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ITS RESOURCE CENTER

Evaluation of NJDOT's Incident Management Support Program

Final Report

Submitted to:
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Statewide Traffic Operations
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RESEARCH TEAM

This report summarizes findings of a research project completed by a research team led by Dr. Lazar Spasovic, Professor of Civil and Environmental Engineering, at NJIT. The research team includes Branislav Dimitrijevic and Dr. Dejan Besenski, senior research staff at the Department of Civil and Environmental Engineering, as well as Jemima Johnson and Kiran Kolluri, graduate research assistants in the Interdisciplinary Program in Transportation at NJIT.

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We owe a special note of thanks to FHWA's New Jersey Division Representatives Bill Hoffman, Safety and Mobility Team Director and Ek Phomsavath, ITS Engineer for providing guidance in the development of the evaluation methodology and for their insightful review and comments on the interim and final reports.

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EXECUTIVE SUMMARY

Background

The New Jersey Department of Transportation (NJDOT) began to address the traffic management aspect of roadway incident response by dispatching its Maintenance Operations Personnel to major traffic incidents in support of New Jersey's Statewide Incident Management Program. When dispatched, Maintenance Operations is part of a collaborative response from NJDOT that fulfills the requirements of the National Incident Management System (NIMS). The responsibility of Maintenance Operations in these situations is to provide traffic control at incident sites, handle the incident clearing activities, coordinate NJDOT resources for incident clearance, and coordinate with the New Jersey State Police (NJSP) to establish alternate routes and diversion signing. Maintenance Operations is equipped to provide full MUTCD (Manual on Uniform Traffic Control Devices) compliant lane closures, including signs, arrow boards, and a truck mounted impact attenuator. These Maintenance Operations activities are consistent with desired characteristics of a Full-Function Service Patrol (FFSP) for traffic incident response and management from the viewpoint of an agency that is responsible for funding, managing, and operating these services. As described in the Federal Highway Administration's (FHWA) Service Patrol Handbook (Houston et al., 2008), when required, maintenance forces are an extension to the Emergency Service Patrols (ESP) for clearing major traffic incidents in addition to performing their daily work of maintaining the roadways (i.e. roadway rehabilitation, safety upgrades, vegetation operations, signage, snow removal, etc.). NJDOT statistics show that the average statewide traffic incident duration has been reduced in the past five (5) years from 2 hours to less than 1 hour, a 50% decrease. This reduction can be attributed in large measure to the deployment of Maintenance Operations Personnel and assets to incident sites in support of the Statewide Incident Management Program.

Study Objective

The objective of this research is twofold:

1. Develop a methodology for evaluating the benefits of reducing duration of major traffic incidents involving lane and/or shoulder closures; and

2. Implement the methodology to analyze the cost-effectiveness (Benefit/Cost analysis) of NJDOT Maintenance Operations supporting the Statewide Incident Management Program during fiscal year (FY) 2009.

The effectiveness of NJDOT's Maintenance Operations is measured vis-à-vis costs and benefits associated with their response to incidents and incident clearance activities. The benefits of early response and quicker clearance of highway incident aftermaths include savings resulting from a highway facility returning more expeditiously to the normal conditions that existed before the incident had occurred. The resulting savings include:

- Reduced traffic delay,
- Reduced emissions,
- Reduced fuel consumption, and
- Savings due to the avoidance of property damage caused by secondary incidents.

Data Collection and Analysis

The study is based on the data collected for the period of August 1, 2008 – May 31, 2009. The data sources include NJDOT SWIFT (Statewide Information for Travelers), NJDOT CDU (Central Dispatch Unit) database, NJDOT Highway Maintenance Management System (HMMS), New Jersey Straight-Line Diagram (SLD), and the New Jersey Congestion Management System (NJCMS). The first three databases provide information related to incidents and costs associated with Maintenance Operations responding to traffic incidents. The SLD database provides basic roadway geometry data, while traffic flow data, including estimated hourly volumes and truck percentage for pertinent roadways, is obtained from the NJCMS.

During the study period, a total of **1,564 incidents** were identified in the HMMS report. Maintenance Operations was dispatched to all of these incidents. The HMMS records were cross-referenced with the incident data recorded in CDU and SWIFT. The CDU and SWIFT databases contain incident data, such as incident description, lane and shoulder closures, and incident duration. After integrating the incident records among the HMMS, CDU, and SWIFT, a dataset of **974 incidents or 63%** of the total number of incidents was assembled. This data contains complete incident timeline information that is needed for the analysis. Due to the time constraints for completing the analysis and this report, the data integration has not been completed for the remaining 590 incident records in the HMMS report (or approximately 38%).

Benefit Evaluation Methodology

Based on the detailed review of the state-of-practice, data requirements for different modeling approaches, character of analyzed Maintenance Operations incident clearance activities, and considering the availability of data, it was decided that the evaluation methodology in this study be based on deterministic macroscopic queuing modeling. In the proposed model, a vehicle queuing and traffic bottleneck analysis is applied to determine cumulative vehicle delays. The model is based on procedures provided in the Highway Capacity Manual and Traffic Incident Management Handbook (USDOT, 2000) and considers incident characteristics, roadway geometry and traffic flow characteristics at the incident location to calculate the impact of each incident on vehicle queuing and delay. The results obtained from the model are then used to calculate the cost of unproductive time, vehicle emissions, fuel consumption, and occurrence of secondary incidents attributable to analyzed primary incidents.

The effect of Maintenance Operations Personnel responding to incidents is calculated as a difference between the impact of incidents with and without their response. Since no data is available for incidents to which Maintenance Operations was not dispatched, it is assumed in the analysis that if involved, they would reduce the duration of an incident by at least 1 minute and up to 30 minutes. This assumption is based on the fact that number, location, and equipment of Maintenance Operations Yards (approximately 80 Yards strategically located throughout the State), provides for a quicker mobilization and deployment to incident sites than any other available resource. Maintenance Operations Crews are fully equipped to set up MUTCD lane closures and traffic diversions/detours, and they can quickly deploy heavy equipment such as front loaders and dump trucks. This enables them to quickly set up safety at the scene and efficiently clear the debris and/or other objects blocking the roadway.

Results

The results of the Benefit/Cost analysis indicates that the B/C ratio of Maintenance Operations deployment to major incidents is greater than 1.0, even when just 1 minute is saved per incident due to their intervention (B/C ratio is 1.31 in this scenario). This is illustrated in Figure EF.1 and Table ET.1. This ratio is obtained by comparing the savings achieved from reducing incident duration by 1-minute per incident, to the total cost of labor associated with Maintenance Operations response to incidents. The cost of labor incurred for the incident response to analyzed 974 incidents during the 10-month analysis period was $510,000. As stated before, this minimum reduction in incident duration is almost certain, given the ability of Maintenance Operations to react whenever and wherever needed in a minimal amount of time. The Figure EF.1 shows that the B/C ratio increases with greater assumed reduction in incident duration from 1.31:1 for a 1-minute reduction to 24:1 for a 15-minute reduction, and 44:1 for a 30-minute reduction.

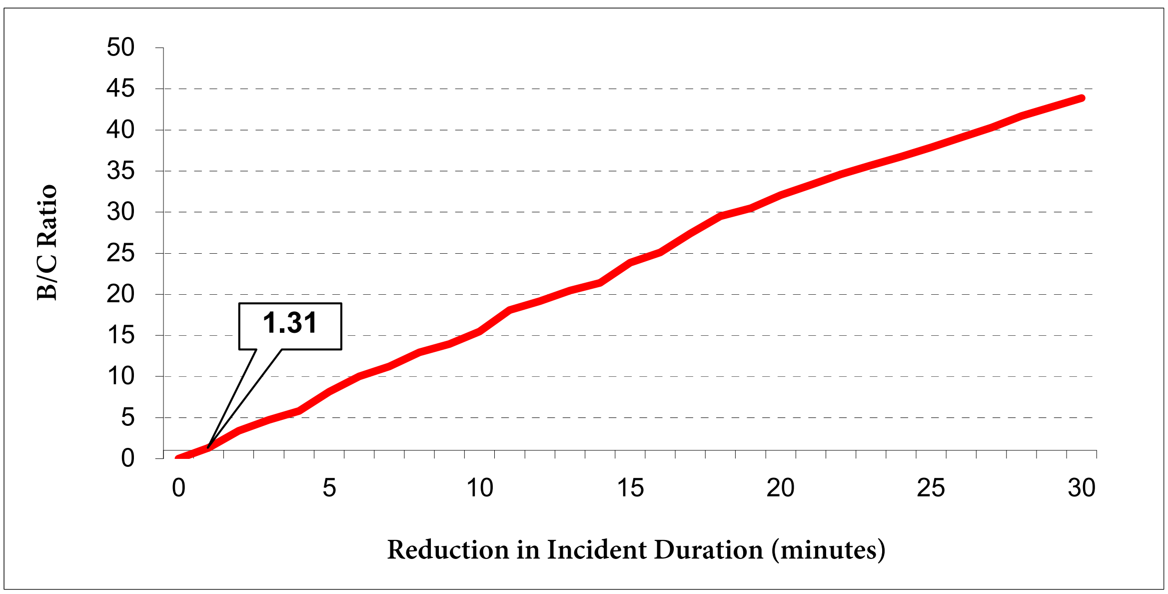

Figure EF.1 – Benefit/Cost (B/C) Ratio of Maintenance Operations Program resulting from assumed reduction in incident duration from 1 to 30 minutes per incident

The results provided in Table ET-1 show that the most significant savings are realized as a result of reduction in travel delay that translates into cost of unproductive time incurred by motorists. They are followed by savings resulting from the reduced fuel consumption (directly proportional to the cost of fuel at the pump), reduced vehicle emissions due to reduced congestion, and avoided secondary incidents.

Table ET.1 – Summary of Results of the Benefit/Cost (B/C) Analysis of NJDOT Maintenance Operations to the Incident Response Program (Analysis Period August 2008-May 2009)

Savings category	Reduction in Incident Duration per Incident due to Maintenance Operations						
	1 minute	5 minutes	10 minutes	15 minutes	20 minutes	25 minutes	30 minutes
Reduction in Incident Duration (Hours)	16	81	162	244	325	406	487
Value of Reduced Travel Delay ($)	$555,415	$3,448.059	$6,551,335	$10,097,678	$13,568,465	$16,032,991	$18,562,284
Value of Reduced Vehicle Emissions ($)	$40,949	$254,337	$483,700	$745,747	$1,002,061	$1,183,966	$1,370,763
Value of Reduced Fuel Consumption ($)	$69,550	$434,057	$833,278	$1,288,295	$1,730,830	$2,043,236	$2,365,928
Value of Avoided Secondary Incidents ($)	$2,771	$13,630	$26,718	$39,297	$51,395	$63,040	$74,257
TOTAL Cost Savings ($)	*$668,684*	*$4,150,083*	*$7,895,032*	*$12,171,017*	*$16,352,752*	*$19,323,233*	*$22,373,232*
B/C Ratio	**1.31**	**8.14**	**15.48**	**23.87**	**32.07**	**37.90**	**43.88**

Of course, greater reduction in incident duration results in greater savings and a higher B/C ratio. For example, a reduction of incident duration by 15 minutes per incident results in a decrease of duration of all analyzed incidents of 244 hours, a 6% reduction. However, as shown in Table ET-1, this reduction translates to a total savings of **$12.1 million**, which is almost **24 times** more than the cost incurred by Maintenance Operations. (The unit costs used in the calculation of the B/C ratio are provided in Table ET.2.)

Table ET.2 – Dollar value of parameters used in calculations

Parameter	Value	Measure	Source
Cost per Driver/Passenger (estimated statewide average hourly wage in New Jersey)	25.46	$/hour	U.S. Department of Commerce, 2008
Cost of Trucks	32.15	$/hour	USDOT, 2005
HC emissions per hour of delay	0.000025676	tons	Guin et al, 2007
CO emissions per hour of delay	0.00033869	tons	Guin et al, 2007
NOx emissions per hour of delay	0.000036064	tons	Guin et al, 2007
Average speed of the vehicles in congestion	20	mph	New Jersey Congestion Management System
Fuel consumption of passenger cars (estimated for an average passenger car at 20 mph speed)	0.070	gallons/mile	California Air Resources Board, EMFAC2002
Fuel consumption of trucks (estimated for an average truck at 20 mph speed)	0.169	gallons/mile	California Air Resources Board, EMFAC2002
Cost savings because of HC reduction	6,700	$/ton	Guin et al, 2007
Cost savings because of CO reduction	6,360	$/ton	Guin et al, 2007
Cost savings because of NOx reduction	12,875	$/ton	Guin et al, 2007
Average price of gasoline in NJ	3.08	$/gallon	AAA Daily Fuel Gauge Report
Average price of diesel in NJ	3.51	$/gallon	AAA Daily Fuel Gauge Report
Average cost of secondary incident (only PDO accidents are considered)	$4,437	$/incident	Blincoe et al., 2002

Chapter 1

INTRODUCTION

This report summarizes the results of an evaluation of the incident management support provided by NJDOT Maintenance Operations. The purpose of the study was to identify and quantify benefits of deploying maintenance crews to incident sites and their assistance in incident clean-up. The benefits are then compared to the costs associated with incident clean-up activities of Maintenance Operations, providing the basis for quantifying the cost-effectiveness of this program.

