FHWA-NJ-2016-002

Highway Repair Consolidation Feasibility

FINAL REPORT
July 2016

Kaan Ozbay, Ph.D.
Professor
Department of Civil and Urban Engineering
Tandon School of Engineering
New York University

Hao Wang, Ph.D.
Assistant Professor
Civil and Environmental Engineering
Rutgers University

Bekir Bartin, Ph.D.
Department of Civil and Urban Engineering
Tandon School of Engineering
New York University

Abdullah Kurkcu, M.Sc.
Department of Civil and Urban Engineering
Tandon School of Engineering
New York University

Matthew Maggio
Research Programmer
Civil and Environmental Engineering
Rutgers University

NJDOT Research Project Manager
Smmamunar Rashid

In cooperation with

New Jersey
Department of Transportation
Bureau of Research
And
U.S. Department of Transportation
Federal Highway Administration

DISCLAIMER STATEMENT

TECHNICAL REPORT
STANDARD TITLE PAGE

1. Report No. FHWA-NJ-2016-002	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle FINAL REPORT Highway Repair Consolidation Feasibility		5. Report Date July 2016 6. Performing Organization Code Rutgers / NYU
7. Author(s) Kaan Ozbay, Ph.D., Hao Wang, Ph.D., Bekir Bartin, Ph.D., Abdullah Kurkcu, and Matthew Maggio		8. Performing Organization Report No.
9. Performing Organization Name and Address Rutgers University, 96 Frelinghuysen Road, Piscataway, NJ 08854 NYU, 8 Metrotech Center, Room 404, Brooklyn, NY 11201		10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address New Jersey Department of Transportation, PO 600, Trenton, NJ 08625 Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Faced with growing number of work zones, the challenge for transportation agencies is to effectively manage the impacts of work zones to alleviate congestion and maintain the safety of motorists without disrupting project schedules. Coordinating work zone activities and improving communication among agencies have already been practiced by various State DOTs and transportation agencies.
The main objective of this study is to understand the types of projects that can be coordinated and to evaluate the effectiveness of coordinating short and long-term projects using a cost-benefit analysis approach to measure the efficiency of various combinations of projects relative to each other and the status quo.

For this purpose the research team conducted an extensive literature review, determined the state of practice in other State DOTs and conducted interviews with NJDOT staff to investigate the types of projects undertaken by NJDOT and if there were already any practice of work zone coordination on NJ roadways. The team, after consulting with the project panel and the NJDOT Mobility and Systems Engineering division, devised a work zone coordination framework that utilizes one common work zone database, including OpenReach and Capital Program Management (CPM) Project Reporting System (PRS) databases.

Work Zone Coordination Spreadsheet (WCS) tool was developed for providing NJDOT with an easy-to-use tool to evaluate the feasibility and effectiveness of coordinating short and long term work zones and measure the benefits of various combinations of projects relative to each other and the status quo. This on-line tool is implemented with a web-based user interface. It integrates all scheduled and active construction projects from the OpenReach database and planned CPM projects from project reporting system (PRS) database. It then identifies conflicts between work zone projects and estimates the benefits of conflict mitigation.

17. Key Words Work zone, coordination, conflict, cost benefit analysis			
19. Security Classif (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 97	22. Price

Form DOT F 1700.7 (8-69)

ACKNOWLEDGEMENTS

The authors wish to thank various staff members without whom this research would not have been possible. Special thanks to Mike Pilsbury of Traffic Operations, Sheryl Grant of Bureau of Program Systems Management and Rashid Smmamunar of Bureau of Research, who helped the research team throughout the project and to Dr. Ender Morgul of NYU / CUSP for reviewing and editing the project report.

TABLE OF CONTENTS

LIST of FIGURES

LIST of TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

AASHTO - American Association of State Highway and Transportation Officials
AAA - American Automobile Association
AADT - Annual Average Daily Traffic
Caltrans - California Department of Transportation
CIA - Construction Impact Analysis
CPM - Capital Program Management
DOT- Department of Transportation
FHWA - Federal Highway Administration
GLRTOC - Great Lakes Regional Transportation Operations Coalition
GSP - Garden State Parkway
HCM - Highway Capacity Manual
LCS - Lane Closure System
NJTPK - New Jersey Turnpike
NCHRP - National Cooperative Highway Research Program
NHTSA - National Highway Traffic Safety Administration
OD - Origination-Destination
PCPHPL – Passenger cars per hour per lane
PRS - Project Reporting System
QUEWZ - Queue and User Cost Evaluation of Work Zones
RILCA - Rutgers Interactive Lane Closure Application
TMP - Transportation Management Plan
TFAF - Traffic Flow Adjustment Factor
VOT - Value of Travel Time
VPHPL – Vehicles per hour per lane
WCS - Work Zone Coordination Spreadsheet
WISE - Work Zone Impact and Strategy Estimator
WZCAT - Work Zone Capacity Analysis Tool

EXECUTIVE SUMMARY

The increasing number of work zones adversely affects the mobility and safety of travelers on already congested roadways. Drivers are constantly faced with unfavorable road conditions and unexpected delays due to work zones. Faced with growing number of work zones, the challenge for transportation agencies is to effectively manage the impacts of work zones to alleviate congestion and maintain the safety of motorists without disrupting project schedules.

