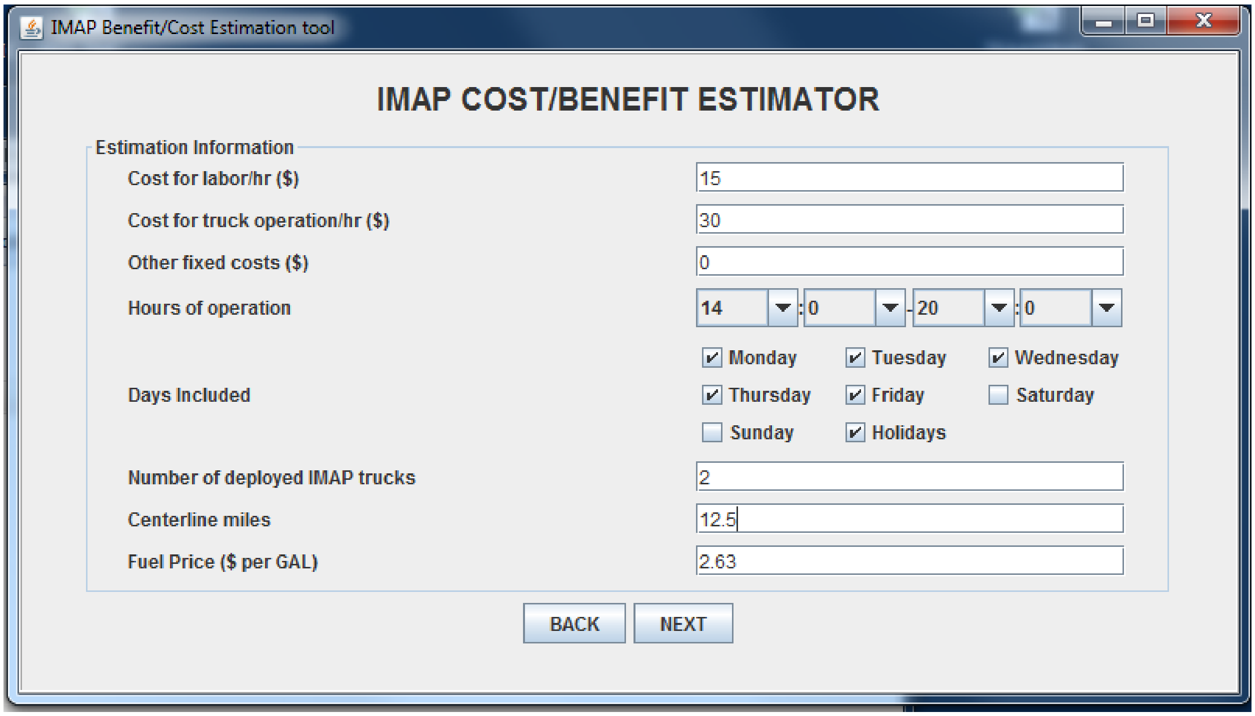


Figure 7-3 IMAP Operational Information for the I-40 Study Facility

Figure 7-4 shows the screenshot of benefit cost parameters filled for the case study. The I-40 study site is in Raleigh-Durham metropolitan area where is classified as urban area. This facility has operated IMAP services since 2005. Therefore, the objective of this case study is to ascertain benefits for existing deployment by comparing difference in delay and energy use with and without IMAP on that facility. Given that sample size of incident data were not consistent over years, crash rate calculated using 2010 TEAAS crash data was the input to the estimate of monthly incident

[2] www.northcarolinagasprices.com

rate. However, incident/crash ratio was calculated using 2010 TIMS incident data. The crash rate per 100 million vehicle miles of travel was 100, and the incident/crash ratio was 1.7 on the facility in 2010. Those values were inserted in the screen of crash information as seen in Figure 7-5.

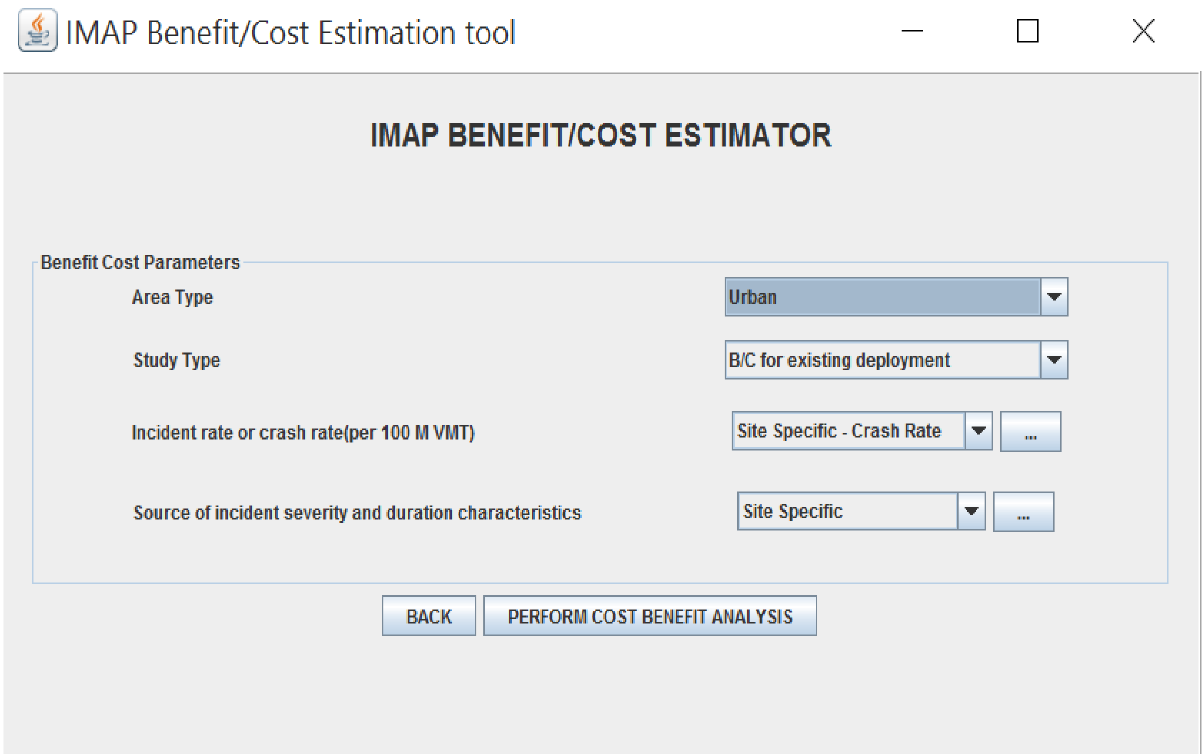


Figure 7-4 Benefit Cost Parameters for the I-40 Study Facility

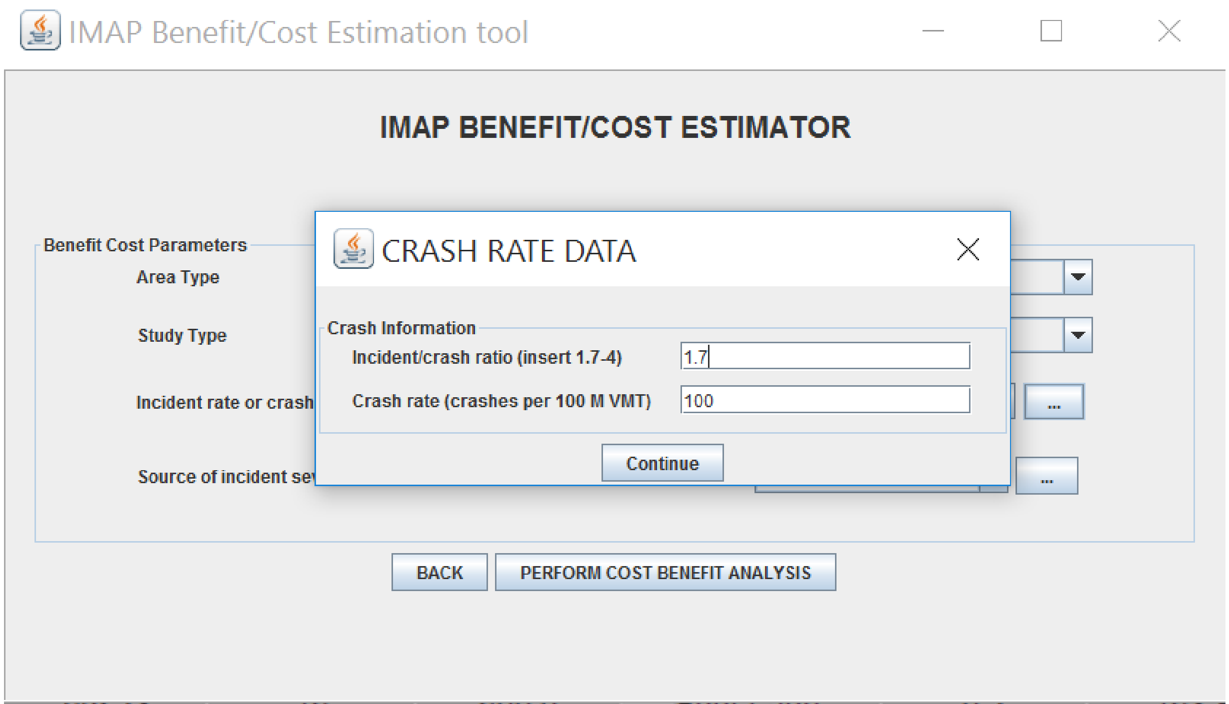
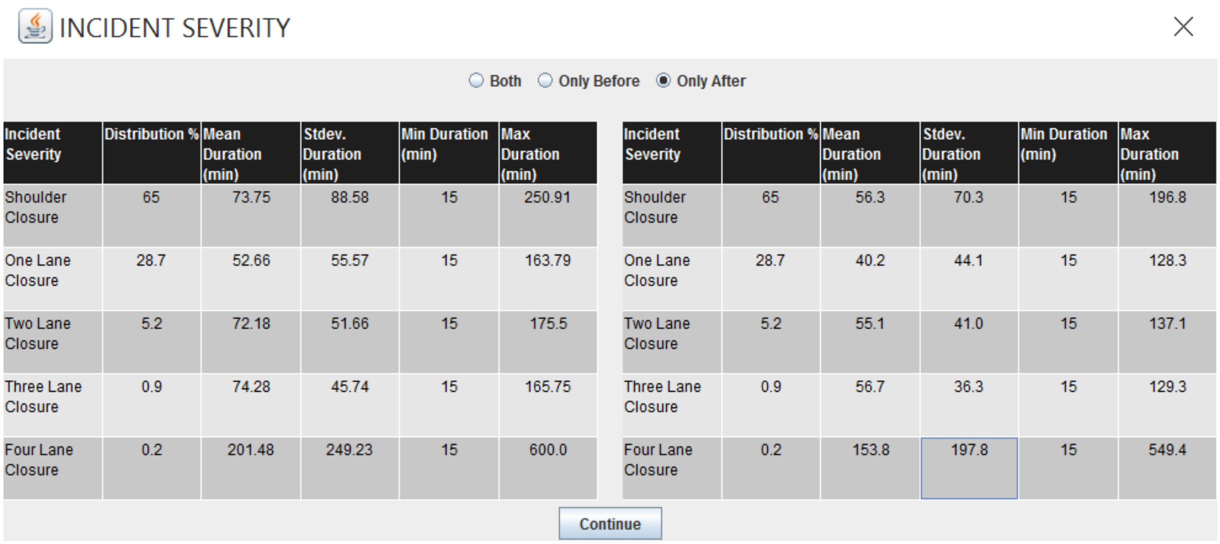


Figure 7-5 Crash Information of I-40 Study Facility

After filling crash information for the facility, incident severity and duration calculated using TIMS incident data in 2010 were filled on the table for only after IMAP (right side) on the tool. The before incident severity and duration characteristics on the left side table in Figure 7-6 were then estimated automatically based on the estimated elasticity and the approach for proposed maximum duration calculation.



INCIDENT SEVERITY

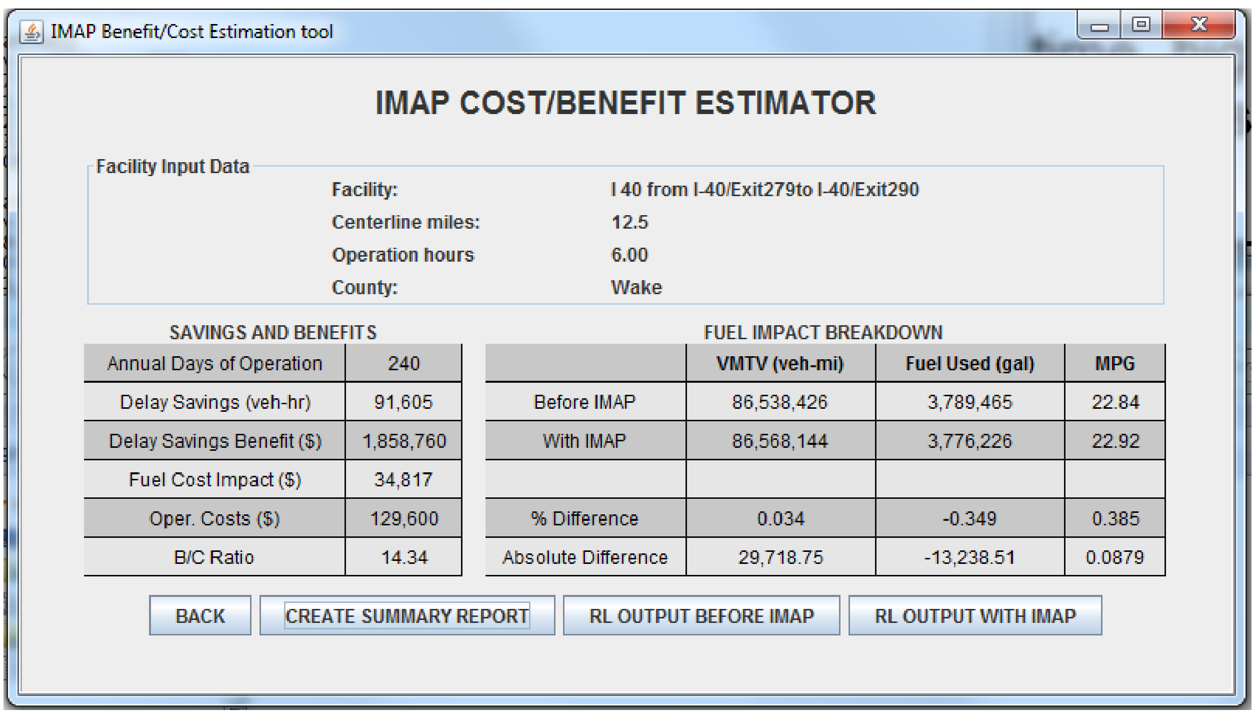
Both | Only Before | Only After

Incident Severity	Distribution %	Mean Duration (min)	Stdev. Duration (min)	Min Duration (min)	Max Duration (min)
Shoulder Closure	65	73.75	88.58	15	250.91
One Lane Closure	28.7	52.66	55.57	15	163.79
Two Lane Closure	5.2	72.18	51.66	15	175.5
Three Lane Closure	0.9	74.28	45.74	15	165.75
Four Lane Closure	0.2	201.48	249.23	15	600.0