As part of NJDOT's Statewide Incident Management Program, Maintenance Operations responds to major traffic incidents and assists the New Jersey State Police and Incident Management Response Team in providing safety at an incident scene and during incident clean-up. When dispatched, Maintenance Operations is part of a collaborative response from NJDOT that fulfills the requirements of the National Incident Management System (NIMS). According to NJDOT statistics, the average statewide traffic incident duration has been reduced in the past five (5) years from 2 hours to less than 1 hour, a 50% decrease. This reduction coincides and can be in large part attributed to the deployment of Maintenance Operations Personnel and assets to incident sites in support of the Statewide Incident Management Program.

NJDOT recently requested approval from the Federal Highway Administration (FHWA) to use Federal Incident Management Program funds to cover the in-house labor costs incurred when NJDOT Maintenance Operations responds to roadway incidents. The activities of Maintenance Operations under this program include response, incident clean-up, traffic safety, and traffic mitigation at incident sites, and they are considered to be an extension of the Emergency Service Patrols (ESP), as described in FHWA's Service Patrol Handbook (Houston et al., 2008). NJDOT requested that funding be provided for a 2-year pilot program after which time, the program will be evaluated and further decisions about continued funding will be made.

FHWA has approved NJDOT's application. One of the conditions of the approval was to evaluate performance of the Maintenance Operations support to the Statewide Incident Management

Program and submit an evaluation report to FHWA within 45 days following the end of the first year of Federal funding. As requested by FHWA, the report should document the program's "*effectiveness including, but not limited to, incident duration, measurements, emission reduction benefits, and benefit/cost analysis.*"[1]. This report is prepared to provide the analysis in accordance with FHWA's request.

1.1. Research Objective

The objective of this research study is twofold:

1. Develop a methodology for evaluating the benefits of reducing the duration of major traffic incidents involving lane and/or shoulder closures; and
2. Implement the methodology to analyze the cost-effectiveness (Benefit/Cost analysis) of NJDOT Maintenance Operations supporting the Statewide Incident Management Program during fiscal year (FY) 2009.

The effectiveness of NJDOT Maintenance Operations is measured vis-à-vis costs and benefits associated with their response to incidents and incident clearance activities. The benefits of early response and faster clearance of highway incident aftermaths include savings resulting from a highway facility returning quicker to the normal conditions that existed before the incident had occurred. The resulting savings include:

- Reduced traffic delay,
- Reduced emissions,
- Reduced fuel consumption, and
- Savings due to the avoidance of property damage caused by secondary incidents.

[1] Letter sent by Mr. Dennis Merida, FHWA New Jersey Division Administrator, to Mr. Stephen Dilts, NJDOT Commissioner (then Deputy Commissioner), dated March 4, 2008.

1.2. Organization of report

This report is organized into eight chapters. This section provides a brief description of the following chapters.

Chapter 2 presents a discussion of the NJDOT Incident Management Program and the role that Maintenance Operations has in responding to traffic incidents.

Chapter 3 reviews the state of practice in evaluating benefits of incident management programs. The literature review relevant to this study is summarized.

Chapter 4 focuses on data collection and analysis. The sources of incident data utilized by NJDOT are described, emphasizing the data critical to evaluation of benefits of quicker incident response and faster incident clean-up. Recommendations for improving data quality and integration are also provided in the conclusion of the chapter.

Chapter 5 provides a detailed description of the implemented methodology for evaluation of incident management support provided by NJDOT Maintenance Operations. The methodology employs proven, well-established theoretical concepts and accounts for impacts of traffic incidents on mobility and congestion, air quality, fuel, and safety. Calculation procedures for estimating the monetary cost of these impacts are also defined in this chapter.

Chapter 6 presents the results of the analysis for NJDOT's Maintenance Operations support program for the period of August 1, 2008 – May 31, 2009. The cost-benefit analysis shows that a deployment of Maintenance Operations to major incidents generates significant savings. It confirms the cost-efficiency of the program.

Chapter 7 summarizes the conclusions of the study.

Chapter 8 provides research recommendations for future improvements.

Chapter 2

NJDOT 'S STATEWIDE INCIDENT MANAGEMENT PROGRAM

NJDOT's Statewide Incident Management Program is established as a collaborative effort between NJDOT and the New Jersey State Police (NJSP) for managing the State's transportation infrastructure and restoring the lanes of traffic in a safe and expeditious manner in the event of traffic incidents. It is a systematic tool used for the command, control, and coordination of a highway emergency response. It allows agencies to work together using common terminology and operating procedures for controlling personnel, facilities, equipment, and communications at the scene of a traffic incident.

The Statewide Incident Management Program employs several NJDOT resources including: the Emergency Service Patrol (ESP), Traffic Operations Centers (TOCs), the Statewide Traffic Management Center (STMC), the Central Dispatch Unit (CDU), as well as NJDOT's Maintenance Operations. These units work together and collaborate with the NJSP to detect, respond to, assist in, and clear various types of traffic incidents. The activities of NJDOT and NJSP personnel at the scene of an incident are managed and coordinated through Incident Management Response Teams (IMRT). NJDOT's Bureau of ITS Engineering provides support in the development and deployment of Intelligent Transportation Systems equipment that can be used by these units to provide for an effective incident management response. A description of key Incident Management Program Representatives is provided as follows:

Emergency Service Patrol (ESP)

The responsibilities of the Emergency Service Patrols (ESP) include the following:

- Utilize roaming vehicles to patrol congested sections of the statewide freeway network in order to quickly detect and respond to minor incidents.
- Assist with incident detection – ESP is routinely the first responder at an incident site.
- Assist NJSP and other secondary responders by diverting traffic around incident scenes and providing for the safety of the motorists.

- Assist disabled vehicles and handle minor repairs (changing a flat tire, jump-starting a vehicle, providing limited towing services, etc.).
- Relocate vehicles/remove debris and provide for safety until Maintenance Operations Personnel arrive on scene.
- Patrol the highway surrounding the incident to prevent secondary incidents from occurring.
- Handle containment of minor spills if necessary.

Traffic Operations Centers (TOC)

The responsibilities of the Traffic Operations Centers (TOC) include the following:

- Manage the flow of traffic on the highways and provide a coordinated response for traffic incidents statewide.
- Once an incident is verified, collect and disseminate traffic condition information to motorists, radio traffic services, media outlets, etc.
- Use Dynamic Message Signs (DMS) and Highway Advisory Radio (HAR) to display messages to inform motorists about traffic delays as a result of an incident and provide appropriate detour routes if applicable.
- Ensure that NJ511 has updated messages for motorists about the incident.
- Routinely check ITS Systems (cameras, traffic control systems, etc.) to monitor the incident scene and keep motorists updated about delays, etc. Monitor traffic control systems and modify signal timing as necessary to assist with the flow of traffic.
- Provide support and an array of response activities for unplanned lane closures such as incidents and emergencies to minimize the traffic impacts for the motorists.
- TOC Personnel analyze the roadway (where the incident has occurred) and take ownership of the roadway until the incident/activity has been cleared and traffic is returned to normal.
- Ensure that an Emergency Service Patrol (ESP) has been dispatched to the incident scene.

Statewide Traffic Management Center (STMC)

NJDOT has established a Statewide Transportation Management Center (STMC), which is operated jointly with the New Jersey Turnpike Authority and the New Jersey State Police. The STMC is operational 24/7, and is jointly staffed by experienced personnel from each of the participating agencies. Each agency manages its own roadways from the STMC, but the co-location affords efficient and effective "statewide" coordination of response to traffic incidents and emergencies. For NJDOT, the STMC serves three functions: (1) normal daytime operations for the northern part of the state (North Region), (2) evening/weekend operations for the entire NJDOT transportation system, and, (3) coordination of any major traffic event that could impact both a toll road and/or a state jurisdiction highway. The new state-of-the-art center has been in operation since May, 2008.

Central Dispatch Unit (CDU)

The Central Dispatch Unit (CDU) works alongside the New Jersey State Police's and the Department of Environmental Protection's Operational Dispatch Units and is responsible for handling all emergency calls that come in from police departments throughout the state. The emergencies can range from a traffic signal malfunction to a disaster (e.g., severe damage to the infrastructure, either from natural causes, such as an earthquake or a flood, or manmade). The CDU is operational 24/7 and is located in the State Police Communications Center in Hamilton Township. In response to emergency calls, CDU dispatches the appropriate staff to ensure that the problem/crisis is resolved with minimal disruption to the traveling public and local communities. In addition to handling emergency calls, the CDU is responsible for dispatching the NJDOT Emergency Service Patrols (ESPs) during ESP hours of operation.

New Jersey State Police (NJSP)

The responsibilities of the New Jersey State Police personnel at the scene of an incident include the following:

- Assist with incident detection, verification and notification
- Serve as the Incident Commander (IC) and/or support the Incident Commander in situations where NJSP is not the IC

- Direct traffic and supervise incident scene clearance
- Provide direction for the clearing of vehicles damaged in collisions at an incident scene
- Provide direction for removing debris from traffic lanes
- Assist with establishing alternate routes and diversion signing
- Coordinate accident investigation resources (i.e. Crime Scene Investigation, Medical Examiner, Towing, etc.)

While not performing incident response functions, NJSP works with their NJDOT partners to conduct Incident Management outreach to local police, fire and emergency squads statewide. In addition, they provide training and instruction in both the Incident Command System and Incident Management System.

Incident Management Response Team (IMRT)

A component of the NJDOT/NJSP Incident Management Program is the Incident Management Response Teams (IMRT). These specially trained teams respond to incidents which have a major impact on transportation and they provide technical, logistical and incident management support to the Incident Commander (IC). The goal of the IMRT member is to keep the traffic safely moving through the following:

- Setting up traffic safety devices, demarcating diversion routes and warning motorists
- Serving as the liaison for NJDOT to mobilize resources
- Safely and quickly restoring lanes of traffic
- Facilitating necessary repairs and reopening the roadway

In addition, NJDOT and NJSP IMRT Members work with other agencies including the toll road authorities, neighboring states (PA, NY, and Delaware) in planning, coordinating and implementing traffic remediation efforts for special events such as major sporting and entertainment events, etc.

NJDOT and NJSP Personnel act as facilitators for multi-agency Task Forces to develop diversion route text and maps for all state highways and interstates on a county-by-county basis to be utilized during all major incidents that completely close a roadway for an extended duration. These diversion plans help to improve traffic flow and management through better communication and more efficient use of available resources. To date, plans have been established for 17 of the 21 New Jersey counties. NJDOT and NJSP are also working on a Diversion Route Plan for the NJ Turnpike and Garden State Parkway.

The NJDOT/NJSP Incident Management Teams will also help, on occasion, to monitor traffic activity on roadways where high-profile construction projects are underway. They assist the Resident Engineer, monitor traffic from the motorists' perspective and make improvements where possible.

2.1. The Role of Maintenance Operations in the Statewide Incident Management Program

To address the traffic management aspect of roadway incident response, NJDOT began dispatching its Maintenance Operations personnel to major traffic incident sites with an expected incident duration greater than 60 minutes. When dispatched, Maintenance Operations is part of a collaborative response from NJDOT that fulfills the requirements of the National Incident Management System (NIMS). When dispatched to traffic incident sites in support of the Incident Management Program, the responsibilities of the Maintenance Operations personnel include:

- Assistance with providing traffic control at the scene of major incidents;
- Providing containment of major spills;
- Determining incident clearance needs and resources (i.e. loaders, mobile sweepers, dump trucks, etc.) and other relevant equipment;
- Handling incident clearance activities (i.e. relocate fluid spills, relocate/remove spilled cargo/debris, and relocate damaged trucks and vehicles from the travel lanes);
- Assisting with the coordination of NJDOT resources (i.e. personnel, equipment) for incident clearance; and

- Assisting NJSP with establishing alternate routes and diversion signing.

Maintenance Operations is equipped to provide a full MUTCD (Manual on Uniform Traffic Control Devices) compliant lane closure, including signs, arrow boards, and a truck mounted impact attenuator. These activities of Maintenance Operations are consistent with desired characteristics of a Full-Function Service Patrol (FFSP) for traffic incident response and management from the viewpoint of an agency that is responsible for funding, managing, and operating these services. As described in FHWA's Service Patrol Handbook (Houston et al., 2008), when required, the maintenance forces are an extension to the Emergency Service Patrols (ESP) for clearing major traffic incidents in addition to performing their daily work of maintaining the roadways (i.e. roadway rehabilitation, safety upgrades, vegetation operations, signage, snow removal, etc.).