Coordinating work zone activities and improving communication among agencies have already been practiced by various State DOTs and transportation agencies, such as Oregon DOT, Great Lakes Regional Transportation Operations Coalition (GLRTOC), Caltrans, Washington State DOT, etc. A review of work zone coordination by other states is presented in the Current State of Practice section of this report. The list of the reviewed agencies and the tools they utilize for coordination purposes was summarized. It was found that there are no universal DOT policies that address how agencies should coordinate or consolidate projects. In addition, only a few states utilize computer tools specific to regional or corridor based work zone coordination. State DOTs mostly coordinate significant and long-term projects. However, the majority of roadway projects include minor repair, roadway maintenance, bridge maintenance, surveying, landscape, and utility work that require relatively short term work zones. There are more maintenance and minor repair projects than major overhaul or expansion projects.

The Rutgers / NYU research team carefully reviewed the NJDOT state-of-practice. The review is based on the interviews with NJDOT experts. During the interviews the team investigated the types of projects undertaken by NJDOT and if there are already any practice of work zone coordination on New Jersey roadways. Based on the interviews, it can be stated that the Capital Program Management (CPM) project managers are in close communication during the project screening process, and therefore they are well aware of any other conflicting CPM projects in close proximity. However, because there is no combined and accessible-to-all database of work zones, it is not a straightforward task for all divisions to coordinate with each other.

The project team, after consulting with the project panel and the NJDOT Mobility and Systems Engineering division, devised a work zone coordination framework that utilizes one common work zone database. Initially, the coordination framework involved two stages: Stage 1 included long-term coordination and Stage 2 included short-term coordination. Stage 1 would take advantage of the fact that Maintenance Engineering projects are known in the beginning of the each year. These projects get awarded and completed within less than a year. In this stage, it was initially proposed to create a database for aforementioned projects and make them visible to the decision makers and coordinate Maintenance projects around CPM projects. Stage 2 aimed to coordinate all work zones including CPM projects and maintenance projects in the short term.

As the first step, it was decided that coordination of maintenance projects with on-call consultants around CPM projects should be improved since they are relatively easier to coordinate than daily work conducted by NJDOT in-house. The research team met with Maintenance Operations on March 11, 2014 regarding the maintenance engineering projects. During the meeting with the Maintenance Operations group, the project team was informed that input and periodic update of each maintenance project in a database throughout projects' delivery timeline would be cumbersome due to staff shortage. For demonstration purposes, the research team created a database for these projects that included all the maintenance engineering projects planned for 2014. However, this was not an ideal work flow because it required continuous back and forth communication between the research team and the NJDOT to simply update the status of all projects.

As an alternative solution, the research team focused on Stage 2 coordination, namely focusing on short-term coordination only (e.g. less than a month), as suggested by the NJDOT Mobility and Systems Engineering division during the quarterly project meeting on January 29, 2015. In order to realize this objective, the research team utilized the OpenReach database. This database is being used on a daily basis by the traffic operation division, and it includes all events including information on historical work zones such as the time and date of work zone, how many lanes closed, description of work zone, and type of project. Based on the suggestions from the research panel, the team updated the work zone coordination framework.

The Rutgers / NYU research team developed the Work Zone Coordination Spreadsheet (WCS) tool. WCS is an online user-friendly computer tool that is developed for providing NJDOT with an easy-to-use way to evaluate the feasibility and effectiveness of coordinating short and long term work zones and measure the benefits of various combinations of projects relative to each other and the do-nothing scenario.

The key functional requirements of the tool identified as a result of the review of the current state of practice in the US, interviews with NJDOT experts and a number of meetings with prospective users of the tool can be listed as follows:

- Integrate all scheduled and active construction projects in the OpenReach database and planned CPM projects.
- Implement as an online tool that can be modified simultaneously by multiple users
- Identify conflicts between work zone projects
- Send conflict notification to involved parties
- Be visible to all responsible parties
- Offer varying user accessibility privileges
- Estimate the benefits of conflict mitigation
- Have the ability to save the analyses in a report format to be shared with the decision makers.

Details on how to use the WCS tool are presented in the Work Zone Coordination Spreadsheet Tool section of the report. The tool is operational and being used by NJDOT. Rutgers / NYU team will continue to provide technical support to the users of the tool. This includes providing access to new users, fixing minor bugs, and ensuring that the tool remains available throughout this initial testing period.

Future work is needed to continue the day-to-day maintenance and development of the tool based on the actual experiences of its users. One improvement will be automating the acquisition of all work zone project data from NJDOT in addition to the OpenReach database. Similarly, the acquisition of traffic data can be improved to incorporate different on- and off-line databases maintained by NJDOT. This can be done given the current flexible database architecture of the WCS tool. Finally, additional coordination and consolidation related tasks can be added based on the needs of the users of the tool to enhance the effectiveness of work zone operations in New Jersey.