Incident Severity	Distribution %	Mean Duration (min)	Stdev. Duration (min)	Min Duration (min)	Max Duration (min)
Shoulder Closure	65	56.3	70.3	15	196.8
One Lane Closure	28.7	40.2	44.1	15	128.3
Two Lane Closure	5.2	55.1	41.0	15	137.1
Three Lane Closure	0.9	56.7	36.3	15	129.3
Four Lane Closure	0.2	153.8	197.8	15	549.4

Continue

Figure 7-6 Incident Severity and Duration Characteristics of I-40 Study Facility



IMAP Benefit/Cost Estimation tool

IMAP COST/BENEFIT ESTIMATOR

Facility Input Data

Facility:	I 40 from I-40/Exit279to I-40/Exit290
Centerline miles:	12.5
Operation hours	6.00
County:	Wake

SAVINGS AND BENEFITS

Annual Days of Operation	240
Delay Savings (veh-hr)	91,605
Delay Savings Benefit ($)	1,858,760
Fuel Cost Impact ($)	34,817
Oper. Costs ($)	129,600
B/C Ratio	14.34

FUEL IMPACT BREAKDOWN

	VMTV (veh-mi)	Fuel Used (gal)	MPG
Before IMAP	86,538,426	3,789,465	22.84
With IMAP	86,568,144	3,776,226	22.92
% Difference	0.034	-0.349	0.385
Absolute Difference	29,718.75	-13,238.51	0.0879

BACK | CREATE SUMMARY REPORT | RL OUTPUT BEFORE IMAP | RL OUTPUT WITH IMAP

Figure 7-7 Benefit/Cost Estimation Result for I-40 Study Facility

After all information filled into the several screen, the benefit/cost estimation was performed. Figure 7-7 depicts the delay savings, changes in fuel consumption, and annual total cost on 240 days over 1 year. Total delay savings across all scenarios were 58,111 veh-hour and $1,183,196 in terms of dollars. Fuel savings for that facility was -89,982 gallon and -$236,652 due to the fact that average across the facility increased 53 mph to 54.1 mph. The costs determined that the total annual cost of deploying IMAP on the facility is $129,600 on the facility. When combined with the benefits, the benefit-cost ratio is 9.13:1.

8. Summary of Findings, Conclusions, and Recommendations

This research project developed frameworks, methodologies, and tools that NCDOT can employ for the following tasks –

- Statewide screening to identify locations with IMAP potential versus current deployment locations
- Benefit-cost analysis for candidate locations for new IMAP deployments
- Benefit-cost analysis for existing IMAP deployments
- Benefit-cost analysis for locations where IMAP service has been removed

The project's research products can be organized into two primary groupings, namely –

- Statewide Screening Framework
    - *Average Historical Congestion Index* (*AHCI*) estimation and analysis
    - Recurring bottleneck identification and characterization
    - Collision classification
    - Screening criteria assessment framework
        - Travel Demand Level
        - Congestion Frequency
        - Secondary Crash Rate (via surrogate of crashes in non-recurring congestion)
        - Crash Severity
- IMAP Benefit-cost Analysis Tool
    - Cost analysis based on deployment characteristics
    - Benefit analysis based on output from FREEVAL

The first three elements of the statewide IMAP screening framework, namely *AHCI* estimation and analysis, recurring bottleneck identification and characterization, and collision classification are incorporated in a software tool that can be provided to NCDOT. The tool operates on a GIS databased created by joining the GADA TEAAS data with the NC Statewide Travel Model shapefile. The tool calculates and adds *AHCI* to each TMC segment within the statewide network (freeways and US primary routes), uses the *AHCI* as the basis for the bottleneck identification for freeways using the methodology described in Chapter 4 and adds the bottleneck attribute to applicable TMC segment, and applies the collision classification methodology to add the classification attribute to the collisions in the database. Therefore, in summary, the software tool creates the augmented statewide TMC segment shapefile that is used in the final screening framework element.

Although, as mentioned, this tool can be provided, the project team's recommendation is that NCDOT incorporate the database routines and algorithms into the enterprise database that is emerging from the department wide data integration activities surrounding the new relationship with HERE as NCDOT's primary traffic data provider. This project report provides the details necessary for database incorporation of the proposed functionality.

With respect to secondary collisions, it is important to note that the project team was not able to document that IMAP service reduces secondary collisions. Therefore, the IMAP benefit-cost tool methodology does not include an IMAP crash reduction factor in the with IMAP versus without IMAP comparison. Nonetheless, high rates of secondary collisions and high proportions of secondary collisions do indicate situation where IMAP service can provide clear benefit. Therefore, the project team was confident in the decision to include secondary crashes in the IMAP screening framework. Furthermore, the project team recommends that the NCDOT Traffic Safety Unit continue to review operational and collision data to see if an IMAP crash reduction factor can eventually be established. Statistical analysis is always challenging for highway safety given the rare and random nature of highway collisions. Also, data resources are improving, and it would not be prudent to abandon the strong intuition that effective IMAP service can reduce the frequency and rate of occurrence of secondary crashes.

The IMAP benefit-cost analysis tool is ready to use. The fidelity of the FREEVAL tool in modeling freeway delay and travel time reliability has been established by SHRP 2 L38 validation efforts. Furthermore, because the IMAP tool uses FREEVAL as the basis for comparative analyses of freeway routes with and without IMAP service, consistency in freeway modeling is more important than the absolute accuracy of the with IMAP and without IMAP results.

The IMAP benefit-cost analysis tool estimates costs based on hourly operator labor costs, hourly IMAP vehicle operating costs, length of the actual or candidate route, and days and hours of operation, and the number of simultaneously operating vehicles. The default rates for these cost elements are based on information provided by NCDOT. However, the rates can be easily modified either for specific conditions or as costs fluctuate over time. Also, an optional fixed cost field is provided to allow the flexibility for including any fixed costs that may not be accounted for in the hourly rates.

Benefits are derived from the FREEVAL output for full reliability runs with identical parameters with the exception that one run simulates operations with no IMAP service and the other run simulates operations with IMAP service. The project team was able to establish from North Carolina data an IMAP service effect of shortening incident durations. Statewide distributions for incident severity and for incident duration were derived. The IMAP benefit-cost analysis tool initiates the FREEVAL analysis using FREEVAL route file (known as a seed file) that must be developed separately. The results of the completed runs are then analyzed to provide benefits in terms of delay savings and fuel savings.

At the time of completion of this project, the need to create a FREEVAL seed for IMAP analysis routes is a serious impediment to NCDOT's ready use of the benefit-cost analysis tool. However, ITRE is currently developing an enhanced version of FREEVAL that will allow easy creation of the required seed file, lowering the analysist time required from hours to minutes. This version of FREEVAL is planned for completion in the last summer or early fall 2016 timeframe. The project team plans to demonstrate the capabilities and ease of use of this new FREEVAL version at the project close out meeting.

Case study results from the tool testing and validation indicate strong benefit-cost ratios for IMAP operation. When the new FREEVAL tool is available and appropriate NCDOT staff are trained and confident in the use of the IMAP benefit-cost analysis tool in conjunction with FREEVAL, the project team recommends that as a first step, NCDOT conduct a benefit-cost analysis for all current IMAP patrol routes, for all routes that have lost service, e.g. I-485 in Charlotte, and for a high-priority route identified on I-95. The prototype statewide screening results indicated that, as expected, the I-95 corridor is an important rural route candidate for new IMAP service.

9. Implementation and Technology Transfer Plan

In additional to this final report, the project team will deliver the IMAP benefit-cost analysis tool. The tool was programmed in Java and will run on any computer that has a compatible version of the Java runtime program installed. If desired, the project team will also provide the TMC segment database augmentation tool that adds *AHCI*, recurrent bottleneck designations, and collision classification attributes. However, as mentioned above, the project team developed this tool to work with the GADA TEAAS joined with the North Carolina Statewide travel model. Therefore, the methods and algorithms embedded in the tool will have the greatest long term value if incorporated into an integrated enterprise database. The project team will provide assistance if necessary in incorporating these capabilities. If the methodologies to add the database attributes of *AHCI*, recurrent bottleneck designation, and collision classification are added to the future integrated enterprise database, NCDOT will be able to easily implement the statewide screening framework developed for the project and described in this final report.

As mentioned above, the IMAP benefit-cost analysis tool is ready for use. However, prior to application of the tool to a specific patrol route, a FREEVAL seed file must be created for the route of interest. While not especially difficult, creating a seed file under the currently available version of FREEVAL does take time, and a valid run must have valid 15-minute demands at the entry point and all on and off ramps along the route for the entire daily operating schedule. Therefore, it would be very difficult for NCDOT to conduct large scale analyses of many patrol routes in house with the current version of FREEVAL.

As also mentioned above, there is a new version of FREEVAL under development at ITRE that will change this situation. The new version of FREEVAL will allow rapid point and click creation of the freeway segmentation using Google Map integration and will allow rapid specification of demands using user selected demand profiles applied to user supplied AADT values. The project team plans to demonstrate the capabilities of the new FREEVAL at the project closeout meeting.

When the new FREEVAL version is ready for distribution in the late summer or early fall of 2016, the project team will on request provide a brief demonstration workshop for interested NCDOT staff. If necessary, a technical assistance project or follow on research project could also be established to provide more extensive training.

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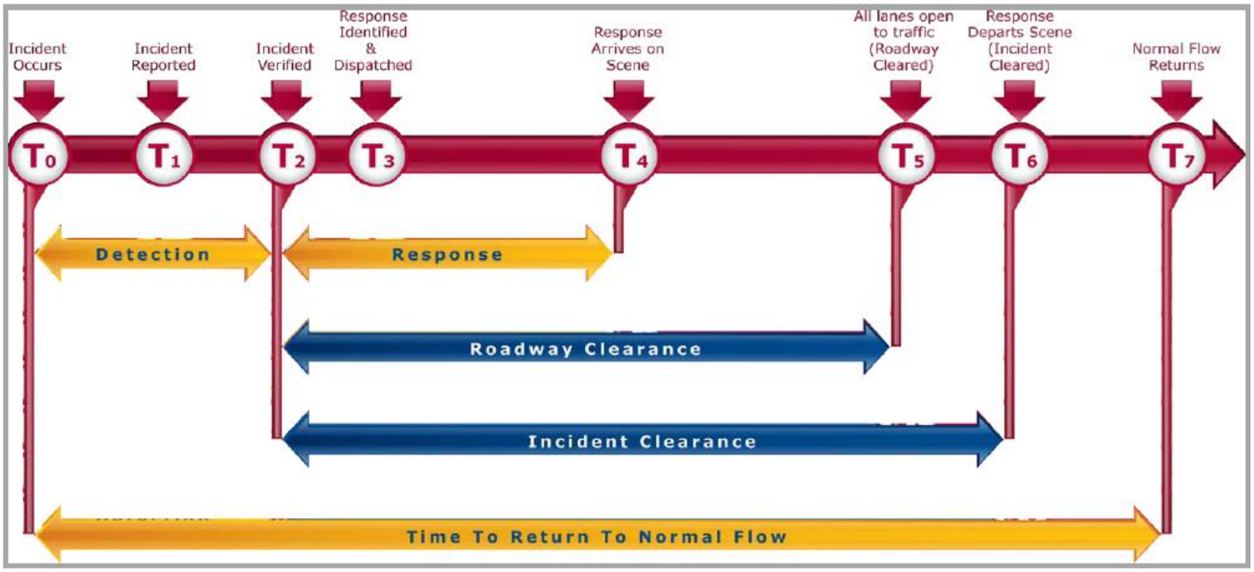
Appendix A - The National Incident Management Timeline

It is important to define a traffic incident management timeline should be defined to define roles and responsibilities for IMAP program. We adopt the national traffic incident management timeline that Georgia has adopted it for traffic incident management (TIM) in Figure A-1.



*SOURCE: GDOT, GEORGIA TRAFFIC INCIDENT MANAGEMENT GUIDELINES, 2011.

Figure A-1 The national incident management timeline

1. Detection

Incident detection involves discovering and identifying the incident.

- Verification (T2): a component of detection involves confirming the incident location and details. If TMC camera coverage is available, operators should assist with verification. However, if camera coverage is not available, motorists and responders assist with verification.

2. Response

The first component of response is notifying response agencies about incident, using details collected during verification. Early notification is the key for a quick incident response. Following notification, response is reacting to an incident with appropriate and available technical, material, and human resources.

3. Roadway Clearance

Roadway clearance time is the number of minutes between verifying the incident (T_2) and confirmation that all travel lanes are open and available for traffic flow (T_5).

4. Incident Clearance

Incident clearance time is the number of minutes between verifying the incident (T_2) and confirming that all responders have left the scene (T_6).

5. Time to return to normal flow

The time to return to normal flow is the period following an incident when traffic is proceeding at its standard or expected rate of speed for a particular segment of roadway.