When deciding to utilize maintenance personnel as part of the incident management and emergence response teams, NJDOT was driven by efficiency and cost-effectiveness criteria. The efficiency of using Maintenance Operations is rooted in their excellent area of coverage of New Jersey roads and the following characteristics:

1. NJDOT operates approximately 80 maintenance yards strategically located across the State's highway network, ensuring timely response to emergencies.
2. Maintenance forces are ready to react 24/7/365. When they do not respond to emergencies, they perform roadway maintenance work. They are well trained, equipped, and experienced, having an ongoing relationship with other participants who provide emergency response (ESP, other NJDOT resources, State Police, local police and fire departments, utility companies, etc.).
3. The cost that NJDOT incurs by assigning Maintenance Operations personnel to incident management tasks is marginal, and includes only direct labor costs associated with incident response.

The alternative to using maintenance crews for incident clean-up would be to assign their responsibilities to other participants who provide incident and emergency response, or to contract private companies specialized in and equipped for incident response and clean-up. It is conceivable that the alternative of hiring private contractors would be far more expensive than using the Maintenance Operations personnel at a marginal cost in labor and no cost in equipment and materials. Consider the start-up costs and number of private contractors it would take to parallel the service, readiness, equipment, and experience of Maintenance Operations. The start-up costs would include dedicated response teams and equipment ready to be mobilized and deployed at any time, as well as a sufficient number of bases (yards) where these contractors would have to be located. This would include costs incurred by NJDOT for managing the contractors. In addition, the cost of the services provided by the private contractors would include operating costs, such as fuel, supplies, and materials.

Chapter 3

REVIEW OF THE STATE OF PRACTICE

NJIT's Research Team conducted an extensive literature search in order to identify studies, research papers, reports, and other publications providing information relevant to this study. The focus of the literature review was methodologies for evaluating impacts of incidents on traffic operations, as well as quantifying benefits of faster cleanup of incidents and restoration of the normal traffic flow. This Chapter summarizes the reviewed literature and highlights the most important concepts constituting the state of practice in evaluating effects of incident management programs. These concepts are subsequently used as a basis for developing the evaluation methodology applied in the benefit-cost analysis of NJDOT's Operation Management incident response.

3.1. Estimation of Savings due to reduction in Vehicle Delay

There are several modeling approaches that can be used for this kind of analysis and they can be divided into two general groups:

- ***Microscopic simulation modeling*** – traffic simulation is used to analyze movement of vehicles in the traffic stream and their interactions before, during, and after an incident. Based on the roadway, traffic stream, and incident characteristics, simulation models can calculate vehicle delay, fuel consumption, and pollutant emissions attributable to incidents. The same simulation model can be used to analyze the effect of reducing (or extending) the duration of an incident and thus determine the benefits of faster incident cleanup. Software packages such as CORSIM, VISSIM, and PARAMICS can be used for developing and implementing these models.
- ***Deterministic macroscopic queuing modeling*** – vehicle queuing and traffic bottleneck analyses is applied to determine delays and subsequently emissions and fuel consumption attributable to incidents. Most of the models are based on procedures provided in the Highway Capacity Manual.

One of the first modeling methodologies based on microscopic simulation approach was developed at the University of Maryland for evaluation of Maryland's Coordinated Highways Action Response Team (CHART) program (Chang et al., 2000). CHART is the statewide highway incident management program of the Maryland State Highway Administration (MSHA). The CHART evaluation methodology uses simulation models developed for a sample of 120 traffic incidents to calculate the corresponding effects on vehicle delay, fuel consumption, and emissions. It has been used for annual evaluation of the CHART performance since 1996. The data for the simulation models, including roadway geometry, traffic stream, incident duration and lane closure information, were provided from the MSHA database. For each incident, the impacted roadway section was simulated using the CORSIM software. Simulations were performed for baseline conditions (no incident), and incident conditions with and without the assistance of the CHART personnel to determine the effects of the incident in two incident response scenarios. It was assumed that duration of an incident would be 35% longer without the assistance of the service patrol, thus generating longer delays, more wasted fuel and excessive vehicle emissions. The difference between the effects of incidents with and without CHART involvement in cleanup and incident management is used as a measure of benefit of the program. The results from simulations of all sample incident sites are then compiled to determine a functional relationship between incident and roadway related factors (e.g. incident duration, total and number of blocked lanes during the incident, vehicle volume, etc.), and measured effects, including excessive delay, fuel consumption, and emissions. A regression analysis is used to develop the underlying functional relationships, which are then applied to all reported incidents during a year in order to calculate the benefits for each incident and the overall annual benefits of the program. Examples of calibrated functional relationships developed in this methodology are shown in equations (1) and (2):

$$\Delta Delay = e^{-10.19} * (V)^{2.8} * (NLB/TNL)^{1.4} * (ID)^{1.78} \quad (1)$$

$$\Delta Fuel = e^{-10.77} * (V)^{2.27} * (NLB/TNL)^{0.9} * (ID)^{1.69} \quad (2)$$

where,

$\Delta Delay$ = Excessive delay due to incidents

$\Delta Fuel$ = Additional fuel consumption due to incidents

TNL = Total number of lanes

NLB = Number of lanes blocked
V = Traffic volume
ID = Incident duration

Similar to the CHART is the model developed for evaluation of New York State's Highway Emergency Local Patrol (H.E.L.P.) program (Haghani et al., 2006). H.E.L.P. is a freeway service patrol (FSP) program that mitigates the negative impacts of traffic incidents through early detection and response, and adequate incident management and cleanup. The FSP programs are facilitated by specialized vehicles with crews that patrol designated highway sections called beats. Once they detect or are dispatched to an incident site, they can provide immediate assistance and traffic management or, if needed, request support from the police and other emergency response personnel. The evaluation methodology for the H.E.L.P. evolved from the CHART model with an added level of detail in simulation analysis. It improved handling of key simulation parameters and settings including incident duration, traffic volume, car-following sensitivity factors, and rubbernecking effects, and implemented regression models to predict the benefit-to-cost ratio as a function of volume-capacity ratio, rubbernecking effect, and potential reduction in total incident duration. The extension study of the H.E.L.P program (Chou et al., 2000) included an extensive simulation based statistical analysis on a sample of 10,000 incidents.

Another class of models utilizes vehicle queuing and bottleneck analysis theory to estimate the travel delay savings resulting from traffic incident management programs. The estimated delay savings are then used to calculate corresponding savings in fuel consumption, vehicle emissions, and secondary accidents. The models implemented in Florida for evaluation of the Road Ranger FSP program (Hagen et al., 2005) and in Virginia for evaluation of the Northern Virginia Safety Service Patrol (NOVA SSP) program (Dougald et al., 2006) are examples of deterministic queuing models. Both applications used Freeway Service Patrol Beat Evaluation (FSPE) model developed by the University of California at Berkeley to calculate the benefit/cost ratios of the respective service patrol programs. FSPE is implemented in Microsoft Excel with added analysis capabilities programmed in Visual Basic for Applications (VBA). The program contains calculation routines implementing the deterministic queuing equations to calculate the savings in travel delay, and a vehicle emissions sub-model to calculate savings in vehicle emissions and fuel consumption. All of the three components of savings are converted to monetary values using appropriate cost units.

Other software packages such as Highway Capacity Software (HCS) or FREEVAL can be employed in calculating travel delays associated with traffic incidents. Both of these software packages implement the vehicle queuing and bottleneck analysis models based on the Highway Capacity Manual. They are different from the FSPE model in that they don't perform beat analysis, but evaluate individual incidents considering traffic conditions before, during, and after the incident, roadway geometry, and incident characteristics (mainly the impact incidents have on capacity – number of blocked lanes, blocked shoulders, etc). FREEVAL software was implemented in evaluation of the potential for deploying Incident Management Assistance Patrols (IMAP's) in North Carolina (Guin et al., 2007). Since FREEVAL can only calculate savings in delay, the study of North Carolina IMAP service did not include estimation of savings in fuel consumption and vehicle emissions.

Guin et al. (2007) proposed a methodology for evaluation of incident management programs that applies deterministic traffic queuing equations and uses a Capacity Reduction Table from the Traffic Incident Management Handbook (USDOT, 2000) to calculate the effect of an incident on roadway capacity. The capacity reduction will depend on the total number of lanes on the analyzed highway segment and number of lanes and shoulders blocked due to the incident. The total vehicle delay resulting from the reduced capacity will further depend on the duration of the incident: the delay will accumulate with an increase in incident duration, i.e. lane and/or shoulder closure. The methodology allows the analysis of incidents with a two-phase clearance: in the first phase, all or some lanes would be blocked by the incident and incident responders; in the second phase, all lanes would be cleared, but the shoulder would remain blocked by the vehicles involved in the incident and incident responders at the scene. The capacity would be partially restored in the second phase, with blockage of the shoulder still having a capacity reduction effect. In their methodology, Guin et al. (2007) defined two scenarios for incident duration: baseline – without a traffic incident management program, and incident duration with a response and clean-up by the traffic incident management personnel. It is assumed that incident duration with a traffic incident management program would be shorter than it would be without the program. Total vehicle delay is calculated for each of these two scenarios for each incident, and the difference between the two constitutes savings (in terms of vehicle delay) from having an incident management program. Similar to the previous methodologies, savings in vehicle delay are used to calculate savings due to reduced vehicle emissions and fuel consumption.

3.2. Estimation of the effect on Secondary Incidents

Secondary incidents are defined as incidents that occur as a result of disruptions in a traffic stream caused by an ongoing incident, or incidents that have cleared but the normal traffic flow conditions have not yet been re-established. In the analysis of secondary incidents, it is assumed that the longer a disruption lasts, the greater the possibility of a secondary incident. Hence, it can be assumed that the reduction of incident duration would reduce the probability of a secondary incident. Looking at the number of incidents and their duration over a period of time, say a month or a year, these probabilities (or reduction thereof) can be used to estimate the number of avoided secondary incidents as a result of reduced incident duration. If an incident management response program effectively reduces incident duration, then resulting reduction in the number of secondary incidents can be thought of as one of the benefits of such a program and should be added to the benefits realized due to reduced travel delay, fuel consumption, and vehicle emissions.

Chou et al. (2009) proposed a simple model for estimation of the number of secondary incidents based on an assumption that the number of secondary incidents over a certain period of time is directly proportional to the cumulative vehicle delay caused by the (primary) traffic incidents over the same period of time. The model can be illustrated by the following equation:

$$N_s = \frac{N_s^{imp} \cdot TD}{TD^{imp}} \tag{3}$$

where:

N_s = Estimated annual number of incidents without the incident management program (IMP);

N_s^{imp} = Annual number of secondary incidents identified in an IMP's incident database;

TD = Total estimated vehicle delay resulting from incidents without the IMP;

TD^{imp} = Total estimated vehicle delay resulting from incidents with the IMP.

The proposed model was implemented in evaluating the New York State DOT H.E.L.P program. In order to implement this model, Chou et al. (2009) first identified the secondary incidents that occurred in the H.E.L.P. area of operation during the analysis period of one year. They developed a simulation model that defined the incident impact area for each incident as a dynamic variable and then filtered out all second incidents that occurred within the incident impact area as secondary incidents. They found that among 693 incidents, 27 were secondary, which is about 4%.

A more simplified model was used by Guin et al. (2007) in the case study of the Georgia NaviGAtor program. They assumed that 15% of all highway incidents are secondary, and that their occurrence is directly proportional to incident duration. They used the following equations to calculate the reduction in the number of secondary incidents as a result of a traffic incident management patrol program:

$$\Delta N_s = 0.15 \times N \times \frac{T - T^{TIM}}{T} \quad (4)$$

where:

ΔN_s = Decrease in secondary incidents due to traffic incident management (TIM) patrols over a time period

N = Total number of crashes in the baseline condition, without the TIM

T = Average incident duration in the baseline condition, without the TIM

T^{TIM} = Average incident duration (TIM condition)

A more complex approach to estimating the relationship between primary and secondary incidents involves regression analysis. The regression models are developed so as to establish functional dependencies between occurrence of secondary incidents and various contributing factors, such as primary incident duration, length of the queue, type of the primary incident, roadway geometric and functional characteristics, environmental factors, etc. Zhan et al. (2009) proposed a logit model to calculate the probability of occurrence of a secondary incident for a given set of factors related to a primary incident. They implemented the model in a case study of three interstate highways in Florida. The authors used incident data for a two-year period to identify secondary incidents and calibrate the regression model. They assumed that incidents occurring within a maximum queue length distance upstream from the existing incident for the duration of the incident may be considered secondary incidents. They identified 225 secondary incidents resulting from 221 primary incidents. Based on the statistical analysis of the calibration of regression model, they concluded that four important factors had a significant effect on the likelihood of secondary crash occurrence. They include: primary incident type, primary incident lane blockage duration, time of day, and roadway type. The R^2 value for the logit model used in this study is 0.336.