INTRODUCTION

The increasing number of work zones of different sizes along a corridor adversely affects the mobility and safety of travelers on already congested roadways. Drivers are constantly faced with unfavorable road conditions as a result of unexpected delays due to work zones. A survey conducted by the Federal Highway Administration (FHWA) showed that 32 percent of the respondents expressed dissatisfaction with work zones [(1)]. In addition, work zone safety is an ongoing problem. In 2010, there were 37,476 injuries and 576 fatalities. Although the number of work zone related accidents has decreased within the last decade, work zone safety is still a major problem in the United States. [(2)].

Faced with growing number of work zones, the challenge for transportation agencies is to effectively manage the impacts of work zones to alleviate congestion and maintain the safety of motorists without disrupting project schedules. FHWA published Administrative Final Rule CFR part 630 Subpart J, “Work Zone Safety and Mobility” in 2004, which requires state and local transportation agencies that receive federal funding to develop a Transportation Management Plan (TMP) to manage safety and mobility of work zones for “significant” projects. Key benefits of a TMP are to help address broader safety and mobility impacts of work zones at corridor and network levels, improve public awareness, and improve intra- and inter-agency coordination [(3)].

Coordinating roadway projects is not a new concept to many state Department of Transportation (DOT)s, and regional and local transportation agencies. Intra-agency communication and coordination practices are conducted by various states such as Utah DOT’s I-15 Team and Traffic Management Committee, New York, New Jersey and Connecticut’s TRANSCOM program, Gary/Chicago/Milwaukee Corridor Action Team Program that involve several DOTs and Toll Authorities, and Oregon DOT’s Statewide Traffic Mobility Committee [(4)]. These intra-agency communication practices aim at coordinating relatively long term and significant projects that have anticipated regional impacts.

It should be noted that the majority of roadway projects include minor repair, maintenance, surveying, landscape, and utility work that require relatively short term work zones. USDOT reports that 70 percent of highway capital expenditures were allocated to system preservation (51.8 percent), expansion (18.3 percent) and enhancement (9 percent), where all these improvements require active work zones on existing roadways with traffic present [(5)]. A similar trend can be observed for the State of New Jersey. The capital program for 2012 prepared by New Jersey Department of Transportation (NJDOT) shows that 44 percent of spending is allocated for roadway and bridge maintenance, as a part of its “fix-it-first” policy, given the poor condition of the existing infrastructure [(6)]. These statistics indicate that there are more maintenance and minor repair projects than there are major overhaul or expansion projects. As it is beneficial for various agencies to collaborate for and coordinate relatively long term and significant projects, it would be beneficial for state DOTs to effectively coordinate, plan and quantify the impact of these relatively short term yet frequent projects.

There are several states that have been practicing corridor planning for coordinating short term and long term projects and streamlining project schedules to reduce the impact of work zones. California Department of Transportation (Caltrans), Michigan DOT and Missouri DOT coordinate multiple maintenance, utility, surveying and construction projects within a corridor. There are also other states that coordinate short term and long term projects on parallel routes to minimize the region-wide impacts of work zones.

NJDOT can benefit from similar enhanced strategies of coordinating and planning projects of different scales, quantify the impact of various combinations of proposed work zones within a corridor or in a specific region, and reduce the negative impact of work zones.

As stated in the RFP issued by NJDOT, "*The main objective of this study is to understand the types of projects that can be coordinated – in terms of construction compatibility, design completion and construction schedules. The secondary objective would be to evaluate the effectiveness of coordinating short – and long-term projects using a cost-benefit analysis tool to measure the efficiency of various combinations of projects relative to each other and the status quo.*"

Various tasks have to be completed to realize these objectives. The most important steps are:

- Conduct interviews with representatives from other state DOTs that have been practicing the coordination of various types of work zones.
- Assemble a panel comprised of representatives from NJDOT units that are involved in work zone decision-making process and identify various types of projects put forth by NJDOT that require short term or long term work zones.
- Work closely with NJDOT contacts to take advantage of TRANSCOM and its already existing regional structure to improve the communication and collaboration in terms of coordinating various repair activities in the region.
- Through one-on-one and/or panel interviews with the identified key personnel, understand organizational flow within NJDOT for communicating, collaborating and scheduling of various types of work zones.
- Determine, through expert interviews with NJDOT engineers and staff, what type of projects can be coordinated, anticipated challenges for coordinating various combinations of these projects and what the appropriate steps are to eliminate such challenges.
- In close collaboration with the assembled panel, develop a framework for managing and coordinating work zone projects.
- Develop a user-friendly spreadsheet based tool that will be used to calculate the cost effectiveness of various combinations of short term and long term work zones based on the developed work zone management and coordination framework.