Appendix B - Glossary of Abbreviations and Terms

AADT – Annual Average Daily Traffic

ADT – Annual Daily Traffic

ASAP – Alabama Service and Assistance Patrol

AVL – Automatic Vehicle Location

CDF – Cumulative Density Function

CHART – Coordinated Highways Action Response Team

CHP – California Highway Police

CMAQ – Congestion Mitigation and Air Quality

CPR – Cardiopulmonary Resuscitation

DOT – Department of Transportation

FDOT – Florida Department of Transportation

FHWA – Federal Highway Administration

FSP – Freeway Service Patrol

FSPE – FSP beat evaluation

GDOT – Georgia Department of Transportation

HCM – Highway Capacity Manual

HAZMAT – Hazardous Materials

HERO – Highway Emergency Response Operations

MAP – Motorist Assistance Program

MM – Mile Marker

MM – Mile Marker to

MoDOT – Missouri Department of Transportation

MOE – Measure of Effectiveness

NCSTM – North Carolina Statewide Transportation Model

NOVA – Northern Virginia

NTIMC – National Traffic Incident Management Coalition

PDF – Probability Density Function

PPP – Public-Private Partnership

RITIS – Regional Integrated Transportation Information System

SAFE – Safety Assistance for Freeway Emergencies

SOP – Standard Operating Procedure

SSP – Safety Service Patrol

TDOT – Tennessee Department of Transportation

TMC – Traffic Management Centers

TOC – Traffic Operation Centers

TTC – Temporary Traffic Control

TxDOT – Texas Department of Transportation

U.S. DOT – United States Department of Transportation

VBA – Visual Basic for Applications

VHD – Vehicle Hourly Delay

VMT – Vehicle Miles of Travel

Appendix C - 2016 IMAP Coverage

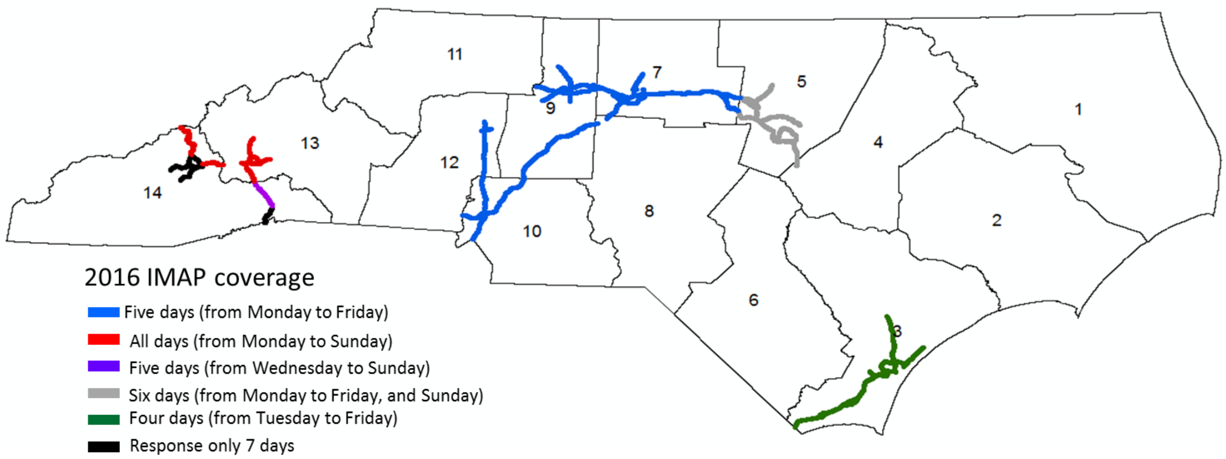


Figure C-1 2016 IMAP Coverage (as of March 2016)

Appendix D - Screening Result by Division

Screening results by division are provided by 30 segments from the highest score. As mentioned in Chapter 4, section 4.2.2.5, these screening results are illustrative only and should not be taken as actionable or definitive.

1. Urban Areas

Division 1

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severity	SCORE
110-05548	I-95	SB	NORTHAMPTON	312	0.23	4	0	0	2	4	0	0.33
110N05548	I-95	SB	NORTHAMPTON	271	0.21	1	0	0	2	2	0	0.25
110P05548	I-95	NB	NORTHAMPTON	265	0.18	4	0	0	1	4	0	0.25
110-05547	I-95	SB	NORTHAMPTON	474	0.14	1	0	0	1	2	0	0.17
110+05548	I-95	NB	NORTHAMPTON	477	0.18	1	0	0	1	2	0	0.17
110+05549	I-95	NB	NORTHAMPTON	306	0.19	1	0	0	1	2	0	0.17

Division 2

There are no urban area interstate segments in Division 2

Division 3

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125+05102	I-40	WB	NEW HANOVER	421	0.01	1	3.57	0	1	2	3	0.29
125N05101	I-40	EB	NEW HANOVER	557	0.48	1	0	0	2	2	0	0.25
125+05103	I-40	WB	PENDER	213	0.02	1	0	0	1	2	0	0.17
125N05102	I-40	EB	NEW HANOVER	195	0.04	1	0	0	1	2	0	0.17
125-05101	I-40	EB	NEW HANOVER	418	0.02	1	0	0	1	2	0	0.17
125-05102	I-40	EB	NEW HANOVER	220	0.01	1	0	0	1	2	0	0.17
125P05102	I-40	WB	NEW HANOVER	172	0.03	1	0	0	1	2	0	0.17
125P05101	I-40	WB	NEW HANOVER	202	0.04	1	0	0	1	2	0	0.17

Division 4

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severity	SCORE
125+04836	I-40	WB	WAKE	1802	0.59	1	0.91	4	2	2	1	0.63
125-04835	I-40	EB	JOHNSTON	1979	0.07	1	1.55	4	1	2	1	0.54
125P05120	I-40	WB	JOHNSTON	1561	0.47	2	3.56	2	2	2	3	0.54
125+05121	I-40	WB	JOHNSTON	1040	0.95	4	5.37	0	2	4	3	0.46
125+04835	I-40	WB	JOHNSTON	1040	1.41	1	0	0	3	2	0	0.33
125+05252	I-95	NB	JOHNSTON	604	0.04	1	11.08	0	1	2	4	0.33
125+04836	I-40	WB	WAKE	1802	0.59	1	0.91	4	2	2	1	0.63
125-04835	I-40	EB	JOHNSTON	1979	0.07	1	1.55	4	1	2	1	0.54
125P05120	I-40	WB	JOHNSTON	1561	0.47	2	3.56	2	2	2	3	0.54
125+05121	I-40	WB	JOHNSTON	1040	0.95	4	5.37	0	2	4	3	0.46
125+04835	I-40	WB	JOHNSTON	1040	1.41	1	0	0	3	2	0	0.33
125+05252	I-95	NB	JOHNSTON	604	0.04	1	11.08	0	1	2	4	0.33
125-15569	I-795	SB	WAYNE	293	0.02	1	6.84	0	1	2	4	0.33
125N05120	I-40	EB	JOHNSTON	1624	0.05	1	0	2	1	2	0	0.33
125N05248	I-95	SB	JOHNSTON	441	0.02	1	43.07	0	1	2	4	0.33
125-05120	I-40	EB	JOHNSTON	1624	0.05	1	0	2	1	2	0	0.33
125-05121	I-40	EB	JOHNSTON	1624	0.05	1	0	2	1	2	0	0.33
125P05249	I-95	NB	JOHNSTON	402	0.06	1	34.32	0	1	2	4	0.33
125P05271	I-95	NB	HALIFAX	302	0.10	1	27.73	0	1	2	4	0.33
125P05119	I-40	WB	JOHNSTON	428	0.05	1	16.04	0	1	2	4	0.33
125P05250	I-95	NB	JOHNSTON	501	0.04	1	12.12	0	1	2	4	0.33
125+05264	I-95	NB	NASH	480	0.03	1	5.11	0	1	2	3	0.29
125-05247	I-95	SB	JOHNSTON	450	0.01	1	4.43	0	1	2	3	0.29
125-05248	I-95	SB	JOHNSTON	441	0.02	1	5.02	0	1	2	3	0.29
125-05262	I-95	SB	NASH	377	0.02	1	5.27	0	1	2	3	0.29
125+05248	I-95	NB	JOHNSTON	348	0.08	4	0	0	1	4	0	0.25
125+05249	I-95	NB	JOHNSTON	495	0.07	1	2.17	0	1	2	2	0.25
125N05119	I-40	EB	JOHNSTON	529	0.04	4	0	0	1	4	0	0.25
125+15570	I-795	NB	WAYNE	299	0.02	1	3.38	0	1	2	2	0.25
125N15569	I-795	SB	WAYNE	215	0.03	4	0	0	1	4	0	0.25
125+05120	I-40	WB	JOHNSTON	696	0.13	1	1.56	0	1	2	1	0.21
125-05118	I-40	EB	JOHNSTON	529	0.05	1	1.03	0	1	2	1	0.21
125-05119	I-40	EB	JOHNSTON	706	0.04	1	1.55	0	1	2	1	0.21
125+05263	I-95	NB	NASH	382	0.02	1	0	0	1	2	0	0.17
125+05250	I-95	NB	JOHNSTON	402	0.04	1	0	0	1	2	0	0.17

Division 5

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125+04982	I-440	WB	WAKE	1823	1.23	4	2.92	4	3	4	2	0.83
125+04965	I-40	WB	WAKE	1829	1.48	1	0.99	4	3	2	1	0.71
125N04904	I-440	EB	WAKE	1236	2.01	4	0	2	4	4	0	0.67
125+04981	I-440	WB	WAKE	2243	1.42	1	0	4	3	2	0	0.67
125P04981	I-440	WB	WAKE	2243	1.42	1	0	4	3	2	0	0.67
125P04964	I-40	WB	WAKE	1532	1.48	4	2.02	2	3	4	2	0.67
125-04984	I-440	EB	WAKE	1831	1.25	1	0	4	3	2	0	0.67
125P04980	I-440	WB	WAKE	1919	1.66	1	0	4	3	2	0	0.67
125N04866	I-40	EB	DURHAM	1285	1.48	1	4.38	2	3	2	3	0.63
125P04860	I-40	WB	WAKE	1346	0.53	4	5.77	2	2	4	3	0.63
125+04857	I-40	WB	WAKE	1980	0.29	2	0	4	2	2	0	0.58
125+04980	I-440	WB	WAKE	1723	2.11	1	0	2	4	2	0	0.58
125N04837	I-40	EB	WAKE	1446	0.64	4	1.77	2	2	4	2	0.58
125N04980	I-440	EB	WAKE	1644	0.48	4	2.57	2	2	4	2	0.58
125N04981	I-440	EB	WAKE	1916	0.39	1	0	4	2	2	0	0.58
125-04862	I-40	EB	WAKE	1407	1.24	2	2.07	2	3	2	2	0.58
125-04980	I-440	EB	WAKE	1916	0.50	1	0	4	2	2	0	0.58
125-04964	I-40	EB	WAKE	1951	0.19	1	1.75	4	1	2	2	0.58
125+04861	I-40	WB	WAKE	1346	0.39	4	0.78	2	2	4	1	0.54
125+04868	I-40	WB	DURHAM	1658	0.57	1	4.24	2	2	2	3	0.54
125+04869	I-40	WB	DURHAM	2512	0.19	2	0.78	4	1	2	1	0.54
125+04966	I-40	WB	WAKE	1587	0.41	4	1.07	2	2	4	1	0.54
125N04962	I-40	EB	WAKE	1236	0.21	2	4.24	2	2	2	3	0.54
125+04838	I-40	WB	WAKE	1517	1.44	1	0	2	3	2	0	0.50
125+04979	I-440	WB	WAKE	1689	1.68	2	0	2	3	2	0	0.50
125+04963	I-40	WB	WAKE	1324	0.25	4	0	2	2	4	0	0.50
125+04985	I-440	WB	WAKE	1870	0.08	1	0	4	1	2	0	0.50
125N04865	I-40	EB	DURHAM	1408	1.77	1	0	2	3	2	0	0.50
125+04991	I-440	WB	WAKE	1546	0.61	4	0	2	2	4	0	0.50
125N04864	I-40	EB	DURHAM	1565	1.15	1	0	2	3	2	0	0.50

Division 6

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125+05224	I-95	NB	ROBESON	552	0.65	1	3.7	0	2	2	3	0.38
125+05229	I-95	NB	CUMBERLAND	512	0.05	1	10.43	0	1	2	4	0.33
125+05242	I-95	NB	HARNETT	589	0.11	2	11.7	0	1	2	4	0.33
125N05240	I-95	SB	HARNETT	403	0.04	1	29.11	0	1	2	4	0.33
125N05229	I-95	SB	CUMBERLAND	476	0.02	1	11.24	0	1	2	4	0.33
125P05240	I-95	NB	HARNETT	356	0.08	1	23.57	0	1	2	4	0.33
125P05230	I-95	NB	CUMBERLAND	527	0.05	1	30.03	0	1	2	4	0.33
125+05227	I-95	NB	CUMBERLAND	555	0.03	1	5.8	0	1	2	3	0.29
125+05232	I-95	NB	CUMBERLAND	463	0.09	1	3.52	0	1	2	3	0.29
125+05221	I-95	NB	ROBESON	472	0.07	2	5.41	0	1	2	3	0.29
125-05221	I-95	SB	ROBESON	664	0.01	1	6.63	0	1	2	3	0.29
125-05241	I-95	SB	HARNETT	615	0.06	1	3.72	0	1	2	3	0.29
125-05230	I-95	SB	CUMBERLAND	727	0.05	1	4.36	0	1	2	3	0.29
125+05231	I-95	NB	CUMBERLAND	721	0.05	1	2.2	0	1	2	2	0.25
125N05227	I-95	SB	CUMBERLAND	401	0.05	4	0	0	1	4	0	0.25
125N05230	I-95	SB	CUMBERLAND	538	0.04	4	0	0	1	4	0	0.25
125N05598	I-95 BUS	SB	CUMBERLAND	220	0.39	1	0	0	2	2	0	0.25
125P05598	I-95 BUS	NB	CUMBERLAND	182	0.23	1	0	0	2	2	0	0.25
125-05223	I-95	SB	ROBESON	558	0.40	1	0	0	2	2	0	0.25
125P05241	I-95	NB	HARNETT	589	0.08	4	0	0	1	4	0	0.25
125P05222	I-95	NB	ROBESON	587	0.11	4	0	0	1	4	0	0.25
125-05226	I-95	SB	ROBESON	578	0.05	1	1.78	0	1	2	2	0.25
125+05230	I-95	NB	CUMBERLAND	777	0.04	1	0	0	1	2	0	0.17
125+05220	I-95	NB	ROBESON	278	0.03	2	0	0	1	2	0	0.17
125+05222	I-95	NB	ROBESON	671	0.05	1	0	0	1	2	0	0.17
125+05223	I-95	NB	ROBESON	590	0.14	1	0	0	1	2	0	0.17
125+05240	I-95	NB	HARNETT	437	0.08	2	0	0	1	2	0	0.17
125+05241	I-95	NB	HARNETT	356	0.10	1	0	0	1	2	0	0.17
125N05222	I-95	SB	ROBESON	658	0.02	1	0	0	1	2	0	0.17
125N05232	I-95	SB	CUMBERLAND	363	0.04	2	0	0	1	2	0	0.17