Sun and Chilukuri (2007) proposed and tested a linear regression model for estimation of secondary incidents, but introduced a more complex methodology for identification of secondary incidents. The authors departed from an approach considering the incident impact area to be equivalent to a fixed distance upstream from the incident (static threshold), usually equivalent to a maximum queue length resulting from an incident. Instead, they proposed this distance should be a dynamic variable (dynamic threshold) that varies with the length of queue throughout the duration of the incident, including traffic recovery time after the incident clearance. They developed a nonlinear (third-order polynomial) regression model to estimate the dynamic threshold (equivalent to queue length) depending on the total duration of an incident. Different models were calibrated for different v/c ratios, number of vehicles, and incident severity. The model was then used to identify the secondary incidents as those falling within the dynamic threshold upstream from the existing (primary) incident with a lane closure. The methodology was tested in the case study of interstate highways I-70 and I-270 in Missouri. Using the accident database for year 2003, which contained 5,514 accidents, the authors identified 397 secondary accidents based on the dynamic threshold method, and 390 secondary accidents based on the static threshold (assumption of the incident impact area equivalent to fixed queue length). While these two numbers seem to be close, the study found that they can differ by up to 30%.

One indicative finding from the reviewed studies of secondary incidents is that their number relative to the number of primary incidents varies greatly. In the study of the New York H.E.L.P. program (Chou et al., 2009), secondary incidents comprised less than 4% of the number of primary incidents that received assistance from the highway patrol. In the analysis of CHART, this number was much higher – 29.3%. The methodology used for evaluation of the NaviGAtor program in Georgia (Guin et al., 2007) assumed this number to be 15%, which is based on widely used findings of a study by Raub (1997). In an evaluation of incident management programs, it is therefore important to adequately select criteria for identification of secondary incidents because this will greatly impact the resulting estimate of savings due to reduced incident duration.

Chapter 4

DATA COLLECTION AND ANALYSIS

The analysis in this study is based on the data collected for the period of August 2008 – May 2009. The data sources include NJDOT SWIFT (Statewide Information for Travelers), the CDU (Central Dispatch Unit) database, NJDOT's Highway Maintenance Management System (HMMS), the New Jersey Straight-Line Diagram (SLD), and the New Jersey Congestion Management System (NJCMS). The first three databases provide information related to incidents and costs associated with Maintenance Operations responding to traffic incidents as part of the Statewide Incident Management Program. The SLD database provides basic roadway geometry data, while traffic flow data, including estimated hourly volumes and truck percentage for the pertinent roadways is obtained from NJCMS.

It is important to note that each of the aforementioned management information systems provides specific information related to its primary function. It was therefore hard to expect to find all the necessary data for the analysis in this study from a single data source. However, each of the databases contains some piece of needed information, and the research team was able to develop a sample dataset for the analysis by integrating the data from these information systems. The following is a summary of data collection, integration, and analysis tasks performed in this study.

4.1. Description of NJDOT Databases

SWIFT Data Management System

NJDOT's Statewide Information for Travelers (SWIFT) is a management information and communications system used by NJDOT's Statewide Traffic Management Center (STMC). SWIFT provides a common platform for the STMC operators to collect information about traffic conditions on major roadways, including information about incidents and to communicate this information back to the traveling public. The public is informed via dynamic message sign (DMS) and the 511 traveler information telephone system. The SWIFT database is physically located at and maintained by TRANSCOM. TRANSCOM is a coalition of 16 transportation and public safety agencies in the New York - New Jersey - Connecticut metropolitan region. TRANSCOM's headquarters is located in Jersey City, NJ. The role of TRANSCOM is to improve the mobility and safety of the traveling public by supporting its member agencies through interagency communication and the enhanced utilization of their existing traffic and transportation management and systems, with a strong ITS component.

The SWIFT dataset obtained for this study consists of two basic tables:

1. Event table (tblEvent) – the information is provided for each incident in a single record. The information in this table includes: incident ID, incident type, the location of the incident described by the facility (roadway) name, milepost, street intersection and geographic coordinates, time that the incident was reported, time that the incident was closed, and incident duration.
2. Action table (tblAction)– each incident is described by a chronological set of records - each documenting a specific action in the database related to an incident beginning with the entry of the incident into the database and concluding with entering the information that the incident is closed. Each record contains a narrative describing the action: e.g. the time when Maintenance Operations was dispatched to an incident scene, lane closure or changes in lane closure, communication with other agencies, etc.

CDU Information Management System

The CDU's Information Management System is used by Statewide Traffic Operations' Central Dispatch Unit (CDU) to record activities related to traffic management operations. These activities include dispatching an Incident Management Response Team (IMRT) or Maintenance Operations to major highway incidents and directing the proper response and use of NJDOT resources. The CDU database also contains records of the activities of the Emergency Service Patrol (ESP), which respond to disabled motorists, accidents and other highway incidents and provides safety, communication and repair functions. In the CDU incident table, each incident is represented by a single record. The information contained in the database which is relevant to this study includes: the time the incident was reported, the type of incident, the location of the incident (route, county, milepost), the time that Maintenance Operations was dispatched to the location of the incident, the time they arrived, and the time of incident clearance.

Highway Maintenance Management System (HMMS)

The costs associated with the response of NJDOT's Maintenance Operations to incidents are recorded and maintained in NJDOT's Highway Maintenance Management System (HMMS). It was agreed by the NJIT Research Team and Working Group Panel that this data should be used for estimating costs in the Benefit/Cost analysis. All the charges accrued by NJDOT's Operations Maintenance as part of the emergency incident response are recorded in HMMS under the work category "*Emergency Safety Services*" (reporting code 700). This allows NJDOT to effectively keep track of (labor) expenses associated specifically with incident management activities. Only labor costs associated with incident response are recorded under this work code and the system prevents the maintenance work to be charged to this work code.

The report containing cost data for the period of August 2008 – May 2009 was provided by NJDOT for the purpose of this analysis. The costs in the report are broken down by incident. The report provides the following data for each identified incident:

- Date of the incident;
- Type of activity (provided services);
- Total labor expense in $;
- Total equipment expense in $;
- Total material expense in $;
- Incident location (route, beginning and end milepost);
- Comments regarding the response.

Starting in the Fall of 2008, a field containing a corresponding CDU incident ID number was added in the appropriate HMMS table which enabled associating the incidents recorded in the CDU database with activities under the work category "*Emergency Safety Services*" in HMMS. This field also added in the HMMS report used in this analysis.

New Jersey Straight-Line Diagram (SLD)

The New Jersey Straight Line Diagram (SLD) is established as the main reference for the State's centerline roadway inventory. The SLD was initially designed as a planning tool but it has become a standard information platform for many other purposes within and outside NJDOT including engineering, maintenance, and safety. The development of the SLD is driven by FHWA requirements and is used as a main reference for identifying road classification with respect to eligibility for federal aid. The SLD information management system, including the data repository and software, is maintained by NJDOT's Bureau of Transportation Data Development (BTDD). The SLD data used in this study includes roadway jurisdictional and functional classification, number and width of lanes, availability and width of shoulders, information on medians, and speed limits. This information is collected for each analyzed incident location from the appropriate SLD tables.

New Jersey Congestion Management System (NJCMS)

The roadway geometry and traffic flow data necessary for the analysis of incidents was obtained from the New Jersey Congestion Management System (NJCMS). The NJCMS is a data management and data analysis system used primarily by the Bureau of Systems Planning to estimate congestion measures for New Jersey highways. It is used to identify congested routes, perform congestion analysis for projects, provide recommendations for possible congestion improvements, and monitor congestion in New Jersey. The most recent version of NJCMS, SD data series, was used in the analysis including the following two data tables:

1. SDLINK.dbf – Links operations data generated by the NJCMS application. This table contains estimated hourly volumes, hourly V/C ratios, hourly speeds, and hourly truck volumes for each link in the network by direction.
2. SDNET.dbf – The NJCMS network file with all the basic roadway geometry and traffic operations data for each link in the network by direction.

The highway links in the NJCMS tables are identified by the Standard Route Identifier (SRI) or Route Name (e.g., I-80, or NJ-46), and by beginning and end mileposts. The link information stored in NJCMS was tied to incidents identified in the HMMS, CDU, and SWIFT databases using these unique link identifiers. Roadway geometry and traffic flow data was then used to calculate link capacities and, in conjunction with incident information, traffic delays caused by an incident.

4.2. Data Integration and Analysis

The CDU database and HMMS report were used as a basis for identifying the incidents to be evaluated, as well as the availability of data elements required for the evaluation. At the outset of this study, it was decided by the Working Group Panel that the evaluation should be focused on incidents to which NJDOT's Operations Maintenance responded as part of the Statewide Incident Management Program. As part of this program, NJDOT's CDU dispatches maintenance units only to incident sites with the estimated incident duration of 90 minutes or more. Furthermore, planned roadway maintenance, emergency roadwork, off-highway incidents, and weather-related emergencies (e.g. flooding, hurricane, snow storm, etc.), which were all recorded in the SWIFT and CDU databases, were excluded from the analysis.

For the period of August 1, 2008 – May 31, 2009, a total of **1,564 incidents** were identified in the HMMS report. Maintenance Operations was dispatched to all of these incidents. The HMMS records were cross-referenced with the incident data from CDU and SWIFT. The CDU and SWIFT databases contain incident data required for evaluation, such as incident description, lane and shoulder closures, and incident duration. After integrating the data HMMS, CDU, and SWIFT, a dataset with **974 incidents, or 62%** of the total number of incidents was assembled. Due to the time constraints for completing the analysis and this report, the data integration has not been completed for the remaining 590 incident records in the HMMS report (or approximately 38%). The graph in Figure 1 illustrates the sources of data and the data integration process.

A review of the SWIFT and CDU databases revealed that each has a subset of unique data elements that are needed for incident analysis. However, since the two databases are not cross-referenced (i.e. there is no common field by which the incidents in the two databases could be linked), the only way to match their incident records was manually by visual inspection. This involved examining and matching the dates, times, locations, and descriptions of the incidents recorded in the CDU and SWIFT databases one by one. Additional tools, such as SLD, online mapping engines and aerial photography were also used to reconcile the information recorded in the two databases for the same incidents.

As the result of incident data integration, two time-stamps were identified for each of the 974 incidents:

- *Incident Detection*: Date and time when incident was reported;
- *Capacity Restored:* Date and time when incident was cleared and roadway capacity was restored to normal.

These time-stamps were consequently used in the analysis to calculate the incident duration.