- Explore the use of emerging web-based communication and collaboration technologies that are inexpensive and easy to deploy and maintain. This can be a secure web site that maintains a contact list of identified decision makers from NJDOT and other agencies with the goal of timely sharing of information and long and short term plans for work zone activities in the region.

This report is organized as follows. The following section presents an extensive review of the relevant literature. Specifically the studies that are related to work zone capacity, queue and delay estimation are reviewed. Current state of practice section distinguishes between the long-term and significant capital projects and short-term yet more frequent projects. It is argued that although many states already coordinate long-term projects starting at the conceptual design phase, following FHWA guidelines, not many states focus on the coordination of the short-term work zones. This section also describes the current state of practice by NJDOT. Description of the NJDOT practice is based on the one-on-one meetings with NJDOT staff from various divisions. Benefit Cost Analysis section presents the potential benefits of reducing work zone exposure. These benefits include not only reduction in congestion, but also in accident, environmental and vehicle maintenance costs. Proposed Work Zone Coordination Framework section describes ideal flow of decision making when work zone coordination is concerned. For this framework to be effective there must be a shared database that includes all the proposed work zones. In this project, the research team proposed that the OpenReach database which contains the active and dormant work zones planned for the next month and the Capital Program Management (CPM) Project Reporting System (PRS) database of long-term and significant projects be combined, and be accessible to all involved parties. Here, the computer tool developed for this research project, namely, Work Zone Coordination Spreadsheet (WCS) tool, plays a central role within this proposed framework. WCS tool utilizes the combined database and helps users determine if there are any potential conflicts. The Work Zone Coordination Spreadsheet Tool section describes the tool in detail. We conclude the report with a summary of the completed work and suggestions.

LITERATURE REVIEW

Various State DOTs have been using various analytical tools to estimate delays due to work zones. Each agency has delay thresholds that will determine the appropriate hours of lane closures for minimal traffic delays. Several tools are available for estimating the effects of various transportation projects. These tools vary in level of complexity, and each tool offers different capabilities. Some tools were designed specifically for work zone applications, while other traffic analysis tools, although not designed specifically for work zones, can be used to analyze work zone situations.

Several DOTs adopted spreadsheet-based tools for estimating the impacts of work zones. The spreadsheets estimate delay and queue lengths as the main output values using the graphical procedures explained in the Highway Capacity Manual (HCM). Calculations are usually carried out in Microsoft® Excel. For example, ALDOT uses a Microsoft® Excel-based lane closure analysis tool, "Lane Rental Model." The tool determines work zone capacity values based on the HCM. These tools require very few inputs and give quick results.

A brief summary of available tools for estimating work zone mobility impacts is presented in the sections that follow.

Tools for Work Zones Capacity, Queue and Delay Estimation

<u>Deterministic Tools</u>

DELAY Enhanced 1.2

DELAY Enhanced 1.2 is an application developed by FHWA's Utah division to estimate the traffic impacts of incidents. The model is applicable to work zones as well. The tool uses the same deterministic queuing model used by other available tools. It requires minimal input data and presents results quickly. The accuracy of delay and queue estimation of the tool depends highly on the capacity assumptions and the accuracy of hourly volume data [7].

QUEWZ

Queue and User Cost Evaluation of Work Zones (QUEWZ) was developed by the Texas Transportation Institute. This tool can estimate the capacity of the short term work zone by using the HCM 2000 model. QUEWZ can estimate the work zone capacity, average speed, average queue length, and travel time costs for a given lane closure schedule at a work zone [7]. It calculates the queue lengths based on the methodology found in HCM 1994. The tool needs more input data as compared to the methods already reviewed. It is easy to use and to obtain results quickly. It also has a simplistic diversion algorithm. The updated version of QUEWZ, QUEWZ-98, runs on DOS. The data required to run QUEWZ can be broken up into 4 sections [16]:

- Lane closure configuration (number of lane closure, length and work zone capacity),
- Schedule of activity (begin – end time for lane closure and activity)
- Traffic volumes (Directional hourly volumes or Annual Average Daily Traffic (AADT))
- Other factors (cost update factor, heavy vehicle percentage etc.)

QuickZone

Developed by Noblis (formerly Mitretek) using FHWA funding, QuickZone has been mentioned in FHWA guidelines as one of the several suggested tools to determine work zone delays [17]. It is coded as a program within Microsoft® Excel. QuickZone considers traffic engineering parameters (as specified in the Highway Capacity Manual) like volume, truck percentage, lane width, etc. It has been widely used, tested, and validated by State and local American DOTs. Current partners of FHWA using QuickZone include: Maryland SHA, CFLHD, Pennsylvania DOT, Ohio DOT, Wisconsin DOT, Washington DOT, Utah DOT, and North Carolina DOT. QuickZone's data requirements are well established and flexible enough to accommodate projects with minimal available data as well as projects that have a wealth of detailed data. It is comprehensive and highly detailed. It incorporates various factors that have impacts on traffic delays at work zones. It is a user friendly spreadsheet that compares the impact of different work zone scenarios in terms of capacity, queue, delay and cost. For instance, users can compare the effect of nighttime work versus daytime work or the effect of diverting traffic to another road along a corridor. This software has evolved over time because of its use in many scientific studies. Currently, QuickZone version 2.0 is available and it is capable of the following operations [18]:

- Quantify corridor delay resulted by capacity reduction,
- Estimation of delay impact based on different phases of construction,
- Impact of different scenarios for construction staging such as time (peak, off-peak), location and season (winter vs. summer),
- Tradeoff analysis between construction cost and user cost,
- Estimation of work completion incentives.