Division 7

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125P04601	I-40	EB	GUILFORD	1232	0.31	4	3.94	2	2	4	3	0.63
125-04602	I-40	WB	GUILFORD	1406	0.22	4	0	2	2	4	0	0.50
125P04602	I-40	EB	GUILFORD	1132	0.51	4	6.86	0	2	4	4	0.50
125N04682	I-40	WB	GUILFORD	850	0.23	4	6.81	0	2	4	3	0.46
125+04603	I-40	EB	GUILFORD	1393	0.64	2	0	2	2	2	0	0.42
125+04602	I-40	EB	GUILFORD	1486	0.38	2	0	2	2	2	0	0.42
125-09614	I-40	WB	GUILFORD	173	0.05	4	66.55	0	1	4	4	0.42
125P04592	I-85	NB	GUILFORD	1232	0.27	1	0	2	2	2	0	0.42
125-04873	I-40	EB	ORANGE	1429	0.05	1	0.94	2	1	2	1	0.38
125P04588	I-85	NB	GUILFORD	653	0.06	4	6.25	0	1	4	3	0.38
125P04873	I-40	WB	ORANGE	1139	0.14	4	5.13	0	1	4	3	0.38
125+04873	I-40	WB	ORANGE	966	0.21	2	2.95	0	2	2	2	0.33
125N09699	I-85	SB	GUILFORD	296	0.04	1	10.39	0	1	2	4	0.33
125P06227	I-85 BUS	NB	GUILFORD	691	1.76	1	0	0	3	2	0	0.33
125-04799	I-85	SB	ORANGE	1337	0.11	1	0	2	1	2	0	0.33
125-04872	I-40	EB	DURHAM	1276	0.03	1	0	2	1	2	0	0.33
125P09614	I-40	EB	GUILFORD	568	0.07	1	36.39	0	1	2	4	0.33
125P09699	I-85	NB	GUILFORD	329	0.05	1	8.29	0	1	2	4	0.33
125P04690	I-40	EB	GUILFORD	661	0.34	4	0	0	2	4	0	0.33
125P04800	I-85	NB	ORANGE	81	0.05	1	423.9	0	1	2	4	0.33
125-04585	I-85	SB	RANDOLPH	584	0.07	1	7.08	0	1	2	4	0.33
125P04688	I-40	EB	GUILFORD	678	0.09	2	11.17	0	1	2	4	0.33
125-04688	I-40	WB	GUILFORD	878	0.05	1	30.32	0	1	2	4	0.33
125P04586	I-85	NB	GUILFORD	535	0.03	1	7.57	0	1	2	4	0.33
125+04682	I-40	EB	GUILFORD	1016	0.06	1	4.04	0	1	2	3	0.29
125+04689	I-40	EB	GUILFORD	945	0.11	2	3.74	0	1	2	3	0.29
125+04684	I-40	EB	GUILFORD	903	0.06	1	4.1	0	1	2	3	0.29
125+04590	I-85	NB	GUILFORD	166	0.04	1	3.83	0	1	2	3	0.29
125-09701	I-85	SB	GUILFORD	360	0.02	1	4.07	0	1	2	3	0.29
125+09703	I-85	NB	GUILFORD	244	0.03	1	6.72	0	1	2	3	0.29

Division 8

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125N04585	I-85	SB	RANDOLPH	584	0.05	2	20.95	0	1	2	4	0.33
125+05528	I-73/I-74	NB	RANDOLPH	601	0.03	1	8.6	0	1	2	4	0.33
125+04595	I-85 BUS	NB	RANDOLPH	388	0.24	1	0	0	2	2	0	0.25
125+04583	I-85	NB	RANDOLPH	772	0.07	2	1.94	0	1	2	2	0.25
125P05534	I-73/I-74	NB	RANDOLPH	584	0.04	4	0	0	1	4	0	0.25
125+04585	I-85	NB	RANDOLPH	812	0.05	1	0.84	0	1	2	1	0.21
125+04596	I-85 BUS	NB	RANDOLPH	796	0.14	1	0	0	1	2	0	0.17
125+04584	I-85	NB	RANDOLPH	641	0.06	1	0	0	1	2	0	0.17
125-06225	I-85 BUS	SB	DAVIDSON	376	0.08	1	0	0	1	2	0	0.17
125N04596	I-85 BUS	SB	RANDOLPH	634	0.14	1	0	0	1	2	0	0.17
125+05532	I-73/I-74	NB	RANDOLPH	848	0.04	1	0	0	1	2	0	0.17
125N04595	I-85 BUS	SB	RANDOLPH	703	0.06	1	0	0	1	2	0	0.17
125N04584	I-85	SB	RANDOLPH	746	0.06	1	0	0	1	2	0	0.17
125+05530	I-73/I-74	NB	RANDOLPH	549	0.03	1	0	0	1	2	0	0.17
125+05534	I-73/I-74	NB	RANDOLPH	691	0.03	1	0	0	1	2	0	0.17
125+05535	I-73/I-74	NB	RANDOLPH	736	0.03	1	0	0	1	2	0	0.17
125N04583	I-85	SB	RANDOLPH	617	0.03	1	0	0	1	2	0	0.17
125N05530	I-73/I-74	SB	RANDOLPH	494	0.05	1	0	0	1	2	0	0.17
125N05527	I-73/I-74	SB	RANDOLPH	301	0.04	1	0	0	1	2	0	0.17
125N05533	I-73/I-74	SB	RANDOLPH	676	0.04	1	0	0	1	2	0	0.17
125N05535	I-73/I-74	SB	RANDOLPH	507	0.05	1	0	0	1	2	0	0.17
125N05520	I-73	SB	RANDOLPH	332	0.03	1	0	0	1	2	0	0.17
125N05529	I-73/I-74	SB	RANDOLPH	396	0.05	1	0	0	1	2	0	0.17
125N05531	I-73/I-74	SB	RANDOLPH	494	0.04	1	0	0	1	2	0	0.17
125N05528	I-73/I-74	SB	RANDOLPH	450	0.07	1	0	0	1	2	0	0.17
125+05529	I-73/I-74	NB	RANDOLPH	413	0.20	1	0	0	1	2	0	0.17
125+05536	I-73/I-74	NB	RANDOLPH	685	0.03	1	0	0	1	2	0	0.17
125N05534	I-73/I-74	SB	RANDOLPH	516	0.05	1	0	0	1	2	0	0.17
125N05536	I-73/I-74	SB	RANDOLPH	400	0.14	1	0	0	1	2	0	0.17
125N05519	I-73	SB	RANDOLPH	400	0.03	1	0	0	1	2	0	0.17

Division 9

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125+04885	I-40 BUS	EB	FORSYTH	2101	3.82	1	0	4	4	2	0	0.75
125P04676	I-40	EB	FORSYTH	1415	0.26	4	8.62	2	2	4	4	0.67
125+04884	I-40 BUS	EB	FORSYTH	1622	5.45	1	0	2	4	2	0	0.58
125+04886	I-40 BUS	EB	FORSYTH	1563	3.06	1	0	2	4	2	0	0.58
125N04888	I-40 BUS	WB	FORSYTH	1549	2.20	1	0	2	4	2	0	0.58
125-04885	I-40 BUS	WB	FORSYTH	1563	3.50	1	0	2	4	2	0	0.58
125P04884	I-40 BUS	EB	FORSYTH	1622	3.30	1	0	2	4	2	0	0.58
125P04885	I-40 BUS	EB	FORSYTH	1332	2.40	1	0	2	4	2	0	0.58
125P04887	I-40 BUS	EB	FORSYTH	1549	4.19	1	0	2	4	2	0	0.58
125P04888	I-40 BUS	EB	FORSYTH	1549	2.68	1	0	2	4	2	0	0.58
125+04887	I-40 BUS	EB	FORSYTH	1658	1.45	1	0	2	3	2	0	0.50
125N04884	I-40 BUS	WB	FORSYTH	1622	1.52	1	0	2	3	2	0	0.50
125N04886	I-40 BUS	WB	FORSYTH	1563	1.29	1	0	2	3	2	0	0.50
125N04885	I-40 BUS	WB	FORSYTH	1332	1.54	1	0	2	3	2	0	0.50
125N04887	I-40 BUS	WB	FORSYTH	1549	1.68	1	0	2	3	2	0	0.50
125-04886	I-40 BUS	WB	FORSYTH	1658	1.93	1	0	2	3	2	0	0.50
125-04884	I-40 BUS	WB	FORSYTH	1332	1.30	1	0	2	3	2	0	0.50
125-04883	I-40 BUS	WB	FORSYTH	1622	1.01	1	0	2	3	2	0	0.50
125P04886	I-40 BUS	EB	FORSYTH	1563	1.36	1	0	2	3	2	0	0.50
125+04889	I-40 BUS	EB	FORSYTH	1244	1.00	1	0	2	2	2	0	0.42
125+04677	I-40	EB	FORSYTH	1707	0.24	1	0	2	2	2	0	0.42
125+04676	I-40	EB	FORSYTH	1474	0.20	4	0	2	1	4	0	0.42
125+04678	I-40	EB	FORSYTH	1203	0.10	1	2.53	2	1	2	2	0.42
125+04883	I-40 BUS	EB	FORSYTH	1123	2.87	1	0	0	4	2	0	0.42
125N04676	I-40	WB	FORSYTH	1512	0.10	1	2.7	2	1	2	2	0.42
125N05024	I-85	SB	DAVIDSON	457	0.05	4	20.07	0	1	4	4	0.42
125-04887	I-40 BUS	WB	FORSYTH	985	3.00	1	0	0	4	2	0	0.42
125-04889	I-40 BUS	WB	FORSYTH	1255	0.55	1	0	2	2	2	0	0.42
125P04582	I-85	NB	DAVIDSON	612	0.06	4	19.47	0	1	4	4	0.42
125P04883	I-40 BUS	EB	FORSYTH	888	3.26	1	0	0	4	2	0	0.42

Division 10

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125+04779	I-77	NB	MECKLENBURG	2300	3.35	4	1.58	4	4	4	1	0.88
125+04783	I-77	NB	MECKLENBURG	1830	1.10	4	4.57	4	3	4	3	0.88
125+04663	I-485	CL.	MECKLENBURG	2591	2.67	0	0	4	4	2	2	0.83
125+04662	I-485	CL.	MECKLENBURG	2244	2.48	0	0	4	4	2	2	0.83
125N04662	I-485	CCL.	MECKLENBURG	1818	2.40	0	0	4	4	2	2	0.83
125N04664	I-485	CCL.	MECKLENBURG	2004	6.26	0	0	4	4	2	2	0.83
125N04663	I-485	CCL.	MECKLENBURG	1833	2.96	0	0	4	4	2	2	0.83
125N04665	I-485	CCL.	MECKLENBURG	1879	2.62	0	0	4	4	2	2	0.83
125N04775	I-77	SB	MECKLENBURG	2528	1.06	1	11.86	4	3	2	4	0.83
125-04663	I-485	CCL.	MECKLENBURG	2618	6.09	0	0	4	4	2	2	0.83
125-04664	I-485	CCL.	MECKLENBURG	2357	5.25	0	0	4	4	2	2	0.83
125P04662	I-485	CL.	MECKLENBURG	1881	3.18	0	0	4	4	2	2	0.83
125P04778	I-77	NB	MECKLENBURG	1862	3.44	4	0	4	4	4	0	0.83
125-04662	I-485	CCL.	MECKLENBURG	2558	2.26	0	0	4	4	2	2	0.83
125+04778	I-77	NB	MECKLENBURG	1862	3.31	1	0	4	4	2	0	0.75
125+04661	I-485	CL.	MECKLENBURG	1911	1.90	0	0	4	3	2	2	0.75
125-04781	I-77	SB	MECKLENBURG	1848	1.45	4	0	4	3	4	0	0.75
125-04788	I-77	SB	MECKLENBURG	1531	1.32	4	10.46	2	3	4	4	0.75
125-04661	I-485	CCL.	MECKLENBURG	2161	1.06	0	0	4	3	2	2	0.75
125+04784	I-77	NB	MECKLENBURG	1638	1.30	4	6.59	2	3	4	3	0.71
125+04775	I-77	NB	MECKLENBURG	2006	1.04	1	0.95	4	3	2	1	0.71
125N04778	I-77	SB	MECKLENBURG	2322	0.29	1	4.07	4	2	2	3	0.71
125N04793	I-77	SB	MECKLENBURG	1213	3.14	2	4	2	4	2	3	0.71
125+04664	I-485	CL.	MECKLENBURG	2590	0.92	0	0	4	2	2	2	0.67
125+04777	I-77	NB	MECKLENBURG	1496	2.41	4	0	2	4	4	0	0.67
125+04665	I-485	CL.	MECKLENBURG	2452	0.32	0	0	4	2	2	2	0.67
125+04776	I-77	NB	MECKLENBURG	1879	1.14	1	0	4	3	2	0	0.67
125+04780	I-77	NB	MECKLENBURG	1642	2.82	4	0	2	4	4	0	0.67
125+04641	I-85	NB	MECKLENBURG	1845	1.39	1	0	4	3	2	0	0.67
125+04648	I-85	NB	CABARRUS	1947	0.32	1	1.79	4	2	2	2	0.67

Division 11

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125N05555	I-74	EB	SURRY	162	0.07	1	0	0	1	2	0	0.17
125N05557	I-74	EB	SURRY	314	0.08	1	0	0	1	2	0	0.17
125-05555	I-74	EB	SURRY	191	0.06	1	0	0	1	2	0	0.17
125P05555	I-74	WB	SURRY	199	0.08	1	0	0	1	2	0	0.17
125P05557	I-74	WB	SURRY	118	0.06	1	0	0	1	2	0	0.17

Division 12

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125-04629	I-85	SB	GASTON	1220	1.07	1	0	2	3	2	0	0.50
125+04629	I-85	NB	GASTON	1312	0.32	1	0	2	2	2	0	0.42
125N05359	I-77	SB	IREDELL	711	0.23	2	18.6	0	2	2	4	0.42
125N05346	I-40	WB	IREDELL	821	0.22	1	7.92	0	2	2	4	0.42
125-04628	I-85	SB	GASTON	1298	0.48	1	0	2	2	2	0	0.42
125P05346	I-40	EB	IREDELL	821	0.21	1	7.97	0	2	2	4	0.42
125N04630	I-85	SB	GASTON	865	1.19	1	0	0	3	2	0	0.33
125N05334	I-40	WB	CATAWBA	827	0.03	1	7.62	0	1	2	4	0.33
125N05344	I-40	WB	IREDELL	615	0.07	1	33.46	0	1	2	4	0.33
125N05353	I-77	SB	IREDELL	927	0.98	4	0	0	2	4	0	0.33
125-04627	I-85	SB	GASTON	1228	0.11	1	0	2	1	2	0	0.33
125-05353	I-77	SB	IREDELL	1165	0.46	4	0	0	2	4	0	0.33
125P04627	I-85	NB	GASTON	1077	0.75	4	0	0	2	4	0	0.33
125P05357	I-77	NB	IREDELL	579	0.14	1	23.85	0	1	2	4	0.33
125P05345	I-40	EB	IREDELL	721	0.14	1	13.18	0	1	2	4	0.33
125P05332	I-40	EB	CATAWBA	334	0.04	1	8.83	0	1	2	4	0.33
125P04628	I-85	NB	GASTON	1149	0.54	4	0	0	2	4	0	0.33
125+04624	I-85	NB	GASTON	843	0.22	1	1.44	0	2	2	1	0.29
125+05359	I-77	NB	IREDELL	755	0.17	1	4.38	0	1	2	3	0.29
125+05349	I-40	EB	IREDELL	470	0.03	1	3.88	0	1	2	3	0.29
125+04628	I-85	NB	GASTON	1179	0.65	2	0	0	2	2	0	0.25
125+04626	I-85	NB	GASTON	1190	0.43	1	0	0	2	2	0	0.25
125+04625	I-85	NB	GASTON	940	0.25	1	0	0	2	2	0	0.25
125+04627	I-85	NB	GASTON	1136	0.56	2	0	0	2	2	0	0.25
125+05343	I-40	EB	IREDELL	858	0.04	4	0	0	1	4	0	0.25
125+05357	I-77	NB	IREDELL	929	0.10	1	2.62	0	1	2	2	0.25
125N04629	I-85	SB	GASTON	1142	0.79	1	0	0	2	2	0	0.25
125N04628	I-85	SB	GASTON	1199	0.21	1	0	0	2	2	0	0.25
125+05333	I-40	EB	CATAWBA	975	0.03	1	2.4	0	1	2	2	0.25
125+05346	I-40	EB	IREDELL	788	0.16	4	0	0	1	4	0	0.25