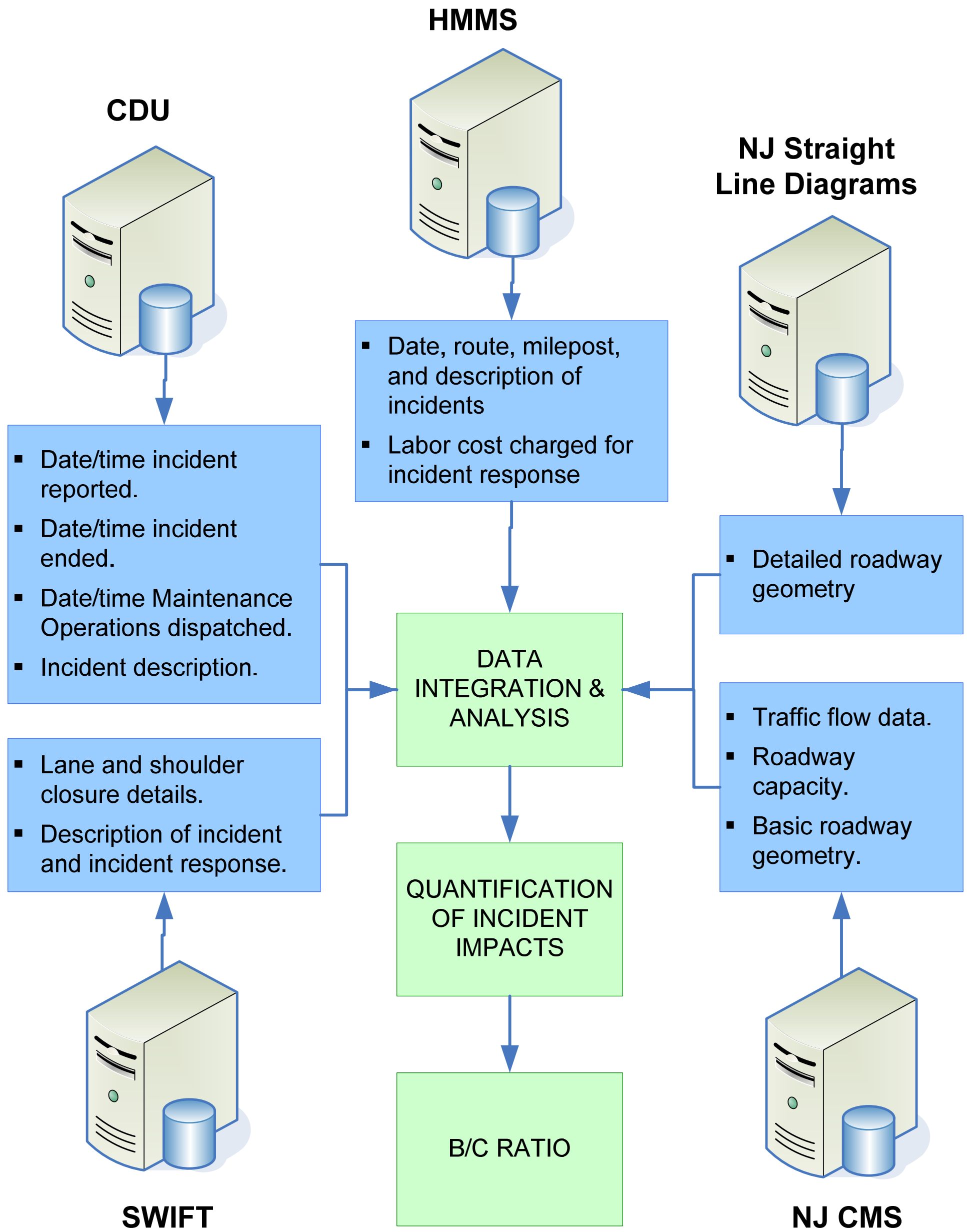

Figure 1 – Incident Data Integration Process Overview

Chapter 5

DEVELOPMENT OF THE BENEFIT EVALUATION METHODOLOGY

Based on the literature review and review of available data, it was decided that the evaluation methodology in this study should be based on deterministic macroscopic queuing modeling. The main advantages of taking deterministic macroscopic queuing as opposed to a traffic simulation approach in this study include the following:

- It requires less data for deterministic macro queuing models without sacrificing the quality of estimates;
- Queuing models do not require as large a sample of incidents as the simulation approach;
- Queuing models require a much shorter time to develop and implement (the study has to be completed within an eight-month period making it very hard to develop, calibrate, and implement simulation models);
- The theory behind the deterministic queuing models is based on the Highway Capacity Manual.

The proposed evaluation methodology is largely based on the methodology of Guin et al. (2007) that was used for the Georgia "NaviGAtor" Highway Emergency Response Operators (HERO) Program. It includes calculation procedures for estimating the following benefits of NJDOT's Maintenance Operations' incident management activities:

- Reduction in hours of travel delay;
- Emission reductions in tons of hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxide (NOx);
- Reduction in wasted gallons of fuel due to idling, stopping, and slow-moving traffic; and
- Reduction in the number of secondary incidents.

Each of the above effects is calculated as a difference between the impacts of an incident with and without the response of NJDOT's Maintenance Operations. Since no data is available for incidents to which Maintenance Operations was not dispatched, it is assumed in the analysis that if involved, their presence and activities would reduce the duration of an incident by 1 to 30 minutes.

Vehicle emissions and wasted fuel are considered to be dependent on the total incurred vehicle delay resulting from a disruption of the traffic flow due to an incident. Therefore, in order to determine the impact of an incident on vehicle emissions and wasted fuel, it is necessary to first calculate the total vehicle delay. The total vehicle delay is also used to calculate the cost of unproductive time of the motorists.

The occurrence of secondary incidents is considered to be dependent on the total duration of a primary incident. This deterministic approach is selected because the dataset used in this analysis did not provide a big enough sample for a meaningful regression analysis of primary and secondary incidents. Additional data sources, such as statewide crash records database would need to be added in the analysis to develop a regression model.

5.1. Calculation of Incident Delay and Delay Savings

The delay caused by a traffic incident is a function of both the duration of the incident and traffic demand during the incident. The delay is measured in terms of vehicle-hours. In a deterministic queuing model applied in this study, motorist delay is associated with a queue that forms as a result of an incident. When they occur, traffic incidents cause disruptions in a normal traffic flow by reducing the effective highway capacity. The severity of the capacity reduction depends on the nature and severity of an incident. An incident with a lane closure will reduce the capacity more than an incident blocking the shoulder.

In the traffic engineering practice, the "Four-to-One rule"[2] is applied as general rule-of-thumb for determining effects of traffic incidents. The rule is: for every minute a lane of traffic is blocked by an incident, four minutes of congestion are created. For example, a vehicle runs out of gas and stops in the right lane during rush hour. If that vehicle continues blocking the right lane for

[2] Source: Highway Capacity Manual, http://mobility.tamu.edu/ums

10 minutes waiting for a tow truck or roadside assistance, it can take around 40 minutes for the congestion caused by that disruption to clear.

The vehicle flow, queue formation, and queue dissipation can be described using a cumulative vehicle volume vs. time graph, as shown in Figure 2. On a highway segment under normal conditions, where demand is smaller than capacity, vehicle flow can be described by vehicle arrival rate λ, in vehicles per hour (represented by the green line in Figure 2). The capacity of the highway segment can be described by the maximum vehicle service rate μ, which is higher than the arrival rate (red line in Figure 2). Arrival and service rates can be considered to be constant and continuous.

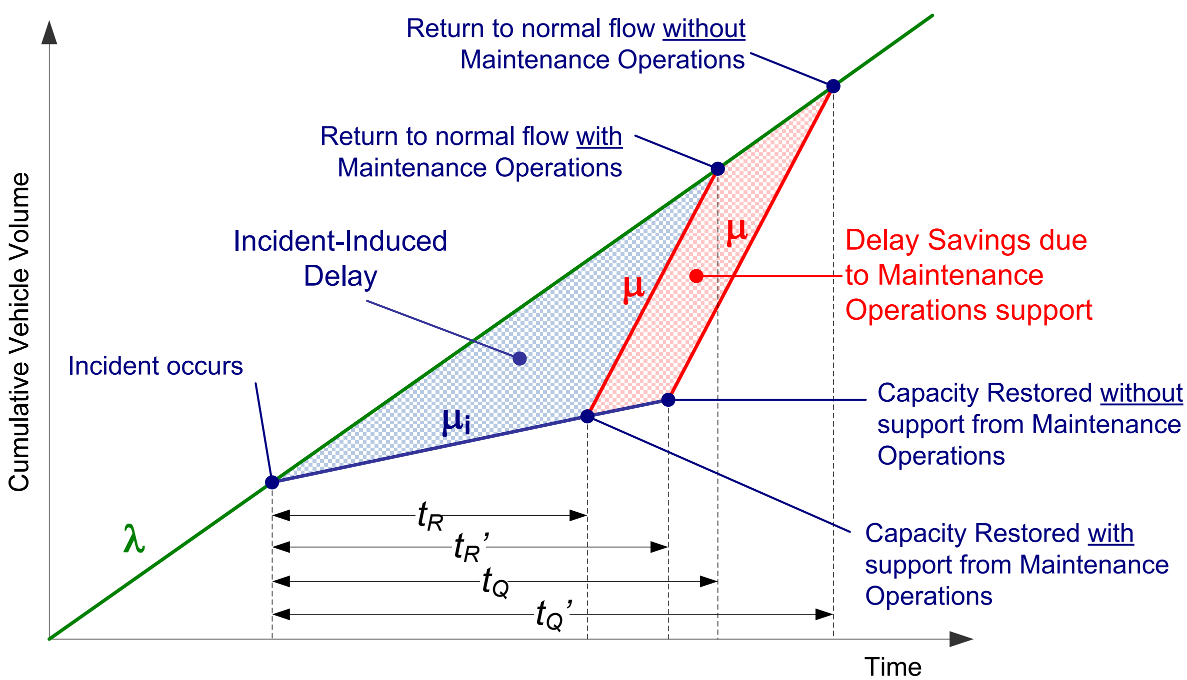

Figure 2 – Cumulative Vehicle Volume vs. Time Graph for a Highway Incident

When an incident occurs, it reduces the capacity from μ to μ_I (represented by the blue line in Figure 2). If μ_i is smaller than λ, vehicle queuing will occur (vehicle flow following the incident occurrence is described by the blue line in Figure 2). The incident capacity μ_i remains until the incident is cleared. If Maintenance Operations is dispatched to the incident site, the incident will be cleared in time t_R; without the Maintenance Operations units at the site, it would take longer to clear the incident - t_R'. Once the incident is cleared, the queue dissipates at the rate μ (red line in Figure 2). Consequently, a response by Maintenance Operations reduces the time necessary for the facility to return to a normal flow from t_Q' to t_Q, and allows the savings in total vehicle delay represented by the red shaded area in Figure 2.

In the context of the data collected from the CDU and SWIFT incident databases, the time of incident occurrence is replaced with **the time of incident reported**, as the actual time of incident occurrence is generally unknown or hard to estimate.

In the methodology applied in this study, vehicle arrival and service rates are allowed to vary on an hourly basis. This is more realistic than assuming constant λ throughout the incident duration, as vehicle demand regularly changes throughout the day, but also is subject to vehicle detours and diversions avoiding the incident site. Similarly, the service rate μ, reflecting the roadway capacity, may also change during the incident if capacity is restored gradually by cleaning up the portion of the roadway and letting the traffic go through before the incident site is completely cleared. The graph in Figure 3 shows this more general case. Areas D1, D2, D3, and D4 represent the accumulated vehicle delays in corresponding time intervals.

Using the notation provided in the graph, the vehicle delay resulting from an incident can be calculated as follows:

$$D_1 = \int_0^{t_1-t_0} \left[\left(\lambda_1 - \mu_1\right) \cdot t + \left(V_0^A - V_0^D\right) \right] dt =$$

$$= \left(\lambda_1 - \mu_1\right) \frac{\left(t_1 - t_0\right)^2}{2} + \left(V_0^A - V_0^D\right) \cdot \left(t_1 - t_0\right) \tag{5}$$

$$D_2 = \int_0^{t_2-t_1} \left[\left(\lambda_2 - \mu_2\right) \cdot t + \left(V_1^A - V_1^D\right) \right] dt =$$

$$= \left(\lambda_2 - \mu_2\right) \frac{\left(t_2 - t_1\right)^2}{2} + \left(V_1^A - V_1^D\right) \cdot \left(t_2 - t_1\right) \tag{6}$$

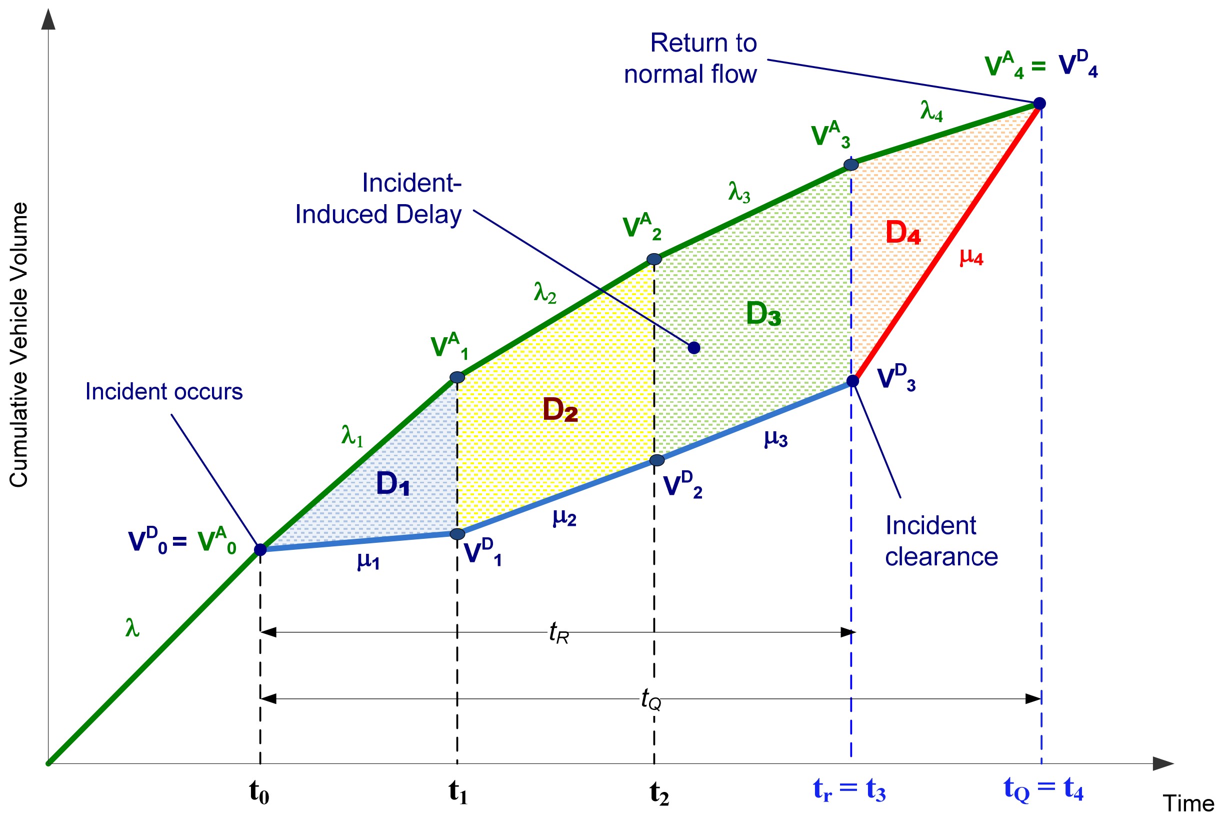

Figure 3 – Cumulative Vehicle Volume vs. Time Graph with Varying Vehicle Arrival and Service Rates

$$\Rightarrow D_i = \int_0^{t_i - t_{i-1}} \left[\left(\lambda_i - \mu_i\right) \cdot t + \left(V_{i-1}^A - V_{i-1}^D\right) \right] dt$$

$$\Rightarrow D_i = \left(\lambda_i - \mu_i\right) \frac{\left(t_i - t_{i-1}\right)^2}{2} + \left(V_{i-1}^A - V_{i-1}^D\right) \cdot \left(t_i - t_{i-1}\right) \qquad (7)$$

Where:

D_i = Vehicle Delay accumulated during the period $\left(t_i - t_{i-1}\right)$;

λ_i = Vehicle Arrival Rate (Demand) during the period $\left(t_i - t_{i-1}\right)$;

μ_i = Vehicle Service Rate (Capacity) during the period $\left(t_i - t_{i-1}\right)$;

V_i^A = Cumulative vehicle arrival volume at time t_i;

V_i^D = Cumulative vehicle departing volume at time t_i.