WZCAT (Work zone capacity analysis tool)

WZCAT was developed to estimate queue and delay for short-term work zones by using principles of Delay Enhanced software. This program works as an add-on to Microsoft® Excel. In 2007, WZCAT was upgraded to a newer version called WZCAT-R [19]. Based on this upgrade, all the in-out ramp volumes upstream of the work zone are included for estimation. Moreover, the traffic flow adjustment factor (TFAF) can be applied to the historical data for the mainline, enter and exit ramps. Figure 1 shows a snapshot of the WZCAT-R software.

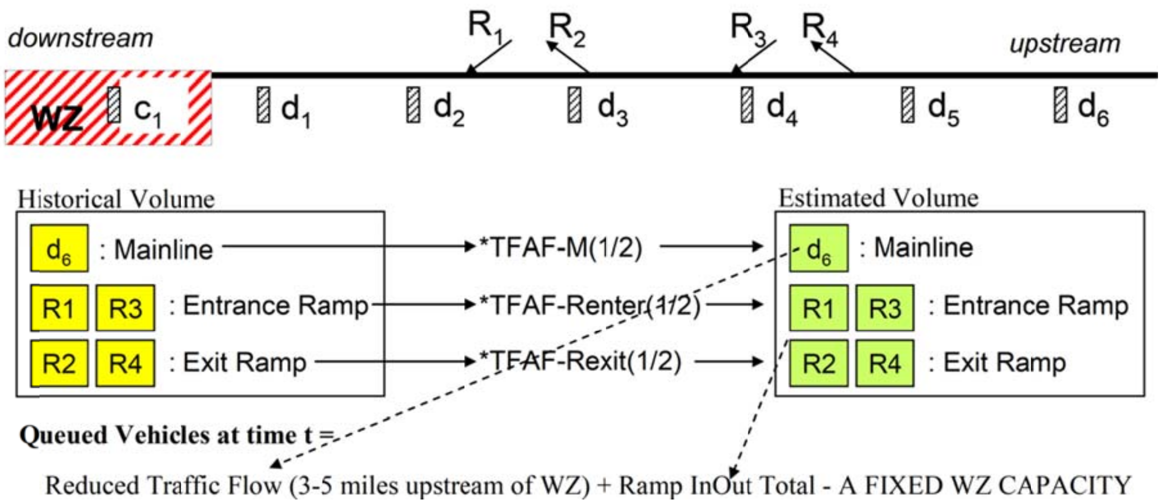


Figure 1. WZCAT-R Delay Estimation [19]

IntelliZone

Jiang and Adeli [21] developed the IntelliZone software by using an "object oriented methodology" for work zone capacity, queue, and delay estimation. This program is capable of handling multiple traffic strategies and multiple segments; it estimates work zone capacities with radial base functions. 17 different factors are used as input parameters for estimation. IntelliZone has a user friendly interface and tools for different work zone scenarios. Figure 2 shows the input analysis and output stages of the IntelliZone program.