Division 13

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125-05208	I-240	WB	BUNCOMBE	1464	1.92	4	0	2	3	4	0	0.58
125N05206	I-240	WB	BUNCOMBE	900	5.47	2	6.59	0	4	2	3	0.54
125+05208	I-240	EB	BUNCOMBE	1464	1.35	2	0	2	3	2	0	0.50
125N05207	I-240	WB	BUNCOMBE	904	0.98	4	30.98	0	2	4	4	0.50
125N05208	I-240	WB	BUNCOMBE	1464	1.44	2	0	2	3	2	0	0.50
125-05207	I-240	WB	BUNCOMBE	904	1.00	4	55.45	0	2	4	4	0.50
125-05206	I-240	WB	BUNCOMBE	657	2.03	4	0	0	4	4	0	0.50
125-05209	I-240	WB	BUNCOMBE	1425	1.27	1	0	2	3	2	0	0.50
125+05328	I-40	EB	BURKE	865	0.03	4	9.03	0	1	4	4	0.42
125+05207	I-240	EB	BUNCOMBE	738	1.33	4	0	0	3	4	0	0.42
125+05209	I-240	EB	BUNCOMBE	1464	0.74	1	0	2	2	2	0	0.42
125N05209	I-240	WB	BUNCOMBE	858	1.51	4	0	0	3	4	0	0.42
125N05201	I-26	EB	BUNCOMBE	327	0.28	1	15.91	0	2	2	4	0.42
125N05203	I-240	WB	BUNCOMBE	720	0.18	4	13.53	0	1	4	4	0.42
125P05208	I-240	EB	BUNCOMBE	1464	0.52	2	0	2	2	2	0	0.42
125P05209	I-240	EB	BUNCOMBE	1425	0.59	1	0	2	2	2	0	0.42
125+05302	I-40	EB	BUNCOMBE	684	0.18	4	5.87	0	1	4	3	0.38
125+05299	I-40	EB	BUNCOMBE	472	0.21	1	6.1	0	2	2	3	0.38
125N05214	I-240	WB	BUNCOMBE	273	0.04	1	86.62	0	1	2	4	0.33
125N05322	I-40	WB	BURKE	554	0.02	1	12.81	0	1	2	4	0.33
125N05327	I-40	WB	BURKE	825	0.01	1	9.18	0	1	2	4	0.33
125N05213	I-240	WB	BUNCOMBE	273	0.07	1	232.79	0	1	2	4	0.33
125N05210	I-240	WB	BUNCOMBE	879	0.73	4	0	0	2	4	0	0.33
125N05299	I-40	WB	BUNCOMBE	573	0.04	1	36.17	0	1	2	4	0.33
125-05202	I-240	WB	BUNCOMBE	836	0.13	2	10.84	0	1	2	4	0.33
125P05206	I-240	EB	BUNCOMBE	738	0.79	4	0	0	2	4	0	0.33
125P05201	I-26	WB	BUNCOMBE	327	0.11	1	15.71	0	1	2	4	0.33
125P05319	I-40	EB	BURKE	501	0.01	1	19.57	0	1	2	4	0.33
125P05304	I-40	EB	BUNCOMBE	649	0.04	1	10.16	0	1	2	4	0.33
125P05205	I-240	EB	BUNCOMBE	809	0.22	4	0	0	2	4	0	0.33

Division 14

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125-05194	I-26	EB	HENDERSON	1086	0.01	1	7.49	0	1	2	4	0.33
125+05295	I-40	EB	HAYWOOD	542	0.05	1	3.55	0	1	2	3	0.29
125-05193	I-26	EB	POLK	795	0.11	1	1.78	0	1	2	2	0.25
125-05195	I-26	EB	HENDERSON	1009	0.04	1	3.32	0	1	2	2	0.25
125P05195	I-26	WB	HENDERSON	720	0.06	4	0	0	1	4	0	0.25
125P05196	I-26	WB	HENDERSON	670	0.05	4	0	0	1	4	0	0.25
125+05194	I-26	WB	HENDERSON	760	0.08	1	0.92	0	1	2	1	0.21
125+05198	I-26	WB	BUNCOMBE	720	0.13	1	1.66	0	1	2	1	0.21
125+05196	I-26	WB	HENDERSON	938	0.07	2	0	0	1	2	0	0.17
125+05296	I-40	EB	HAYWOOD	593	0.05	1	0	0	1	2	0	0.17
125+05294	I-40	EB	HAYWOOD	295	0.03	1	0	0	1	2	0	0.17
125+05197	I-26	WB	HENDERSON	792	0.05	1	0	0	1	2	0	0.17
125N05295	I-40	WB	HAYWOOD	495	0.04	1	0	0	1	2	0	0.17
125N05196	I-26	EB	HENDERSON	640	0.04	1	0	0	1	2	0	0.17
125N05197	I-26	EB	HENDERSON	516	0.04	1	0	0	1	2	0	0.17
125N05195	I-26	EB	HENDERSON	757	0.02	1	0	0	1	2	0	0.17
125+05195	I-26	WB	HENDERSON	1039	0.06	1	0	0	1	2	0	0.17
125N05294	I-40	WB	HAYWOOD	343	0.03	1	0	0	1	2	0	0.17
125N05194	I-26	EB	HENDERSON	167	0.02	1	0	0	1	2	0	0.17
125N05296	I-40	WB	HAYWOOD	578	0.07	1	0	0	1	2	0	0.17
125-05293	I-40	WB	HAYWOOD	372	0.03	1	0	0	1	2	0	0.17
125-05294	I-40	WB	HAYWOOD	594	0.05	1	0	0	1	2	0	0.17
125-05196	I-26	EB	HENDERSON	793	0.07	1	0	0	1	2	0	0.17
125-05197	I-26	EB	HENDERSON	702	0.09	1	0	0	1	2	0	0.17
125-05295	I-40	WB	HAYWOOD	621	0.04	1	0	0	1	2	0	0.17
125P05194	I-26	WB	HENDERSON	760	0.04	1	0	0	1	2	0	0.17
125P05296	I-40	EB	HAYWOOD	593	0.04	1	0	0	1	2	0	0.17
125P05197	I-26	WB	HENDERSON	518	0.04	1	0	0	1	2	0	0.17
125P05295	I-40	EB	HAYWOOD	463	0.04	1	0	0	1	2	0	0.17
125P05294	I-40	EB	HAYWOOD	279	0.05	1	0	0	1	2	0	0.17

2. Rural Areas

Division 1

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
110-05549	I-95	SB	NORTHAMPTON	422	0.29	4	0	0	2	4	0	0.3
110P05549	I-95	NB	NORTHAMPTON	306	0.16	4	0	0	1	4	0	0.25
110+05414	I-95	NB	NORTHAMPTON	416	0.07	1	0	0	1	2	0	0.15
110+05550	I-95	NB	NORTHAMPTON	416	0.08	1	0	0	1	2	0	0.15
110N05549	I-95	SB	NORTHAMPTON	422	0.18	1	0	0	1	2	0	0.15

Division 2

There are no rural area interstate segments in Division 2

Division 3

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125-05103	I-40	EB	PENDER	103	0.01	1	7.24	0	1	2	4	0.55
125+05116	I-40	WB	JOHNSTON	193	0.03	1	5.18	0	1	2	3	0.45
125-05115	I-40	EB	SAMPSON	181	0.01	1	5.49	0	1	2	3	0.45
125-05104	I-40	EB	PENDER	152	0.01	1	2.82	0	1	2	2	0.35
125-05111	I-40	EB	DUPLIN	139	0.01	1	2.92	0	1	2	2	0.35
125P05109	I-40	WB	DUPLIN	180	0.03	4	0	0	1	4	0	0.25
125+05110	I-40	WB	DUPLIN	180	0.01	1	0	0	1	2	0	0.15
125+05104	I-40	WB	PENDER	109	0.01	1	0	0	1	2	0	0.15
125+05105	I-40	WB	PENDER	139	0.04	1	0	0	1	2	0	0.15
125+05112	I-40	WB	SAMPSON	156	0.01	1	0	0	1	2	0	0.15
125+05114	I-40	WB	SAMPSON	157	0.02	1	0	0	1	2	0	0.15
125+05113	I-40	WB	SAMPSON	166	0.02	1	0	0	1	2	0	0.15
125+05115	I-40	WB	SAMPSON	195	0.03	1	0	0	1	2	0	0.15
125+05106	I-40	WB	DUPLIN	156	0.01	1	0	0	1	2	0	0.15
125+05107	I-40	WB	DUPLIN	149	0.02	1	0	0	1	2	0	0.15
125N05103	I-40	EB	PENDER	220	0.01	1	0	0	1	2	0	0.15
125+05109	I-40	WB	DUPLIN	128	0.02	1	0	0	1	2	0	0.15
125+05111	I-40	WB	DUPLIN	200	0.01	1	0	0	1	2	0	0.15
125N05110	I-40	EB	DUPLIN	134	0.03	1	0	0	1	2	0	0.15
125N05111	I-40	EB	DUPLIN	126	0.02	1	0	0	1	2	0	0.15
125N05105	I-40	EB	PENDER	113	0.01	1	0	0	1	2	0	0.15
125N05112	I-40	EB	SAMPSON	139	0.02	1	0	0	1	2	0	0.15
125-05113	I-40	EB	SAMPSON	143	0.01	1	0	0	1	2	0	0.15
125-05110	I-40	EB	DUPLIN	184	0.01	1	0	0	1	2	0	0.15
125P05104	I-40	WB	PENDER	105	0.02	1	0	0	1	2	0	0.15
125P05111	I-40	WB	DUPLIN	200	0.03	1	0	0	1	2	0	0.15
125P05105	I-40	WB	PENDER	131	0.02	1	0	0	1	2	0	0.15
125P05108	I-40	WB	DUPLIN	113	0.02	1	0	0	1	2	0	0.15
125P05114	I-40	WB	SAMPSON	141	0.03	1	0	0	1	2	0	0.15
125P05103	I-40	WB	PENDER	93	0.03	1	0	0	1	2	0	0.15
125P05110	I-40	WB	DUPLIN	147	0.03	1	0	0	1	2	0	0.15
125P05113	I-40	WB	SAMPSON	166	0.02	1	0	0	1	2	0	0.15
125P05115	I-40	WB	SAMPSON	148	0.03	1	0	0	1	2	0	0.15
125P05106	I-40	WB	DUPLIN	149	0.02	1	0	0	1	2	0	0.15
125P05107	I-40	WB	DUPLIN	113	0.01	1	0	0	1	2	0	0.15
125-05105	I-40	EB	PENDER	161	0.01	2	0	0	1	2	0	0.15
125-05109	I-40	EB	DUPLIN	167	0.01	1	0	0	1	2	0	0.15
125P05112	I-40	WB	SAMPSON	100	0.02	1	0	0	1	2	0	0.15

Division 4

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125P05245	I-95	NB	JOHNSTON	254	0.03	4	36.23	0	1	4	4	0.65
125+05269	I-95	NB	HALIFAX	253	0.11	1	17.99	0	1	2	4	0.55
125+05256	I-95	NB	JOHNSTON	315	0.06	1	12.16	0	1	2	4	0.55
125+05266	I-95	NB	NASH	349	0.06	1	9.18	0	1	2	4	0.55
125+05258	I-95	NB	WILSON	264	0.02	1	7.41	0	1	2	4	0.55
125N05266	I-95	SB	NASH	290	0.02	1	59.44	0	1	2	4	0.55
125N05267	I-95	SB	HALIFAX	234	0.02	1	37.45	0	1	2	4	0.55
125N05245	I-95	SB	JOHNSTON	254	0.03	1	18.55	0	1	2	4	0.55
125N05268	I-95	SB	HALIFAX	230	0.15	1	31.49	0	1	2	4	0.55
125N05269	I-95	SB	HALIFAX	306	0.15	1	29.43	0	1	2	4	0.55
125N05259	I-95	SB	WILSON	360	0.03	1	15.28	0	1	2	4	0.55
125-05260	I-95	SB	WILSON	398	0.04	1	7.2	0	1	2	4	0.55
125-05261	I-95	SB	NASH	385	0.05	1	9.42	0	1	2	4	0.55
125P05117	I-40	WB	JOHNSTON	249	0.04	1	11	0	1	2	4	0.55
125P05267	I-95	NB	HALIFAX	233	0.08	1	38.34	0	1	2	4	0.55
125P05270	I-95	NB	HALIFAX	228	0.05	1	156.4	0	1	2	4	0.55
125P05257	I-95	NB	JOHNSTON	314	0.04	1	47.83	0	1	2	4	0.55
125-05268	I-95	SB	HALIFAX	253	0.23	2	5.98	0	2	2	3	0.5
125+05262	I-95	NB	NASH	385	0.04	1	3.68	0	1	2	3	0.45
125+05261	I-95	NB	NASH	385	0.03	1	5.49	0	1	2	3	0.45
125+05268	I-95	NB	HALIFAX	247	0.16	2	6.50	0	1	2	3	0.45
125+05259	I-95	NB	WILSON	305	0.02	1	5.44	0	1	2	3	0.45
125-15571	I-795	SB	WILSON	282	0.02	1	3.60	0	1	2	3	0.45
125-05267	I-95	SB	HALIFAX	249	0.11	1	6.44	0	1	2	3	0.45
125-05264	I-95	SB	NASH	283	0.01	1	5.89	0	1	2	3	0.45
125-05269	I-95	SB	HALIFAX	306	0.09	1	3.9	0	1	2	3	0.45
125+05267	I-95	NB	HALIFAX	318	0.24	1	3.05	0	2	2	2	0.4
125-05245	I-95	SB	JOHNSTON	367	0.02	2	3.21	0	1	2	2	0.35
125-05116	I-40	EB	JOHNSTON	265	0.01	1	2.52	0	1	2	2	0.35
125+05246	I-95	NB	JOHNSTON	355	0.05	1	1.64	0	1	2	1	0.25