To simplify the calculation, it can be assumed that:

$$t_0 = 0; \qquad V_0^A = V_0^D = 0.$$

Then:

t_Q = Time duration in queue (hours);

t_R = Incident duration (hours);

$$\begin{aligned} V_1^A &= V_0^A + \lambda_1 \cdot t_1 & V_1^D &= V_0^D + \mu_1 \cdot t_1 \\ V_2^A &= V_1^A + \lambda_2 \cdot (t_2 - t_1) & V_2^D &= V_1^D + \mu_2 \cdot (t_2 - t_1) \\ &\ldots\ldots\ldots\ldots & &\ldots\ldots\ldots\ldots\ldots \\ V_i^A &= V_{i-1}^A + \lambda_i \cdot (t_i - t_{i-1}) & V_i^D &= V_{i-1}^D + \mu_i \cdot (t_i - t_{i-1}) \end{aligned} \tag{8}$$

The time of return to normal flow (t_4 in the graph) can be calculated as:

$$t_5 = t_4 + \frac{V_4^A - V_4^D}{\mu_5 - \lambda_5} \tag{9}$$

or in a more general case:

$$t_n = t_{n-1} + \frac{V_{n-1}^A - V_{n-1}^D}{\mu_n - \lambda_n} \tag{10}$$

where *n* is the index of the last time interval in an incident analysis. The total vehicle delay due to the incident is calculated as a sum of cumulative delays for each time interval within the incident duration:

$$T_d = \sum_{i=1}^{n} D_i = \sum_{i=1}^{n} (\lambda_i - \mu_i) \frac{(t_i - t_{i-1})^2}{2} + \left(V_{i-1}^A - V_{i-1}^D\right) \cdot (t_i - t_{i-1}) \tag{11}$$

This equation can be applied in calculating the cumulative vehicle delay both with and without Maintenance Operations response. The difference between the two is defined as Incident Delay Savings (veh-hours) – ΔT_d:

$$\Delta T_d = T_{d-Base} - T_{d-IMS} \tag{12}$$

where:

$T_{d\text{-}Base}$ = Total vehicle delay without Maintenance Operations support in incident response (vehicle-hours);

$T_{d\text{-}IMS}$ = Total vehicle delay with Maintenance Operations support in incident response (vehicle-hours).

The vehicle arrival rates (λ_i) for this analysis are obtained from the NJCMS database for each hour of the incident duration for a pertinent roadway. Service rates (μ_i) are calculated considering the roadway base (normal) capacity and level of disruption due to the incident.

Calculation of the Capacity

The normal capacity (μ) can be calculated in the following steps:

a) Freeways

1. Determine the Free-Flow Speed (*FFS*) depending on the roadway geometric and traffic flow characteristics:

$$FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID} \tag{13}$$

Where:

BFFS = Base Free-Flow Speed (mph), assumed to be 70 mph for Urban Freeways and 75 mph for Rural Freeways. (Mannering et al., 2008, Chp.6)

f_{LW} = Adjustment factor for lane width (mph) (Mannering et al., 2008, Table 6.3)

f_{LC} = Adjustment factor for lateral clearance (mph) (Mannering et al., 2008, Table 6.4)

f_N = Adjustment factor for number of lanes (mph) (Mannering et al., 2008, Table 6.5)

f_{ID} = Adjustment factor for interchange density (mph) (Mannering et al., 2008, Table 6.6)

2. Determine roadway capacity using the calculated *FFS* and Capacity Relationship Tables for Freeways (Mannering et al., 2008, Table 6.2).

3. Assuming that capacity is represented by the flow rate at Level of Service "E" (LOS E), the Maximum Flow Rate (MSF) at capacity is determined using the appropriate table in Mannering et al. (2008) (Table 6.1).

4. After determining the *MSF*, the Service Flow rate (SF) can be calculated as:

$$SF = MSF \cdot N \cdot f_{HV} \cdot f_p \tag{14}$$

Where:

N = Number of lanes;

f_{HV} = Adjustment factor for heavy vehicles (Mannering et al., 2008, Table 6.7)

f_p = Adjustment factor for driver population (assumed regular users, fp =1)

Normal capacity flow rate (μ) is calculated from Equation 14 as SF for N equal to the total number of lanes.

b) Multi-lane highways

1. Determine the Free-Flow Speed (*FFS*) depending on the roadway geometric and traffic flow characteristics:

$$FFS = BFFS - f_{LW} - f_{LC} - f_M - f_A \tag{15}$$

Where:

BFFS = Base Free-Flow Speed (mph), assumed to be equal to the speed limit + 7 mph where posted speed limit is 40-45 mph, and speed limit + 5 mph where posted speed limit is 50-55 mph. (Mannering et al., 2008, Chp.6)

f_{LW} = Adjustment factor for lane width (mph) (Mannering et al., 2008, Table 6.3)

f_{LC} = Adjustment factor for lateral clearance (mph) (Mannering et al., 2008, Table 6.13)

f_N = Adjustment factor for median type (mph) (Mannering et al., 2008, Table 6.14)

f_{ID} = Adjustment factor for access points (mph) (Mannering et al., 2008, Table 6.15)

2. Determine roadway capacity using the calculated *FFS* and Capacity Relationship Tables for Multi-lane Highways (Mannering et al., 2008, Table 6.12).

3. Assuming that capacity is represented by the flow rate at Level of Service "E" (LOS E), the Maximum Flow Rate (MSF) at capacity is determined using the appropriate table in Mannering et al. (2008) (Table 6.11).

4. After determining the *MSF*, the Service Flow rate (SF) can be calculated as:

$$SF = MSF \cdot N \cdot f_{HV} \cdot f_p \tag{16}$$

Where:

N = Number of lanes;

f_{HV} = Adjustment factor for heavy vehicles (Mannering et al., 2008, Table 6.7)

f_p = Adjustment factor for driver population (assumed regular users, fp =1)

Normal capacity flow rate (μ) for multi-lane highways is calculated from Equation 16 as SF for N equal to total number of lanes.

c) Two-way, two lane highways

The normal capacity of two-way, two-lane highways is assumed to be 2,300 vehicles per hour for both directions, as explained in Mannering et al. (2008).

The roadway geometry data necessary for the calculation of *FFS*, *MSF*, and *SF*, as well as traffic volume and classification data (e.g. hourly volume and truck percentage) for analyzed roadway segments are obtained from the New Jersey Congestion Management System (NJCMS). The estimated vehicle volumes in 2008 were used in the analysis.

Capacity Reduction Due to an Incident

The extent of capacity reduction depends on the severity of an incident, specifically on the lane and shoulder blockages that it causes. When an incident occurs that blocks one or more lanes, or a shoulder of a highway, it reduces the physical space available for the movement of vehicles; but it also causes behavioral adjustments of drivers, such as reduction of travel speed, lane changing, and "rubber-necking". For this reason, the actual reduction of capacity is greater and is not simply proportional to the available number of lanes as compared to the total number of lanes on a highway. Table 1 is taken from Guin et al. (2007)[3] and it provides relative capacity availability depending on the total number of lanes on a freeway, and the type of blockage caused by an incident.

Capacity reductions summarized in Table 1 apply to freeways, but drivers' behavior on multi-lane highways during incident conditions, in many aspects, resembles their behavior on freeways under similar conditions. It was therefore decided that the same capacity reduction should be applied in the analysis of incidents on multi-lane highways. Two-way, two-lane highways are a bit different as there is only one lane in each direction and often times, two-way traffic on these roads can operate even when one (and only) lane in one direction is blocked. The reduced capacity calculated using the factors from Table 1 is applied in equation (11) to calculate incident delays, and equation (12) to calculate the benefit of dispatching Maintenance Operations.

Based on the economic theory of supply and demand applied to a traffic system (Ossenbruggen, 1984), it can be expected that the traffic demand that is usually present on a roadway would be reduced in case of an incident with a lane blockage. Such an incident effectively reduces the supply (roadway capacity) and causes an increase of the "price" of travel (travel time). In this situation, a certain portion of demand would disappear - i.e. - the demand would adjust to the supply to create a new equilibrium. The reduction in demand occurs through detours and the

[3] Adopted from The Traffic Incident Management Handbook (USDOT, 2000) and expanded using extrapolation.

diversion of vehicles in their attempt to avoid the incident location. The level of diversion will depend on a variety of factors. The motorist advisory and information systems, such as dynamic message signs (DMS) and the 511 system, as well as the existence of alternative routes have an important role in increasing the percentage of detoured traffic. As a result, the hourly vehicle arrival rates would have to be adjusted downward to reflect reduced number of vehicles entering the queue at the incident location.

Table 1 – Available capacity depending on lane closures

Number of Lanes	Shoulder Disablement	Shoulder Crash	Lanes Blocked						
			One	Two	Three	Four	Five	Six	Seven
2	0.95	0.81	0.35	0.00	NA	NA	NA	NA	NA
3	0.99	0.83	0.49	0.17	0.00	NA	NA	NA	NA
4	0.99	0.85	0.58	0.25	0.13	0.00	NA	NA	NA
5	0.99	0.87	0.65	0.40	0.20	0.10	0.00	NA	NA
6	0.99	0.89	0.71	0.50	0.25	0.17	0.08	0.00	NA
7	0.99	0.91	0.75	0.57	0.36	0.21	0.14	0.07	0.00
8	0.99	0.93	0.78	0.63	0.41	0.25	0.19	0.13	0.06

With this in mind, the following adjustments were implemented into the model to account for traffic diversions:

a) Freeways:

1. Full closure:
    1. First hour = 0% diversion, no capacity
    2. Second Hour = 25% diversion, no capacity
    3. Third Hour and on = 25% diversion, 1 lane open to simulate detour

- Partial closure
    1. First Hour = 0% diversion
    2. Second Hour and on = 15% diversion

b) Multi-lane highways

1. Full closure
    1. First Hour = 0% diversion, no capacity
    2. Second Hour = 25% diversion, no capacity
    3. Third Hour and on = 25% diversion, 1 lane open to simulate detour
2. Partial closure
    1. First Hour = 0% diversion
    2. Second Hour and on = 15% diversion

c) Other roads (2-lane, 2-way highways)

- If an incident is blocking a lane (in either or both directions), 35% of the capacity will be available for both directions.
- When there is a 2-lane closure, a 25% diversion is assumed starting in the second hour.
- If the incident is blocking a shoulder:
    3. Accident/Crash: treat as having a 19% reduction in capacity in both directions.
    4. Disablement: treat as having a 5% reduction in capacity in both directions.

d) Ramps and Jug-handles

- First hour = treat as one lane blocked, no diversion
- Second hour and on = treat as a shoulder crash, no diversion.