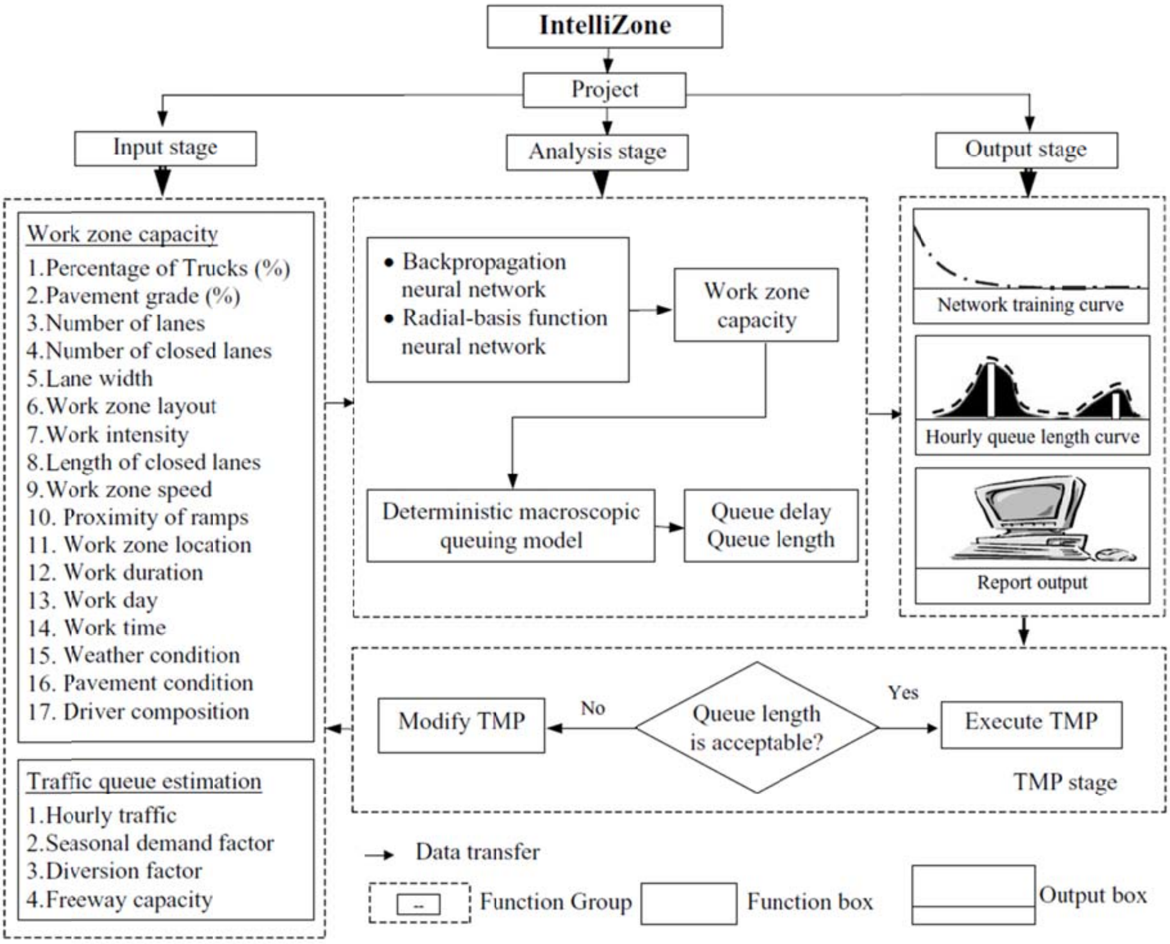


Figure 2. IntelliZone Working Diagram [21]

FREEVAL (FREeway EVALuation)

The FREEVAL software was developed by ITRE/NCSU as a computational tool. Since FREEVAL is based on the HCM freeway facility concept, it is ideal for work zone analysis. This program can be used with Microsoft® Excel and Visual Basic. The FREEVAL outperforms QUEWZ and QuickZone work zone tools in terms of capturing the effect of ramps or the weaving segments of a work zone. Schroeder and Rouphail [22] developed the FREEVAL-WZ to assess work zone impacts on multilane highways and freeways.

Similar to other software the FREEVAL-WZ is limited in how it handles network or long corridor analysis for work zone impacts. Figure 3 shows a snapshot from the FREEVAL-WZ running page.