Division 5

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125P05471	I-85	NB	WARREN	219	0.02	1	70.38	0	1	2	4	0.55
125+04815	I-85	NB	DURHAM	834	0.04	1	3.48	0	1	2	3	0.45
125-05468	I-85	SB	VANCE	257	0.02	1	4.38	0	1	2	3	0.45
125+05470	I-85	NB	WARREN	291	0.03	4	0.00	0	1	4	0	0.25
125P05470	I-85	NB	WARREN	204	0.04	4	0	0	1	4	0	0.25
125+05473	I-85	NB	WARREN	242	0.07	1	0.00	0	1	2	0	0.15
125+05452	I-85	NB	GRANVILLE	834	0.04	1	0.00	0	1	2	0	0.15
125+05469	I-85	NB	WARREN	220	0.03	1	0.00	0	1	2	0	0.15
125+05471	I-85	NB	WARREN	219	0.03	1	0.00	0	1	2	0	0.15
125N04814	I-85	SB	DURHAM	850	0.04	1	0.00	0	1	2	0	0.15
125N05468	I-85	SB	VANCE	257	0.04	1	0.00	0	1	2	0	0.15
125N05469	I-85	SB	WARREN	255	0.03	1	0.00	0	1	2	0	0.15
125+05472	I-85	NB	WARREN	314	0.02	2	0.00	0	1	2	0	0.15
125N05470	I-85	SB	WARREN	257	0.02	1	0.00	0	1	2	0	0.15
125N05471	I-85	SB	WARREN	257	0.03	1	0.00	0	1	2	0	0.15
125N05456	I-85	SB	GRANVILLE	86	0.06	1	0.00	0	1	2	0	0.15
125N05472	I-85	SB	WARREN	219	0.03	1	0.00	0	1	2	0	0.15
125-04815	I-85	SB	DURHAM	850	0.03	1	0	0	1	2	0	0.15
125-04814	I-85	SB	DURHAM	850	0.04	1	0	0	1	2	0	0.15
125-05452	I-85	SB	GRANVILLE	850	0.04	1	0	0	1	2	0	0.15
125-05470	I-85	SB	WARREN	257	0.02	1	0	0	1	2	0	0.15
125-05471	I-85	SB	WARREN	352	0.05	1	0	0	1	2	0	0.15
125-05469	I-85	SB	WARREN	329	0.03	1	0	0	1	2	0	0.15
125-05472	I-85	SB	WARREN	346	0.04	1	0	0	1	2	0	0.15
125P05469	I-85	NB	WARREN	291	0.03	1	0	0	1	2	0	0.15
125P04814	I-85	NB	DURHAM	698	0.04	1	0	0	1	2	0	0.15
125P05456	I-85	NB	GRANVILLE	223	0.05	2	0	0	1	2	0	0.15
125P05472	I-85	NB	WARREN	219	0.03	1	0	0	1	2	0	0.15
125P05468	I-85	NB	VANCE	220	0.06	1	0	0	1	2	0	0.15

Division 6

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125N05243	I-95	SB	HARNETT	468	0.04	1	16.24	0	1	2	4	0.55
125N05226	I-95	SB	ROBESON	459	0.04	1	36.87	0	1	2	4	0.55
125-05224	I-95	SB	ROBESON	443	0.04	1	7.52	0	1	2	4	0.55
125-05215	I-95	SB	ROBESON	356	0.02	1	9.48	0	1	2	4	0.55
125P05239	I-95	NB	HARNETT	100	0.15	1	204.26	0	1	2	4	0.55
125P05236	I-95	NB	CUMBERLAND	501	0.07	1	17.64	0	1	2	4	0.55
125P05225	I-95	NB	ROBESON	369	0.03	1	17.57	0	1	2	4	0.55
125P05233	I-95	NB	CUMBERLAND	362	0.06	1	18.04	0	1	2	4	0.55
125+05237	I-95	NB	CUMBERLAND	448	0.09	1	4.18	0	1	2	3	0.45
125+05233	I-95	NB	CUMBERLAND	518	0.07	1	3.50	0	1	2	3	0.45
125+05217	I-95	NB	ROBESON	360	0.01	1	6.26	0	1	2	3	0.45
125+05226	I-95	NB	ROBESON	483	0.03	1	6.33	0	1	2	3	0.45
125-05234	I-95	SB	CUMBERLAND	543	0.02	1	6.1	0	1	2	3	0.45
125-05237	I-95	SB	CUMBERLAND	403	0.10	1	6.66	0	1	2	3	0.45
125-05217	I-95	SB	ROBESON	256	0.00	1	5.01	0	0	2	3	0.4
125+05236	I-95	NB	CUMBERLAND	501	0.08	1	2.70	0	1	2	2	0.35
125-05235	I-95	SB	CUMBERLAND	514	0.04	1	2.44	0	1	2	2	0.35
125-05236	I-95	SB	CUMBERLAND	461	0.09	1	2.03	0	1	2	2	0.35
125-05216	I-95	SB	ROBESON	348	0.01	1	2.31	0	1	2	2	0.35
125N05237	I-95	SB	CUMBERLAND	461	0.10	4	0.00	0	1	4	0	0.25
125-05242	I-95	SB	HARNETT	468	0.10	4	0	0	1	4	0	0.25
125+05219	I-95	NB	ROBESON	278	0.01	1	0.00	0	1	2	0	0.15
125+05225	I-95	NB	ROBESON	437	0.03	1	0.00	0	1	2	0	0.15
125+05243	I-95	NB	HARNETT	442	0.05	1	0.00	0	1	2	0	0.15
125+05600	I-95 BUS	NB	CUMBERLAND	225	0.03	1	0.00	0	1	2	0	0.15
125+05234	I-95	NB	CUMBERLAND	362	0.05	1	0.00	0	1	2	0	0.15
125+05238	I-95	NB	HARNETT	390	0.07	1	0.00	0	1	2	0	0.15
125N05224	I-95	SB	ROBESON	443	0.02	1	0.00	0	1	2	0	0.15
125N05238	I-95	SB	HARNETT	403	0.05	1	0.00	0	1	2	0	0.15
125N05242	I-95	SB	HARNETT	468	0.11	1	0.00	0	1	2	0	0.15

Division 7

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125N05285	I-85	SB	ORANGE	574	0.05	1	5.70	0	1	2	3	0.45
125+06829	I-85/US-70	EB	ORANGE	209	0.24	1	0	0	2	2	0	0.2
125+05286	I-85	NB	ORANGE	592	0.03	1	0.00	0	1	2	0	0.15
125+05287	I-85	NB	ORANGE	350	0.05	1	0.00	0	1	2	0	0.15
125-06828	I-85/US-70	WB	ORANGE	61	0.07	1	0.00	0	1	2	0	0.15
125N05286	I-85	SB	ORANGE	623	0.04	1	0.00	0	1	2	0	0.15
125N05287	I-85	SB	ORANGE	698	0.06	1	0.00	0	1	2	0	0.15
125-05286	I-85	SB	ORANGE	562	0.06	1	0	0	1	2	0	0.15
125-05285	I-85	SB	ORANGE	624	0.03	2	0	0	1	2	0	0.15
125-05287	I-85	SB	ORANGE	698	0.07	1	0	0	1	2	0	0.15
125P05287	I-85	NB	ORANGE	337	0.04	1	0	0	1	2	0	0.15
125P05285	I-85	NB	ORANGE	601	0.02	1	0	0	1	2	0	0.15
125P05286	I-85	NB	ORANGE	682	0.04	1	0	0	1	2	0	0.15
125N06828	I-85/US-70	WB	ORANGE	350	0.00	0	0	0	0	0	0	0
125P06828	I-85/US-70	EB	ORANGE	337	0.00	0	0	0	0	0	0	0

Division 8

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125+05538	I-73/I-74	NB	MONTGOMERY	132	0.01	1	0.00	0	1	2	0	0.15
125+05540	I-73/I-74	NB	MONTGOMERY	195	0.02	1	0.00	0	1	2	0	0.15
125+05524	I-73/I-74	NB	RANDOLPH	223	0.04	1	0.00	0	1	2	0	0.15
125+05526	I-73/I-74	NB	RANDOLPH	252	0.02	1	0.00	0	1	2	0	0.15
125+05542	I-73/I-74	NB	MONTGOMERY	208	0.02	1	0.00	0	1	2	0	0.15
125+05521	I-73	NB	RANDOLPH	611	0.01	1	0.00	0	1	2	0	0.15
125N05524	I-73/I-74	SB	RANDOLPH	176	0.03	1	0.00	0	1	2	0	0.15
125N05521	I-73	SB	RANDOLPH	546	0.03	1	0.00	0	1	2	0	0.15
125N05537	I-73/I-74	SB	MONTGOMERY	106	0.02	1	0.00	0	1	2	0	0.15
125+05523	I-73/I-74	NB	RANDOLPH	223	0.04	1	0.00	0	1	2	0	0.15
125+05525	I-73/I-74	NB	RANDOLPH	232	0.02	1	0.00	0	1	2	0	0.15
125+05541	I-73/I-74	NB	MONTGOMERY	235	0.02	1	0.00	0	1	2	0	0.15
125+05543	I-73/I-74	NB	RANDOLPH	223	0.02	1	0.00	0	1	2	0	0.15
125N05526	I-73/I-74	SB	RANDOLPH	205	0.03	1	0.00	0	1	2	0	0.15
125N05541	I-73/I-74	SB	MONTGOMERY	150	0.02	1	0.00	0	1	2	0	0.15
125N05538	I-73/I-74	SB	MONTGOMERY	98	0.06	1	0.00	0	1	2	0	0.15
125N05540	I-73/I-74	SB	MONTGOMERY	187	0.02	1	0.00	0	1	2	0	0.15
125N05525	I-73/I-74	SB	RANDOLPH	197	0.02	1	0.00	0	1	2	0	0.15
125N05542	I-73/I-74	SB	MONTGOMERY	172	0.02	1	0.00	0	1	2	0	0.15
125+05522	I-73	NB	RANDOLPH	841	0.02	1	0.00	0	1	2	0	0.15
125N05539	I-73/I-74	SB	MONTGOMERY	143	0.03	1	0.00	0	1	2	0	0.15
125-05524	I-73/I-74	SB	RANDOLPH	212	0.02	1	0.00	0	1	2	0	0.15
125-05525	I-73/I-74	SB	RANDOLPH	232	0.02	1	0.00	0	1	2	0	0.15
125-05540	I-73/I-74	SB	MONTGOMERY	222	0.01	1	0.00	0	1	2	0	0.15
125-05543	I-73/I-74	SB	RANDOLPH	211	0.04	1	0.00	0	1	2	0	0.15
125-05537	I-73/I-74	SB	MONTGOMERY	106	0.01	1	0.00	0	1	2	0	0.15
125-05539	I-73/I-74	SB	MONTGOMERY	187	0.02	1	0.00	0	1	2	0	0.15
125-05523	I-73/I-74	SB	RANDOLPH	211	0.03	1	0.00	0	1	2	0	0.15
125-05541	I-73/I-74	SB	MONTGOMERY	186	0.02	1	0.00	0	1	2	0	0.15

Division 9

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125+05048	I-40	EB	DAVIE	543	0.03	1	9.23	0	1	2	4	0.55
125+05047	I-40	EB	DAVIE	507	0.02	1	11.47	0	1	2	4	0.55
125P05046	I-40	EB	DAVIE	126	0.02	1	93.18	0	1	2	4	0.55
125-05046	I-40	WB	DAVIE	580	0.02	1	5.19	0	1	2	3	0.45
125+05046	I-40	EB	DAVIE	490	0.02	1	2.60	0	1	2	2	0.35
125-05045	I-40	WB	DAVIE	551	0.01	1	1.16	0	1	2	1	0.25
125N05020	I-85	SB	DAVIDSON	901	0.03	1	0.00	0	1	2	0	0.15
125N05349	I-40	WB	IREDELL	113	0.12	1	0.00	0	1	2	0	0.15
125N05045	I-40	WB	DAVIE	113	0.03	1	0.00	0	1	2	0	0.15
125N05026	I-85	SB	DAVIDSON	402	0.04	1	0.00	0	1	2	0	0.15
125N05048	I-40	WB	DAVIE	601	0.03	1	0.00	0	1	2	0	0.15
125N05046	I-40	WB	DAVIE	126	0.02	1	0.00	0	1	2	0	0.15
125N05047	I-40	WB	DAVIE	580	0.03	1	0.00	0	1	2	0	0.15
125-05047	I-40	WB	DAVIE	601	0.07	1	0.00	0	1	2	0	0.15
125-05349	I-40	WB	IREDELL	507	0.02	1	0.00	0	1	2	0	0.15
125P05026	I-85	NB	DAVIDSON	418	0.04	1	0.00	0	1	2	0	0.15
125P05045	I-40	EB	DAVIE	113	0.03	1	0.00	0	1	2	0	0.15
125P05048	I-40	EB	DAVIE	428	0.03	1	0.00	0	1	2	0	0.15
125P05020	I-85	NB	DAVIDSON	1135	0.03	1	0.00	0	1	2	0	0.15
125P05047	I-40	EB	DAVIE	483	0.03	2	0.00	0	1	2	0	0.15
125P05349	I-40	EB	IREDELL	113	0.12	1	0.00	0	1	2	0	0.15

Division 10

There are no rural area interstate segments in Division 10

Division 11

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125+05560	I-74	WB	SURRY	175	0.03	1	43.36	0	1	2	4	0.55
125+05366	I-77	NB	SURRY	397	0.09	1	10.25	0	1	2	4	0.55
125-05369	I-77	SB	SURRY	323	0.05	1	19.36	0	1	2	4	0.55
125-05364	I-77	SB	YADKIN	415	0.05	1	18.26	0	1	2	4	0.55
125P05365	I-77	NB	YADKIN	348	0.11	1	42.51	0	1	2	4	0.55
125+05368	I-77	NB	SURRY	303	0.07	1	4.50	0	1	2	3	0.45
125-05362	I-77	SB	IREDELL	292	0.03	1	4.59	0	1	2	3	0.45
125-05350	I-77	SB	SURRY	364	0.02	1	2.06	0	1	2	2	0.35
125+05363	I-77	NB	YADKIN	293	0.04	1	1.51	0	1	2	1	0.25
125+05365	I-77	NB	YADKIN	412	0.07	4	0.00	0	1	4	0	0.25
125N05366	I-77	SB	SURRY	42	0.09	4	0.00	0	1	4	0	0.25
125-05365	I-77	SB	YADKIN	402	0.07	4	0	0	1	4	0	0.25
125N05370	I-77	SB	SURRY	187	0.27	1	0.00	0	2	2	0	0.2
125P05370	I-77	NB	SURRY	177	0.25	1	0	0	2	2	0	0.2