5.2. Calculating the reduction in Vehicle Emissions

It is assumed that vehicle emissions are directly proportional to the total time vehicles spend in the queue. Therefore, reducing the duration of an incident and thus the queue, will also reduce the total vehicle emissions. The total vehicle emissions resulting from the traffic delay can be calculated using Equation 12 shown below:

$$E_{HC} = T_d \cdot e_{HC}; \qquad E_{CO} = T_d \cdot e_{CO}; \qquad E_{NOx} = T_d \cdot e_{NOx} \tag{17}$$

Where:

E_{HC}, E_{CO}, E_{NOx} = Total emissions of HC, CO, and NOx in tons;

e_{HC}, e_{CO}, e_{NOx} = Vehicle emissions of HC, CO, and NOx in tons/hour; these are considered as constants and are given in Table 2.

The total savings in vehicle emissions can be calculated by replacing the total delay by delay reduction in Equations 12:

$$\Delta E_{HC} = \Delta T_d \cdot e_{HC}; \quad \Delta E_{CO} = \Delta T_d \cdot e_{CO}; \quad \Delta E_{NOx} = \Delta T_d \cdot e_{NOx} \qquad (18)$$

Where:

ΔE_{HC}, ΔE_{CO}, ΔE_{NOx} = Reduction in emissions of HC, CO, and NOx in tons due to reduced delay.

5.3. Calculating Reduction in Wasted Fuel

It is assumed that the vehicle fuel consumption is directly proportional to the total time it spends in the queue. It is also assumed that trucks consume diesel and all other vehicles gasoline. The total fuel consumed by the vehicles in the queue is calculated using the following formula:

$$F_{PC} = T_d \cdot V_{avg} \cdot g_{PC}; \qquad F_{TR} = T_d \cdot V_{avg} \cdot g_{TR} \qquad (19)$$

Where:

F_{PC}, F_{TR} = Total fuel consumption during the incident (queue) of passenger cars and trucks respectively, in gallons;

g_{PC}, g_{TR} = Average fuel economy of passenger cars (gallons of gasoline per mile) and trucks (gallons of diesel per mile) respectively. The estimated fuel economy of passenger cars and trucks is given in Table 2;

V_{avg} = Average speed of vehicles during an incident, assumed to be 20 mph.

The total savings in fuel can be calculated by replacing the total delay by delay reduction in Equations 14:

$$\Delta F_{pc} = \Delta T_d \cdot V_{avg} \cdot g_{pc}; \qquad \Delta F_{tr} = \Delta T_d \cdot V_{avg} \cdot g_{tr} \tag{20}$$

Where:

ΔF_{pc}, ΔF_{tr} = Reduction in consumed fuel by passenger cars and trucks respectively, in gallons.

5.4. Calculating Reduction in Secondary Incidents

The initial approach to analyzing the impact of Maintenance Operations support in incident response on secondary incidents was to develop a regression model to establish a functional relationship between the incident duration and occurrence of secondary incidents. However, in the analysis of the data sample for August 2008, only 3 secondary incidents were identified. This is too small of a sample for any regression model, so the decision was made to use a simplified method described in the evaluation study of the NaviGAtor program in Georgia (Guin et al., 2007).

As explained in the literature review section (Task 1), in the case study of the Georgia NaviGAtor program, Guin et al. assumed that 15% of all highway incidents are secondary, and that their occurrence is directly proportional to incident duration. This assumption is based on widely used findings of a study by Raub (1997). With this, the equation used in the preliminary methodology to calculate the reduction in the number of secondary incidents is as follows:

$$\Delta N_s = 0.15 \cdot N \cdot \frac{\Delta T_I}{T_{I-Base}} \tag{21}$$

Where:

ΔNs = Decrease in secondary incidents due to Maintenance Operations response;

N = Total number of incidents to which Maintenance Operations responded;

ΔT_I = Reduction in incident duration resulting from Maintenance Operations response;

$T_{I\text{-}Base}$ = Total duration of incidents without Maintenance Operations response.

5.5. Calculating Cost Savings

To calculate a Benefit/Cost (B/C) ratio of the Maintenance Operations support in incident response, it is necessary to express all of the above benefits in monetary terms. This means that savings in time, vehicle emissions, fuel, and secondary incidents, has to be multiplied by the appropriate unit costs in order to obtain the total dollar savings (benefit). Thus, the total cost savings can be calculated as follows:

Vehicle Delay

$$\Delta C_d = \Delta T_d \cdot \left[\left(P_{PC} \cdot occ \cdot C_{PERS} \right) + \left(P_{TR} \cdot C_{TR} \right) \right] \tag{22}$$

Where:

ΔC_d = Total cost savings due to reduced vehicle delay ($);

P_{PC} = Percent of passenger cars in traffic (this value is obtained from the NJCMS database for each incident location);

occ = Average occupancy of passenger cars obtained from the NJCMS database for each incident location (persons/vehicle);

C_{PERS} = Average value of time per passenger ($/person-hour) – provided in Table 2.

P_{TR} = Percent of trucks in traffic (this value is obtained from the NJCMS database for each incident location);

C_{TR} = Average cost of truck per hour of delay ($/truck-hour) – provided in Table 2.

Vehicle Emissions

$$\Delta C_e = \Delta E_{HC} \cdot c_{HC} + \Delta E_{CO} \cdot c_{CO} + \Delta E_{NOx} \cdot c_{NOx} \tag{23}$$

Where:

ΔC_e = Total cost savings due to reduced vehicle emissions ($);

c_{HC}, c_{CO}, c_{NOx} = Unit cost savings from the reduction of emissions of HC, CO, and NOx respectively ($/ton) – provided in Table 2.

Fuel

$$\Delta C_f = \Delta F_{PC} \cdot c_{gas} + \Delta F_{TR} \cdot c_{diesel} \quad (24)$$

Where:

ΔC_f = Total cost savings due to a reduced amount of wasted (consumed) fuel ($);

c_{gas}, c_{diesel} = Market price at the pump of gasoline and diesel ($/gallon) – provided in Table 2.

Secondary Incidents

$$\Delta C_{si} = \Delta N_s \cdot c_a \quad (25)$$

Where:

ΔC_{si} = Total cost savings due to a reduced number of secondary incidents ($);

c_a = Average cost per accident ($/accident) – given in Table 2.

Therefore, the **TOTAL BENEFIT (COST SAVINGS)** of Maintenance Operations support to incident response can be calculated as:

$$B = \Delta C_d + \Delta C_e + \Delta C_f + \Delta C_{si} \quad (26)$$

where B stands for benefits.

Table 2 – Dollar value of parameters used in calculations

Parameter	Value	Measure	Source
Cost per Driver/Passenger (estimated statewide average hourly wage in New Jersey)	25.46	$/hour	U.S. Department of Commerce, 2008
Cost of Trucks	32.15	$/hour	USDOT, 2005
HC emissions per hour of delay	0.000025676	tons	Guin et al, 2007
CO emissions per hour of delay	0.00033869	tons	Guin et al, 2007
NOx emissions per hour of delay	0.000036064	tons	Guin et al, 2007
Average speed of the vehicles in congestion	20	mph	NJCMS
Fuel consumption of passenger cars (estimated for an average passenger car at 20 mph speed)	0.070	gallons/mile	California Air Resources Board, EMFAC2002
Fuel consumption of trucks (estimated for an average truck at 20 mph speed)	0.169	gallons/mile	California Air Resources Board, EMFAC2002
Cost savings because of HC reduction	6,700	$/ton	Guin et al, 2007
Cost savings because of CO reduction	6,360	$/ton	Guin et al, 2007
Cost savings because of NOx reduction	12,875	$/ton	Guin et al, 2007
Average price of gasoline in NJ	3.08	$/gallon	AAA Daily Fuel Gauge Report
Average price of diesel in NJ	3.51	$/gallon	AAA Daily Fuel Gauge Report
Average cost of secondary incident (only PDO accidents are considered)	$4,437	$/incident	Blincoe et al., 2002

As an example of how benefits of reducing incident duration can be calculated, let us look at the incident on Interstate highway I-280, on October 23, 2008, Thursday, at 3:00 PM. The incident is caused by heavy debris blocking all three lanes of the highway at Milepost 11 (East Orange, NJ). The estimated duration of the incident was 110 minutes. However, due to timely response by Maintenance Operations, the roadway is cleared in 95 minutes. With the estimated volume of 2,200 vehicles per hour (2.5% trucks) and using the unit costs presented in Table 2, it can be calculated that this 15-minute reduction in incident duration generates the following savings:

- Travel Time Savings = $64,800.00
- Fuel Consumption Savings = $ 2,772.00
- Vehicle Emission Savings = $ 4,430.00

Total savings, therefore, amounts to $72,002.00. This does not include the benefit of preventing the incident of extending into the afternoon and evening peak hours when traffic demand was expected to increase to 3,500 vehicles per hour.

Chapter 6
EVALUATION RESULTS

The evaluation methodology and benefit/cost calculation models are implemented to evaluate the effectiveness of NJDOT's Maintenance Operations for the period of August 2008 – May 2009. The incident data obtained from the management information systems described in Chapter 4 provide a detailed overview of the incident timeline and allows for the determination of incident duration, level of disruption (i.e. lane or shoulder closure), and the cost of deploying Maintenance Operations to incidents. In order to process the data more efficiently and reduce the calculation time, an MS Access application has been developed that automates retrieval of the input parameters, calculation of the benefit/cost measures, and produces tabulated reports summarizing the results of the analysis. The inputs consist of incident, roadway, and cost parameters from the SWIFT, NJCMS, and HMMS tables.

6.1. Incident Data Summary Statistics

The analysis was performed on a sample of 974 incidents as outlined in Chapter 5. These incidents, as well as the rest of the total of 1,564 incidents to which Maintenance Operations responded during the analyzed 10-month period, include only major incidents with an estimated duration of 60 minutes or more. The average duration of the incidents to which Maintenance Operations responded is around 3.9 hours.

It is also important to note that Maintenance Operations forces respond to incidents that occur on the roadway system under NJDOT's jurisdiction. This system includes interstate, state, and U.S. highways. Table 3 provides the statistics on the number of responses by highway system and roadway type for the sample of 974 incidents analyzed in the study.

In comparison, an estimated 75,000 crashes occurred on New Jersey's interstate, state, and U.S. highway network during the 10-month period between 08/01/2007 and 05/31/2008[4]. The majority of these crashes were property-damage only crashes, and there was no need to involve Maintenance Operations personnel and assets in the clean-up. Therefore, it can be concluded that Maintenance Operations responds to a relatively small portion of traffic incidents and only when warranted by the severity of the traffic disruption and damage to the infrastructure.

Table 3 – Number of responses by highway system and roadway type

Roadway System	Incident Count	%
Interstate	227	23
U.S. Highways	314	32
N.J. Highways	433	45
TOTAL	974	100

Roadway Type	Incident Count	%
Freeways	227	23
Multilane Highways	559	58
2-Way 2-Lane Highways	188	19
TOTAL	974	100

6.2. Estimating Benefits of Maintenance Operations Incident Response

As explained in Chapter 5, the analysis focused on determining the savings (or reduction) of costs associated with travel delay, fuel consumption, vehicle emissions, and secondary incidents, resulting from quicker incident clearance. To be able to calculate the savings, one would need to know how much faster incidents are cleared with the assistance of NJDOT's Maintenance Operations as compared to incidents to which they do not respond. Unfortunately, no data was available about the duration of similar incidents without the response by Maintenance Operations. In order to estimate the benefits of deploying Maintenance Operations to major traffic incidents, the duration of each incident to which it responded was increased by 1-30

[4] Based on the analysis of reported crashes for years 2007 and 2008 performed by NJIT's Research Team. The source of crash data is the New Jersey Accident Records Database maintained by NJDOT, accessible for download at http://www.state.nj.us/transportation/refdata/accident/. The data for the first six months of 2009 was not available at the time this study was conducted.

minutes, assuming that participation of Maintenance Operations in incident clearance effectively reduced the overall incident duration and corresponding disruption of the traffic flow.

This assumption is based on the fact that the number, location, and equipment of Maintenance Operations Yards (around 80 yards strategically located throughout the State) provides for a quicker mobilization and deployment to incident sites than any other available resource. Maintenance Operations crews are fully equipped to set up a MUTCD lane closure and traffic diversion/detour and they can quickly deploy heavy equipment - such as front loaders and dump trucks to the incident scene. This enables them to quickly set up safety at the scene and efficiently clear debris or other objects blocking traffic.

With this in mind, the costs of person-delay, consumed fuel, vehicle emissions, and secondary incidents were calculated for each incident for the scenario without Maintenance Operations response, assuming an increase in the incident duration of 1-30 minutes. The results are then compared to corresponding costs with the response by Maintenance Operations to obtain the cost savings. The cost savings translate into benefits, which are in turn compared to the total cost of labor associated with Maintenance Operations response to incidents. The results of the benefit-cost analysis are presented next.