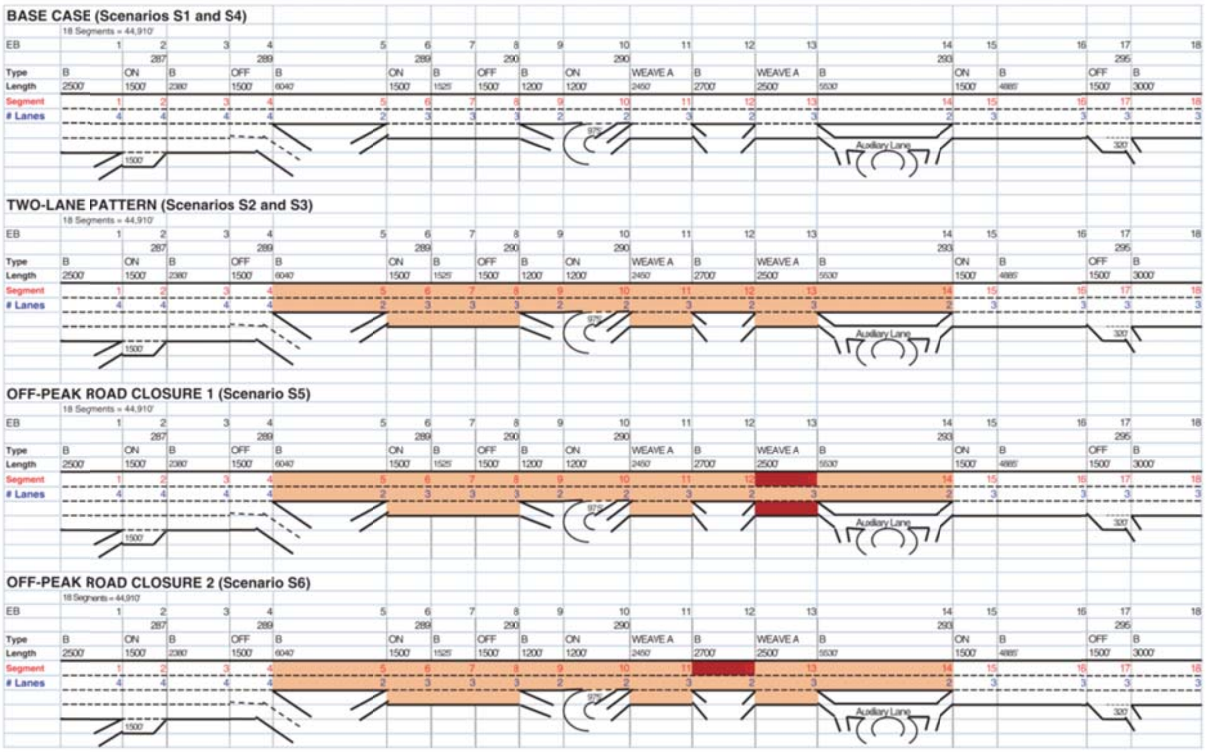


Figure 3. Snapshot from the FREEVAL Screen [22]

RILCA

Rutgers Interactive Lane Closure Application (RILCA) was first developed for the New Jersey Turnpike Authority (NJTA) by the Rutgers Research Team. NJTA is responsible for operating and maintaining two major tolled roads in New Jersey, namely the New Jersey Turnpike (NJTPK) and Garden State Parkway (GSP).

RILCA was later adopted by the NJDOT for planning its freeway lane closures for work zones. 18 freeways in NJ were added to RILCA as requested by the NJDOT traffic engineers. RILCA was developed using the ArcView® GIS software package as the main development environment. The interactive GIS map of the NJTPK, GSP, and other major freeways in NJ and its surrounding network are displayed using ArcView. Various analysis and visualization options are provided for the interactive planning of lane closures. The tool features the geometric details of the NJTPK, GSP, and the surrounding highways and local streets. It provides users the following applications [20, 21]:

- Hourly volume information on selected links at a given time period on any given date.
- Link characteristics (such as number of lanes, AADT, milepost, link length).

- A function that generates a lane closure schedule for selected links based on the hourly volume data.
- A simple visualization function that shows the extent of expected delays resulting from lane closures and the possibility of spill back onto the upstream links, all in the form of link colors.
- Allowable lane closure hours for a day, a week, or a month.
- Delay and queue length estimation for incidents.
- Travel time information between interchanges at a given time period on any given date (NJTPK only).
- Historical accident and historical weather information.

The flowchart of RILCA is shown in Figure 4.

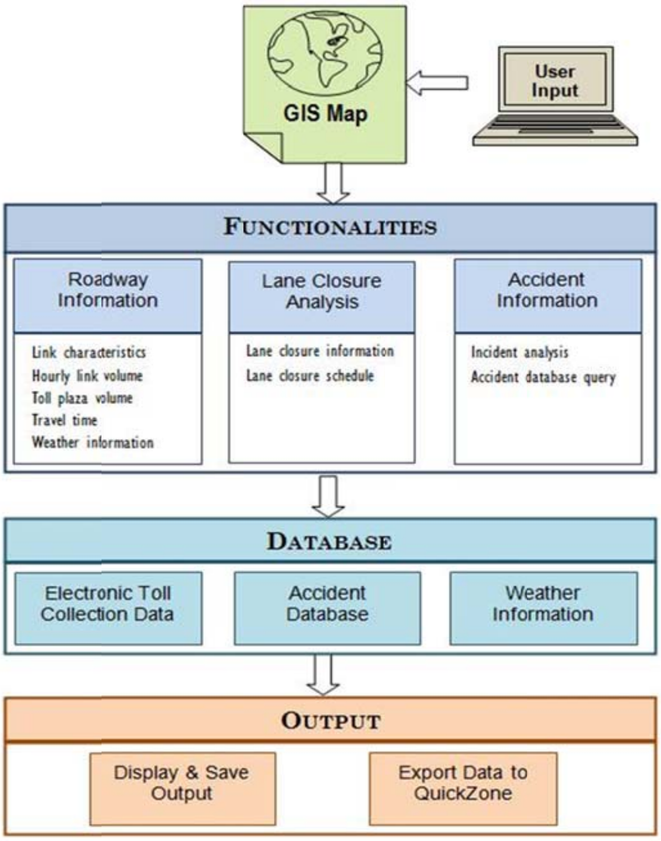


Figure 4. RILCA Flowchart [23]

A novel feature of RILCA is its ability to export hourly volume data and geometric characteristics of a selected highway link to QuickZone. One drawback of QuickZone is that users need to input very detailed traffic data for analyzing the impacts of long term lane closures. If a detailed long term lane closure analysis is required then RILCA can either present users the conduct short term lane closure analysis in RILCA or export the corresponding traffic volume data from RILCA to QuickZone.