Division 12

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125N05339	I-40	WB	CATAWBA	768	0.05	1	12.12	0	1	2	4	0.55
125+05035	I-85	NB	CLEVELAND	928	0.03	1	4.57	0	1	2	3	0.45
125+05361	I-77	NB	IREDELL	444	0.04	1	1.74	0	1	2	2	0.35
125+05340	I-40	EB	IREDELL	809	0.07	1	2.22	0	1	2	2	0.35
125-05361	I-77	SB	IREDELL	292	0.03	1	1.94	0	1	2	2	0.35
125N05342	I-40	WB	IREDELL	715	0.06	4	0.00	0	1	4	0	0.25
125+05362	I-77	NB	IREDELL	292	0.05	1	0.00	0	1	2	0	0.15
125+05045	I-40	EB	DAVIE	470	0.03	1	0.00	0	1	2	0	0.15
125+05342	I-40	EB	IREDELL	705	0.04	2	0.00	0	1	2	0	0.15
125N05340	I-40	WB	IREDELL	674	0.04	1	0.00	0	1	2	0	0.15
125N05362	I-77	SB	IREDELL	227	0.04	1	0.00	0	1	2	0	0.15
125N05035	I-85	SB	CLEVELAND	649	0.06	1	0.00	0	1	2	0	0.15
125N05361	I-77	SB	IREDELL	271	0.04	1	0.00	0	1	2	0	0.15
125N05341	I-40	WB	IREDELL	700	0.04	1	0.00	0	1	2	0	0.15
125N05360	I-77	SB	IREDELL	381	0.08	1	0.00	0	1	2	0	0.15
125-05360	I-77	SB	IREDELL	445	0.06	2	0.00	0	1	2	0	0.15
125-05034	I-85	SB	CLEVELAND	918	0.07	1	0.00	0	1	2	0	0.15
125-05341	I-40	WB	IREDELL	747	0.05	1	0.00	0	1	2	0	0.15
125P05362	I-77	NB	IREDELL	228	0.05	1	0.00	0	1	2	0	0.15
125P05035	I-85	NB	CLEVELAND	657	0.04	1	0.00	0	1	2	0	0.15
125P05342	I-40	EB	IREDELL	673	0.04	1	0.00	0	1	2	0	0.15
125P05361	I-77	NB	IREDELL	271	0.05	1	0.00	0	1	2	0	0.15
125P05340	I-40	EB	IREDELL	628	0.04	1	0.00	0	1	2	0	0.15
125P05360	I-77	NB	IREDELL	380	0.03	1	0.00	0	1	2	0	0.15
125P05339	I-40	EB	CATAWBA	608	0.06	1	0.00	0	1	2	0	0.15
125P05341	I-40	EB	IREDELL	658	0.03	1	0.00	0	1	2	0	0.15
125-05339	I-40	WB	CATAWBA	854	0.04	1	0.00	0	1	2	0	0.15
125+05341	I-40	EB	IREDELL	658	0.00	0	0.00	0	0	0	0	0
125-05340	I-40	WB	IREDELL	700	0.00	0	0.00	0	0	0	0	0

Division 13

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125+05318	I-40	EB	BURKE	459	0.01	1	5.78	0	1	2	3	0.45
125+05317	I-40	EB	BURKE	524	0.01	1	1.72	0	1	2	2	0.35
125-05316	I-40	WB	MCDOWELL	587	0.01	1	3.11	0	1	2	2	0.35
125P05316	I-40	EB	MCDOWELL	369	0.04	4	0	0	1	4	0	0.25
125P05309	I-40	EB	MCDOWELL	309	0.38	1	0	0	2	2	0	0.2
125+05311	I-40	EB	MCDOWELL	342	0.02	1	0.00	0	1	2	0	0.15
125+05310	I-40	EB	MCDOWELL	280	0.06	1	0.00	0	1	2	0	0.15
125N05309	I-40	WB	MCDOWELL	0	0.06	1	0.00	0	1	2	0	0.15
125N05316	I-40	WB	MCDOWELL	433	0.02	1	0.00	0	1	2	0	0.15
125N05317	I-40	WB	BURKE	479	0.01	1	0.00	0	1	2	0	0.15
125N05310	I-40	WB	MCDOWELL	369	0.01	1	0.00	0	1	2	0	0.15
125N05311	I-40	WB	MCDOWELL	318	0.01	1	0.00	0	1	2	0	0.15
125-05310	I-40	WB	MCDOWELL	410	0.01	1	0	0	1	2	0	0.15
125-05309	I-40	WB	MCDOWELL	482	0.01	1	0	0	1	2	0	0.15
125-05315	I-40	WB	MCDOWELL	496	0.01	1	0	0	1	2	0	0.15
125P05310	I-40	EB	MCDOWELL	307	0.03	1	0	0	1	2	0	0.15
125P05311	I-40	EB	MCDOWELL	251	0.03	1	0	0	1	2	0	0.15
125P05317	I-40	EB	BURKE	420	0.02	1	0	0	1	2	0	0.15
125-05317	I-40	WB	BURKE	518	0.00	1	0	0	0	2	0	0.1

Division 14

TMC Seg.	Road	Dir.	County	VpL	CF	SC	Severity	VpLs	CFs	SCs	Severitys	SCORE
125P05193	I-26	WB	POLK	760	0.06	1	9.83	0	1	2	4	0.55
125+05291	I-40	EB	HAYWOOD	298	0.32	1	2.95	0	2	2	2	0.4
125-05291	I-40	WB	HAYWOOD	372	0.07	1	1.79	0	1	2	2	0.35
125+05193	I-26	WB	POLK	715	0.60	2	0.75	0	2	2	1	0.3
125P05290	I-40	EB	HAYWOOD	298	0.23	4	0	0	2	4	0	0.3
125+05191	I-26	WB	POLK	936	0.04	1	0.91	0	1	2	1	0.25
125P05192	I-26	WB	POLK	471	0.04	4	0	0	1	4	0	0.25
125-05192	I-26	EB	POLK	737	0.07	1	0.74	0	1	2	1	0.25
125+05192	I-26	WB	POLK	471	0.04	1	0.00	0	1	2	0	0.15
125+05293	I-40	EB	HAYWOOD	313	0.04	1	0.00	0	1	2	0	0.15
125+05292	I-40	EB	HAYWOOD	316	0.12	1	0.00	0	1	2	0	0.15
125N05191	I-26	EB	POLK	496	0.02	1	0.00	0	1	2	0	0.15
125N05291	I-40	WB	HAYWOOD	273	0.12	1	0.00	0	1	2	0	0.15
125+05290	I-40	EB	HAYWOOD	298	0.16	1	0.00	0	1	2	0	0.15
125N05290	I-40	WB	HAYWOOD	376	0.19	1	0.00	0	1	2	0	0.15
125N05292	I-40	WB	HAYWOOD	328	0.05	1	0.00	0	1	2	0	0.15
125N05192	I-26	EB	POLK	241	0.03	1	0.00	0	1	2	0	0.15
125N05193	I-26	EB	POLK	656	0.07	1	0.00	0	1	2	0	0.15
125N05293	I-40	WB	HAYWOOD	297	0.05	1	0.00	0	1	2	0	0.15
125-05290	I-40	WB	HAYWOOD	376	0.15	1	0	0	1	2	0	0.15
125-05292	I-40	WB	HAYWOOD	373	0.08	1	0	0	1	2	0	0.15
125-05191	I-26	EB	POLK	496	0.02	1	0	0	1	2	0	0.15
125P05291	I-40	EB	HAYWOOD	261	0.13	1	0	0	1	2	0	0.15
125P05293	I-40	EB	HAYWOOD	230	0.04	1	0	0	1	2	0	0.15
125P05292	I-40	EB	HAYWOOD	271	0.05	1	0	0	1	2	0	0.15
125-05289	I-40	WB	HAYWOOD	376	0.13	1	0	0	1	2	0	0.15
125P05191	I-26	WB	POLK	471	0.04	1	0	0	1	2	0	0.15

Appendix E - Congestion Contour and Collision Classification Tool

This project developed a tool titled "Congestion Contour and Collision Classification Tool (4CTool)" that enables users to generate link-based congestion contour map and classify collisions by types of congestion.

The first step to run the 4CTool, user downloads the crashclassifier.jar software. There are two ways to run the tool. First is double click on the tool. The Tool will open. Second is using command prompt. User can open command prompt, navigate to the folder that contains the tool, and type the command "java –jar crashclassifier.jar".

The 4CTool has a screen for user input. The user will enter all threshold information and input data for the running the tool correctly. Figure E-1 shows the entry setup screen of the tool.

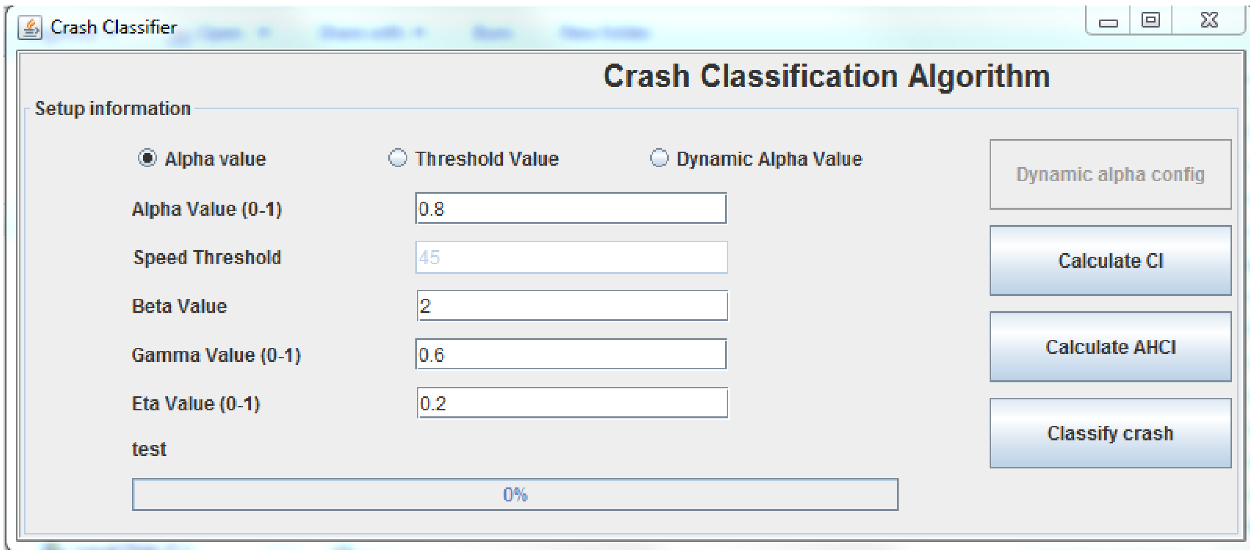


Figure E-1 Entry Screen of 4CTool

As a first step, user should select a way to distinguish between congested and un-congested state by the specified speed during a time stamp. User should select one of three options using: an alpha value, a specified speed threshold (Threshold Value shown in Figure E-2), and alpha value by posted speed limit (Dynamic Alpha Value shown in Figure E-3). In case of using an alpha value, user can insert the value from 0 to 1. The default value for the alpha value is 0.8 for this project. With respect to using a specified speed threshold, user can insert a specified speed threshold (miles per hour). The default value for the speed threshold is 45 mph in the tool. Finally, if user selects dynamic alpha value, alpha values should be inserted by speed limit varying from 55 mph to 75 mph.

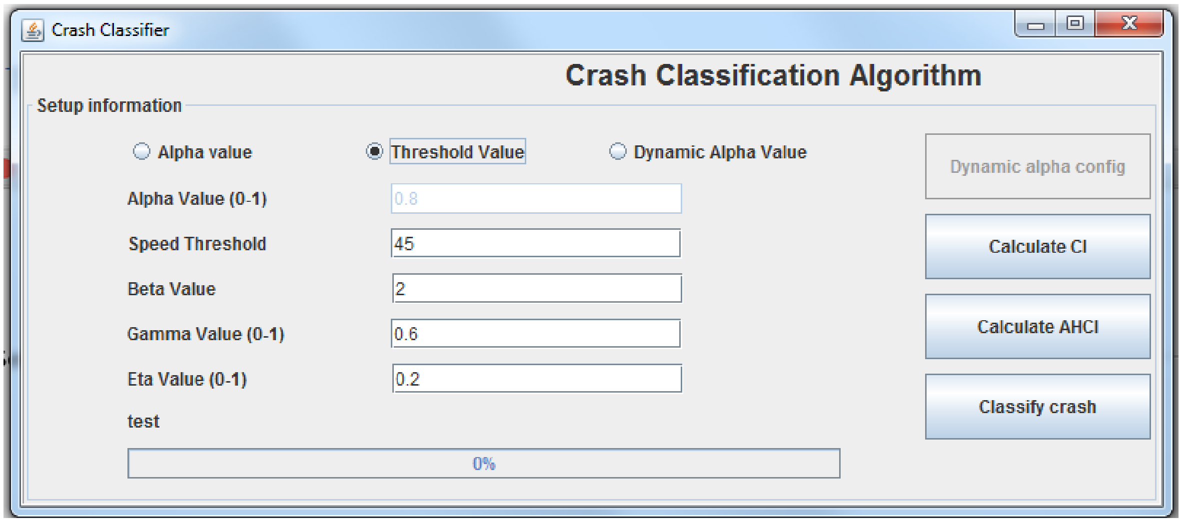


Figure E-2 Threshold Value on Entry Screen of 4CTool

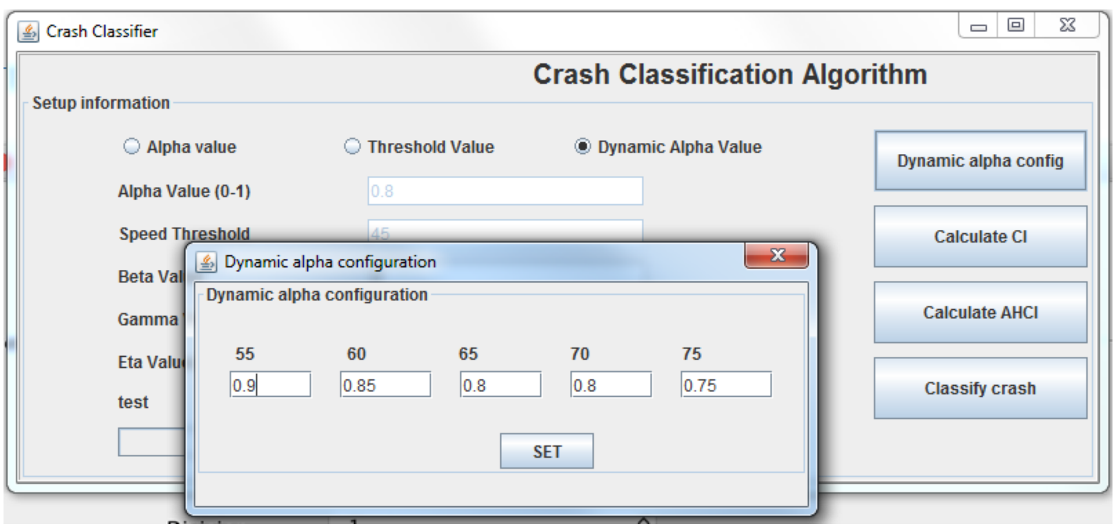


Figure E-3 Dynamic Alpha Value on Entry Screen of 4CTool

User clicks on "Calculate CI" button once all the threshold is entered in the alpha value setup. The tool requests users select the posted speed limit file of each segment (file format: csv file). As seen in Figure E-4, the file includes TMC code, route class, speed limit, and order information. Mandatory information for this posted speed limit file should contain TMC code in the first column and speed limit data in third column.