6.3. Summary of the Benefit-Cost (B/C) Analysis

The total costs of labor associated with Maintenance Operations responding to the analyzed 974 incidents was $510,000. This cost is next compared to the benefits of faster incident clearance resulting from the assistance provided by Maintenance Operations. This analysis is summarized in Table 4, and B/C ratios for different incident duration reduction scenarios are illustrated in Figure 4. Both Figure 4 and Table 4 show that the B/C ratio of Maintenance Operations deployment to major incidents is greater than 1.0, even when just 1 minute is saved per incident as a result of their intervention (B/C ratio is 1.31 in this scenario). As stated before, this minimum reduction in incident duration is almost guaranteed, given the ability of Maintenance Operations to react whenever and wherever needed in a minimal amount of time.

Greater reduction in incident duration results in greater savings and a higher B/C ratio. A 15-minute reduction in duration per incident generates savings that are almost 24 times the cost of Maintenance Operations services. A 30-minute reduction generates savings 44 times the cost of Maintenance Operations services which is equivalent to a B/C ratio of 44:1.

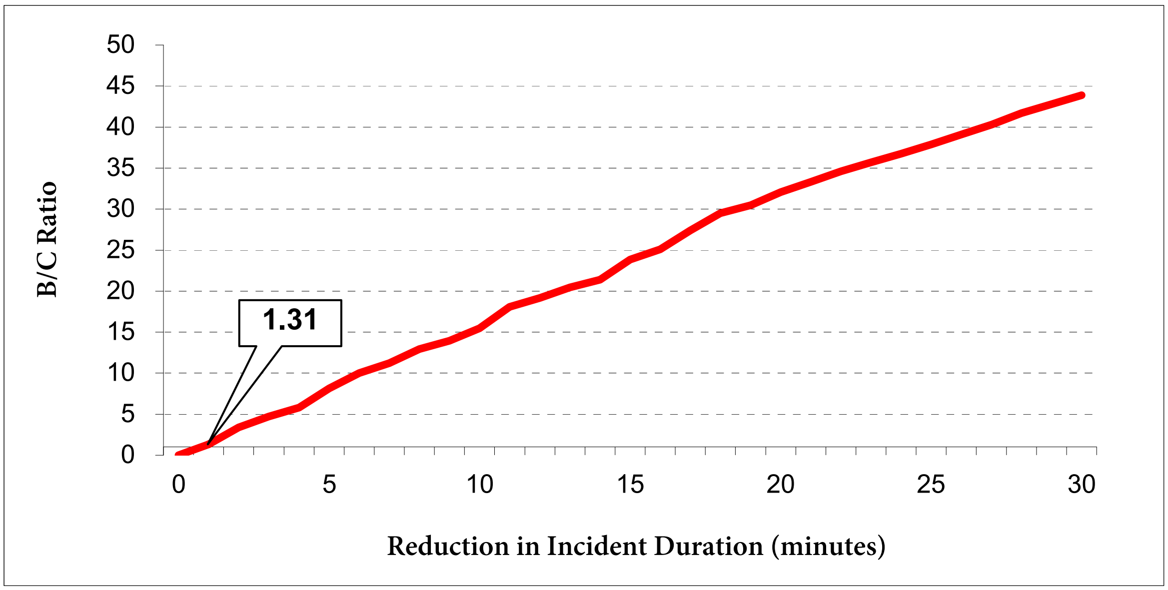

Figure 4 – Benefit/Cost (B/C) Ratios of Maintenance Operations support in incident response resulting from an assumed reduction in incident duration from 1 to 30 minutes per incident

The results provided in Table 4 show that the most significant savings are realized as a result of a reduction in travel delay which translates into the cost of unproductive time incurred by motorists. They are followed by savings resulting from the reduced fuel consumption (directly proportional to the cost of fuel at the pump), reduced vehicle emissions due to reduced congestion, and avoided secondary incidents. For example, a reduction of incident duration by 15 minutes per incident results in a decrease of duration of all analyzed incidents of 244 hours, a 6% reduction. However, as shown in Table 4, this reduction translates to a total savings of **$12.1 million**, which is almost **24 times** more than the cost incurred by Maintenance Operations.

Table 4 – Summary Results of the Benefit/Cost (B/C) Analysis of NJDOT Maintenance Operations to Incidents Response Program (Analysis Period - August 2008-May 2009)

Savings category	Reduction in Incident Duration per Incident due to Maintenance Operations						
	1 minute	5 minutes	10 minutes	15 minutes	20 minutes	25 minutes	30 minutes
Reduction in Incident Duration (Hours)	16	81	162	244	325	406	487
Value of Reduced Travel Delay ($)	$555,415	$3,448,059	$6,551,335	$10,097,678	$13,568,465	$16,032,991	$18,562,284
Value of Reduced Vehicle Emissions ($)	$40,949	$254,337	$483,700	$745,747	$1,002,061	$1,183,966	$1,370,763
Value of Reduced Fuel Consumption ($)	$69,550	$434,057	$833,278	$1,288,295	$1,730,830	$2,043,236	$2,365,928
Value of Avoided Secondary Incidents ($)	$2,771	$13,630	$26,718	$39,297	$51,395	$63,040	$74,257
TOTAL Cost Savings ($)	*$668,684*	*$4,150,083*	*$7,895,032*	*$12,171,017*	*$16,352,752*	*$19,323,233*	*$22,373,232*
B/C Ratio	**1.31**	**8.14**	**15.48**	**23.87**	**32.07**	**37.90**	**43.88**

Chapter 7

CONCLUSION

The results of the study reveal tremendous benefits of reducing incident duration on New Jersey's highways. More importantly, they show that NJDOT Maintenance Operations provides an important service in cleaning up traffic incidents which leads towards the reduction of incident duration and subsequently, significant monetary savings for the traveling public and society. The results also show that NJDOT is able to perform this job cost-effectively – a reduction of 1 minute in duration per incident results in a savings of 1.31 times the cost of Maintenance Operations response, and savings resulting from a 15-minute reduction per incident generates savings almost 24 times the cost of Maintenance Operations services. Based on the review of the requirements that a private contractor (or contractors) would need to meet to be able to parallel the service, readiness, equipment, skill and experience of Maintenance Operations forces, it was concluded that this alternative would be far more expensive than utilizing available Maintenance Operations resources.

The objective of the study was accomplished by applying a systematic research approach, which included a review of a state of practice, data collection and integration, and system analysis. An extensive review of available models and methodologies, as well as widely used references on the evaluation of impacts of traffic incidents, allowed the Research Team to select the most appropriate evaluation model, given the constraints in time and data availability. Data integration was an important part of the study. Information from four different databases maintained by NJDOT was cross-referenced and integrated in order to assemble as complete a dataset of incidents as possible. Further improvements of databases and their connectivity are strongly recommended to NJDOT. This is expected to make future analysis easier and less labor intensive.

Finally, the analysis showed a significant influence of a range of parameters on the overall outcome of earlier clean-up of traffic incidents. Beside travel time (or its cost component), early incident clean up has ramifications on the environment (air quality), energy efficiency and traffic safety. All of these elements must be considered in order to fully understand the extent of savings realized through emergency incident cleanup performed by NJDOT Maintenance Operations.

Chapter 8

RESEARCH RECOMMENDATIONS

The evaluation methodology presented in this report is based on sound traffic flow and economic theory, and provides a good basis for the evaluation of effectiveness of traffic incident emergency response. With some improvements and an increased level of detail, it can become even more robust and allow for additional performance analysis. This would require a more detailed analysis of data recorded in the HMMS, CDU, and SWIFT databases, and possibly collection of additional data that is currently not found in any of these three MIS systems. Potentially, the useful extension of this study would require a more detailed analysis of secondary incidents and how their occurrence relates to duration and severity of primary incidents.

In this section, we will concentrate on suggested improvements in managing and storing the data related to incidents and NJDOT activities in response to these incidents. The recommendations can be summarized as follows:

1. Introducing a common incident identifier code (ID). The coordination between data systems could be improved by creating a common incident identifier that would be used in both the SWIFT and CDU/HMMS databases. The common identifier would allow the data from these databases to be related to each other more efficiently and it would improve the analysis of incidents.
2. Reconciling data in different databases. It would also be beneficial for future analysis to institute a process of reconciling the incident data recorded in CDU and SWIFT, especially the timing, location, incident type classification, and data related to Maintenance Operations being dispatched to the incident site. This could be done in real time or as part of a regular (weekly, monthly, annual) review and update process.
3. Provide more details about lane closures. For more detailed analysis of impacts of lane closures and earlier clean-up by Maintenance Operations, it would also be beneficial to record how many lanes are closed and if partial clean up occurs (i.e. some lanes are cleaned-up and open to traffic while the incident is still ongoing). There is currently an

ability to record this information in the SWIFT database, but it does not appear to be used at this time.

4. Detailed time-record of all events during the progression of an incident. Further improvement in evaluating the incident response and performance of incident management teams could be made by recording the times of each event on the incident time diagram shown in Figure 5. This would allow for a more detailed analysis of activities related to incident management, and would provide the ability to ascertain areas of improvement (e.g. potential to reduce time between the report of an incident and dispatching Maintenance Operations to the incident scene).

Several variables representing elapsed times between events, as shown in Figure 5, can be detected and measured to assess the effect of incident response and clearance on traffic operations. These variables are defined as follows:

- *Incident Detection Time*: Time elapsed between the moment of an incident occurrence and the moment at which Traffic Operations receives the information about the incident (incident detection).
- *Incident Response Unit Preparation Time*: Time elapsed between incident detection by the NJDOT's Traffic Operations and the moment that Maintenance Operations are dispatched to the incident site.
- *Incident Response Unit Travel Time*: Time elapsed between the moment of dispatching a Maintenance Operations unit from a maintenance yard and the arrival of the unit at the incident site.
- *Response Time*: Sum of the Maintenance Operations unit's preparation time and the travel time between the maintenance yard and the incident site.
- *Incident Clearance Time*: Time elapsed between the arrival of the Maintenance Operations unit and complete clearance of an incident. Complete clearance of an incident means that full capacity of the roadway is restored (i.e., all lanes and shoulders are clear of vehicles, debris and/or other obstacles disrupting the traffic flow).
- *Incident Duration*: Time elapsed between the moment of incident occurrence and restoration of full roadway capacity.

- *Queue Dissipation Time*: Time elapsed between the moment of restoration of full roadway capacity and the moment at which the roadway has recovered from the incident and returns to normal conditions (i.e. elimination of any queues caused by the incident.)
- *Time to Return to Normal Flow*: Total time elapsed between the moment of incident occurrence and return to a normal traffic flow.

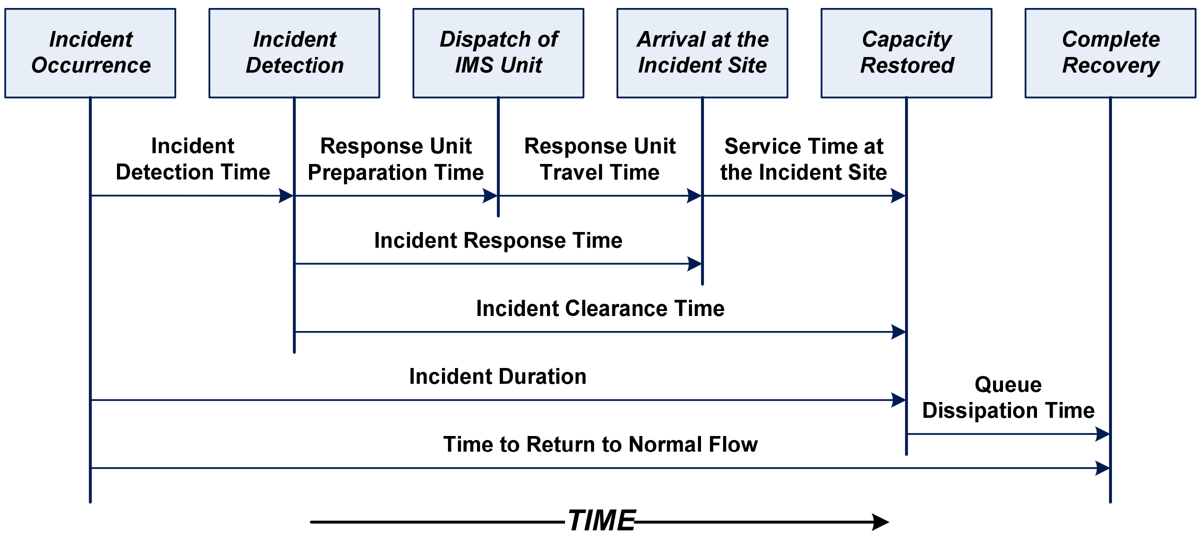

Figure 5 – Incident Duration Time Diagram

Ideally, all of the above variables would be collected by NJDOT units responding to an incident. The benefit estimation model can then be used to calculate benchmark performance measures for different types of incidents assuming different response, clearance, and incident duration times. These benchmarks can then be used to estimate the effects of an incident management program over a certain period of time considering a specific distribution of the program's performance statistics.

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