	A	B	C	D	E
1	Tmc	Route Class	SPEEDLimit	Order	
2	125+04594	I	55	131894	
3	125+04595	I	55	131874	
4	125+04628	I	60	131928	
5	125+04631	I	60	131934	
6	125+04645	I	65	131966	
7	125+04646	I	65	131968	
8	125+04663	I	65	15030	
9	125+04664	I	65	15032	
10	125+04679	I	65	111346	
11	125+04682	I	65	111352	
12	125+04784	I	55	132199	
13	125+04787	I	55	132205	
14	125+04802	I	65	132101	
15	125+04803	I	65	132102	
16	125+04836	I	70	120095	
17	125+04840	I	55	132320	
18	125+04873	I	65	120146	
19	125+04874	I	65	120148	
20	125+04889	I	55	111183	
21	125+04892	I	60	111189	
22	125+04961	I	60	120101	
23	125+04962	I	65	120103	

Figure E-4 A Screenshot of the Posted Speed Limit File

As a next step, the tool requests users select a folder including link speed data in a specified study period shown in Figure E-5. The speed data can be downloaded directly through ritis.org and should include TMC code, time stamp, speed, reference speed, and travel time information. The research team recommends using monthly data since it makes run time shorter than using annual data.

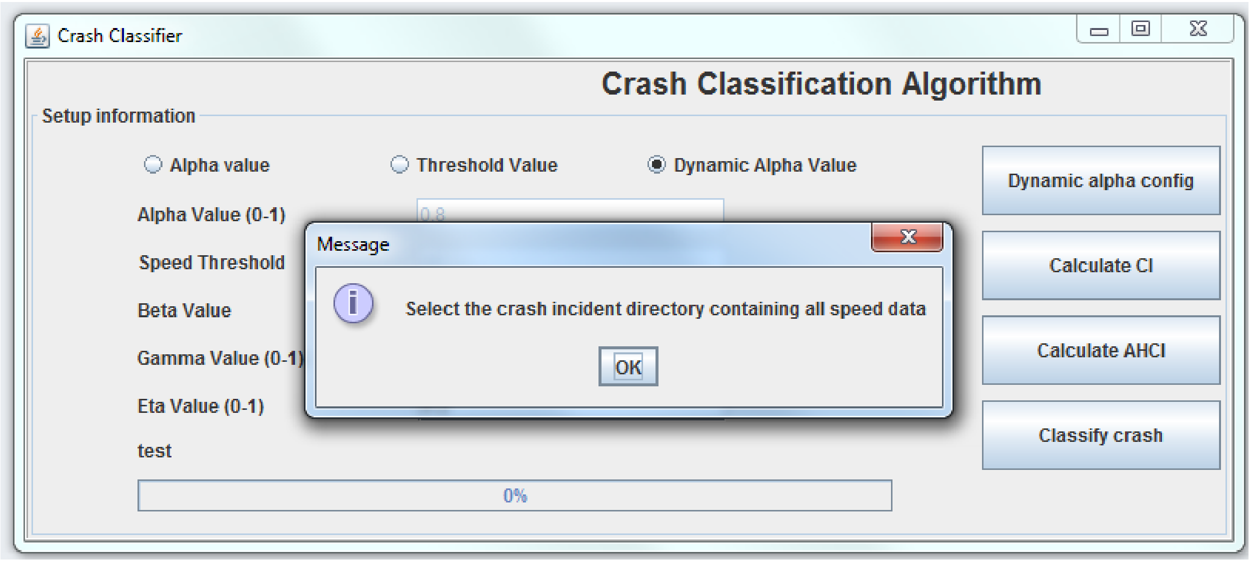


Figure E-5 Message for Selecting the Folder Containing Speed Data

tmc_code	measurement_tstamp	speed	reference_speed	travel_time_minutes
125P04845	8/1/2014 0:00	56	56	0.26
125N05599	8/1/2014 0:00	65	65	0.4
125N10200	8/1/2014 0:00	62.17	63	1
125P16977	8/1/2014 0:00	65	65	0.49
125-04848	8/1/2014 0:00	58	58	0.35
125P16980	8/1/2014 0:00	65	65	0.43
125-05600	8/1/2014 0:00	65	65	0.33
125-15619	8/1/2014 0:00	65.19	65	4.45
125-15618	8/1/2014 0:00	60	65	4.28
125P15619	8/1/2014 0:00	65	65	0.84
125+04896	8/1/2014 0:00	63.78	61	0.38
125N05214	8/1/2014 0:00	62	62	0.56
125+05559	8/1/2014 0:00	66.45	65	1.38
125+16977	8/1/2014 0:00	65	65	1.25
125-10200	8/1/2014 0:00	56.52	52	0.44
125+04882	8/1/2014 0:00	53	53	0.27
125N04984	8/1/2014 0:00	65	65	0.49

Figure E-6 A Screenshot of a speed raw data (August, 2014)

After selecting the folder including all speed data interested, the tool runs automatically and provide calculating process in the tool as seen in Figure E-7.

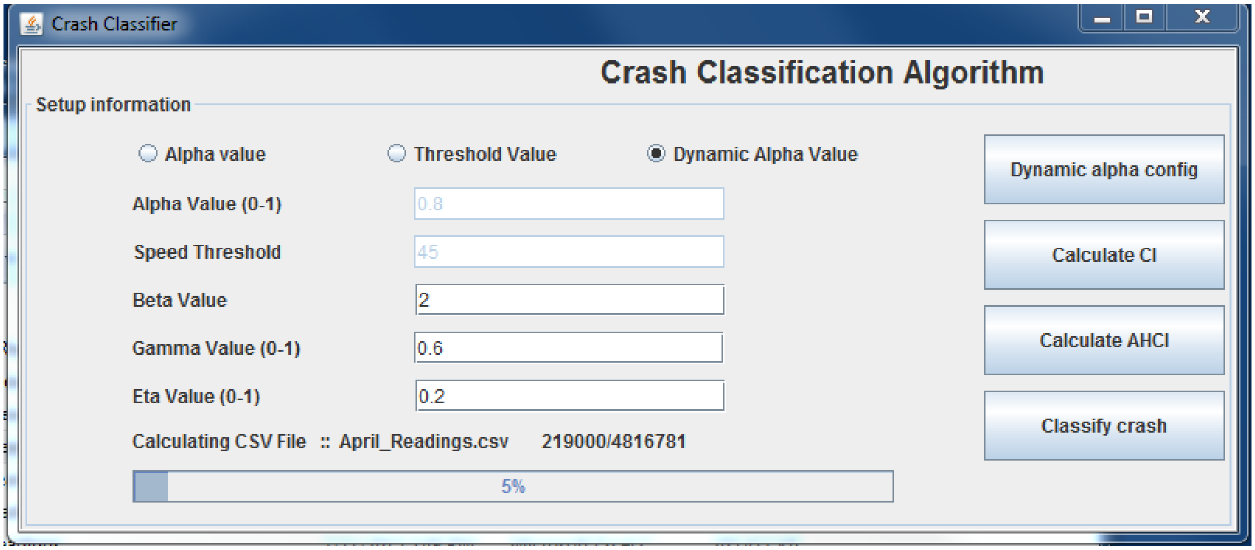


Figure E-7 A Screenshot of Calculating CI

With respect to calculating AHCI and create AHCI contour map, user can generate by clicking 'Calculate AHCI' on the tool. The tool requests same process with 'Calculate CI'. After the calculating AHCI, user can find the output of AHCI calculation in the same folder where the tool is. For example, an output name was AHCI_Output_146228911123.csv.

Finally, users can classify crashes by types of congestion using the tool. In order to classify crashes, users must extract outputs for both 'Calculate CI' and 'Calculate AHCI'. In addition, the ordered AHCI contour map is required for classifying crashes. TMCs in the AHCI output file calculated from 'Calculate AHCI' is not in order. To impose order in each TMC, the TMC identification file downloaded automatically when downloading speed file via ritis.org can be used. TMCs in the identification file are in order on each road. By using this order, users can put number in the AHCI file.

Before click 'Classify crash', three thresholds are needed to be determined. Beta is the threshold of spatial difference with AHCI values of between the segment identified bottlenecks and its downstream segment. Gamma value in this tool is the threshold clearly defined recurrent congestion, while eta value is the threshold clearly defined non-recurrent congestion. This project proposed using the following defaults for those thresholds:

- Beta value (>1): 2
- Gamma value (0-1): 0.6
- Eta value (0-1): 0.2

As a next step, the tool request users insert a TEAAS crash data file. The format of the crash data file is csv and the file includes attributes shown in Figure E-8.

CRSH_ID	CRASH_DATE	CYEAR	WKDAY	CTIME	ON_ROAD	SPDLMT	Tmc	Miles
1.04E+08	6/30/2014	2014	2	3:44:00 PM	I 85	55	125+04621	2.02
1.04E+08	6/14/2014	2014	7	4:04:00 PM	I 85	65	125P04650	0.79
1.04E+08	1/5/2014	2014	1	7:44:00 PM	I 85	70	125+05024	2.84
1.04E+08	1/6/2014	2014	2	7:29:00 AM	I 77	55	125+04788	0.68
1.04E+08	1/24/2014	2014	6	2:47:00 PM	I 85	55	125+04650	2.15
1.04E+08	1/21/2014	2014	3	3:40:00 AM	I 95	65	125P05256	0.63
1.04E+08	1/2/2014	2014	5	6:39:00 PM	I 77	55	125P04779	0.56
1.04E+08	1/27/2014	2014	2	11:01:00 AM	I 85	60	125P04640	0.7
1.04E+08	1/13/2014	2014	2	6:34:00 PM	I 85	70	125P05026	0.61
1.04E+08	2/12/2014	2014	4	2:42:00 PM	I 95	70	125+05265	3.75
1.04E+08	1/9/2014	2014	5	9:09:00 AM	I 77	65	125P04792	0.71
1.04E+08	2/7/2014	2014	6	5:30:00 PM	I 85	60	125P04637	0.57
1.04E+08	1/31/2014	2014	6	8:45:00 PM	I 77	55	125P04783	0.26
1.04E+08	1/16/2014	2014	5	6:55:00 AM	I 85	65	125+04652	2.09
1.04E+08	2/7/2014	2014	6	8:12:00 PM	I 77	70	125+05361	4.44
1.04E+08	3/19/2014	2014	4	6:54:00 AM	I 77	55	125+04784	0.85
1.04E+08	3/6/2014	2014	5	8:08:00 PM	I 85	60	125P04640	0.7
1.04E+08	2/5/2014	2014	4	2:12:00 PM	I 77	65	125+04793	1.76
1.04E+08	3/3/2014	2014	2	3:23:00 PM	I 85	60	125+04587	5.25
1.04E+08	2/25/2014	2014	3	11:01:00 AM	I 95	70	110+05549	3.71

Figure E-8 A Screenshot of TEAAS Crash Data

After running 'Classify crashes', users can find the output in the same folder where the tool is as well. The title name is similar with 'ResultFile1454151515.csv'. In the result file, CRASH TYPE should be created and the types are classified into four types: 1=crashes in not congested condition, 2=crashes in non-recurrent congestion, 3=crash in recurrent congestion, and 99=no available. 99 values can be generated when the crash date occurred on weekend but an AHCI contour was created using only weekday information.

Appendix F - Detailed Available Incident Characteristics in North Carolina

Incident characteristics	**Data list**	**AMS of FHWA (2012)**	**TIMS**	**Major incident summary from SMARTLINK**	**RITIS**	**IMAP log**	**TEAAS**
Incident type	Crash/vehicle accident/collision	✓	✓	✓	✓		✓
	Disabled vehicles	✓	✓	✓			
	Fire	✓	✓				
	Debris/road obstruction	✓	✓	✓	✓		
	Abandoned vehicles	✓					
	Congestion/traffic condition		✓		✓		
	Construction/road work		construction✓		Road work✓		
	Fog		✓				
	Maintenance		✓				
	Night time construction		✓				
	Night time maintenance		✓				
	Signal problem		✓				
	Special event		✓		✓		
	Weather event		✓		✓		
	Weekend construction		✓				
	Automatic congestion		✓				
	Secondary incident			✓			
	Disturbances				✓		
	Incident(?) in ritis				✓		
	Others			✓	✓		
Incident collision type	Animal						✓
	Angle						✓
	Other collision with vehicle						✓
	Movable object						✓
	Other non-collision						✓
	Ran off road						✓
	Fixed object	✓					✓
	Overturn	✓					✓
	Vehicle/side	✓					✓
	Vehicle/head-on	✓					✓
	Vehicle/rear-end	✓					✓

Incident characteristics	Data list	AMS of FHWA (2012)	TIMS	Major incident summary from SMARTLINK	RITIS	IMAP log	TEAAS
Incident timeline*	Start of incident (T0)	✓	✓		✓ (time opened)		✓
	Detection (T2-T0)	✓					
	Record (T1)			✓(Law Enf. &DOT)		✓ (reg)	
	Verification (T2)	✓					
	IMAP dispatch (T3)					✓ (disp)	
	On-scene arrival (T4)	✓				✓ (arrv)	
	Lane closed					✓ (lnclsd)	
	Lane/shoulder open (T5)	✓		✓		✓ (Lnop)	
	All clear (T6)	✓	✓	✓	✓ (time closed)	✓ (Deprt?)	
	Time to normal (T7)			✓ (recovery)			
	DMS					✓ (DMS)	
	TIMS					✓ (TIMS)	
	Duration				✓		
Incident severity	KAPCO injury scale (k-fatal, a-serious, b-moderate, c-minor, o-none, u-unknown)	✓					✓
	Number of each injury scale						✓
	LOW, Medium, High		✓				
	Severity index - EPDO						✓
Incident location	Route	✓	✓	✓		✓	✓
	Travel direction	✓	✓	✓		✓	✓
	Milepost or GPS coordinates	✓	✓	✓			✓
	Mile marker					✓	✓

* followed the national traffic incident management timeline in Appendix A.

Incident characteristics	Data list	AMS of FHWA (2012)	TIMS	Major incident summary from SMARTLINK	RITIS	IMAP log	TEAAS
Incident blockage	Cross section feature affected Lane Partial lane Right shoulder Left shoulder Median Off maintained way	✓ ✓ ✓ ✓ ✓ ✓					
	Lane type Through/GP Through/HOV Auxiliary On-ramp Off-ramp	✓ ✓ ✓ ✓ ✓					
	Lane closed (number of lanes closed)		✓	✓	✓	✓	
	Number of total lanes		✓			✓	
	Percent of closed lanes				✓		
Number of involved vehicles		✓					
Person (any person involved in a crash)							✓
Posted speed limit							✓
Crash related information	Crash rates						✓
	Comprehensive crash costs						✓
	Crash facts						✓
	County crash profiles						✓
	City/county rankings						✓
	Holiday crash data						✓
	Animal crash data						✓

Incident characteristics	Data list	AMS of FHWA (2012)	TIMS	Major incident summary from SMARTLINK	RITIS	IMAP log	TEAAS
IMAP services provided	Extinguish fire					✓	
	First aid					✓	
	Tagged vehicle					✓	
	Removed vehicle					✓	
	Pushed or pulled					✓	
	Traffic control					✓	
	Tire					✓	
	Fuel					✓	
	Assisted other unit					✓	
	Mechanical assist					✓	
	Jump start					✓	
	Called wrecker					✓	
	Secured load					✓	
	Called for assistance					✓	
	Directions					✓	
	Transported					✓	
	Unable to locate					✓	
	No assistance					✓	
	Other					✓	
	Disregarded stop					✓	
	Called maintenance					✓	
	Fluids					✓	
	Delayed response					✓	