Simulation Tools

Microscopic simulation models simulate the movement of individual vehicles based on theories of car following and lane-changing. Typically, vehicles enter a transportation network using a statistical distribution of arrivals (a stochastic process), and are tracked through the network over small time intervals (e.g., one second or a fraction of a second). Typically, upon entry, each vehicle is assigned a destination, a vehicle type, and a driver type. In many microscopic simulation models, each vehicle's traffic operational characteristics are based on relationships developed in prior research and influenced by vertical grade, horizontal curvature, and super-elevation. Computer time and storage requirements for microscopic models are large, usually limiting the network size and the number of simulation runs that can be completed. Examples of microscopic simulation models include Traffic Software Integrated System/Corridor Simulation (TSIS/CORSIM), INTEGRATION, SimTraffic, Wide Area Traffic Simulation (WATSim), VISSIM, and Parallel Microscopic Traffic Simulator (PARAMICS). Schroder and Rouphail (22) summarized and compared work zone analysis tools in terms of analysis inputs.

Table 1 lists the specifications of deterministic and simulation based work zone tools. Table 2 shows the summary of the survey of various States for assessing the traffic impacts at work zones compiled by Edara and Cottrell [(24)]. The most common tool for determining the capacity at work zone appears to be the experience of the DOT staff. For the estimation of traffic impacts, HCM- based tools and spreadsheets are the most popular among DOTs.

Table 1. Work Zone Impacts and Analysis Tools [22]

Work Zone Analysis Input	Deterministic: FREEVAL	Deterministic: QUEWZ-98	Deterministic: QUICKZONE	Simulation: CORSIM	Simulation: VISSIM	Simulation: AIMSUN	Simulation: PARAMICS	Simulation: DYNASMART
Freeway segment type								
Basic	✓	✓	✓	✓[a]	✓[a]	✓[a]	✓[a]	✓[a]
Ramps and weaving	✓	—	—	✓[a]	✓[a]	✓[a]	✓[a]	✓[a]
Analysis details								
Max. analysis period	3 h	24 h	10 years	~52 h	~24 h	1,000 h	~24 h	24 h
Analysis time units	15 min	1 h	1 h	Flexible	Flexible	Flexible	Flexible	Flexible
Traffic operation impacts								
Capacity reduction: number of lanes	✓	✓	✓	✓	✓	✓	✓	✓
Capacity reduction: factor	✓	✓	✓	—[b]	—[b]	—[b]	—[b]	✓
Speed reduction	✓	—	—	✓	✓	✓	✓	✓
Demand reduction	✓	✓	✓	✓	✓	✓	✓	✓
Rerouting	✓[c]	✓[c]	✓	✓	✓	✓	✓	✓
Trip retiming	✓[c]	✓[c]	✓	✓	✓	✓	✓	✓
Side-street demand increase	—	—	✓	✓	✓	✓	✓	✓
Other factors affecting work zone analysis								
High truck percentage	✓	✓[d]	—	✓	✓	✓	✓	✓
Off-ramp congestion	—	—	—	✓	✓	✓	✓	✓
Commuter versus tourist traffic	—	—	—	—	✓[e]	✓[e]	✓[e]	✓[e]
Auxiliary lanes (C–D roads)	—	—	—	✓	✓	✓	✓	✓
Incidents	✓[f]	—	—	✓	✓	✓	✓	✓
Special priorities (HOV, BRT)	—	—	—	✓	✓	✓	✓	✓
Facility performance measures								
Segment LOS	✓	—	—	PP	PP	PP	PP	PP
Vehicle delay	✓	—	✓	✓	✓	✓	✓	—[g]
Travel time	✓	—	—	✓	✓	✓	✓	✓
Speeds	✓	✓	—	✓	✓	✓	✓	✓
Average queue length	—	—	—	—[h]	✓	✓	✓	✓
Longest queue length	✓	✓	—	—[h]	✓	✓	✓	✓
Queue duration	✓	—	—	—[h]	PP	PP	✓[i]	✓
User cost	—[e]	✓	✓	—[j]	—[j]	—[j]	—[j]	—[j]
Emissions	—	✓	—	✓	✓	✓	✓	—
Network performance impacts								
Minor street queue spillback	—	✓	✓	✓	✓	✓	✓	✓
Traffic diversion	—	[k]		—	✓	✓	✓	✓
Visual performance output								
Bird's eye view animation	—	—	—	✓	✓	✓	✓	✓
4-D animation	—	—	—	—	✓	✓	✓	—
Network plots	—	—	—	PP	PP	PP	✓	PP
Data plots by time	✓	PP	✓	PP	PP	PP	✓	✓
Data plot by segment	✓	—	—	PP	PP	PP	✓	✓

NOTE: HOV = high-occupancy vehicle, BRT = bus rapid transit, PP = postprocessing necessary.
[a]Segment types modeled implicitly in simulation.
[b]Microsimulation arrives at capacity estimates implicitly through model algorithm (car-following, lane-changing).
[c]Rerouting and trip retiming modeled as modified demand flows.
[d]Truck percentage specified for entire facility.
[e]Modeled implicitly through different behavioral parameters by vehicle type.
[f]FREEVAL can model 15-min incidents through lane closures or capacity reduction factors.
[g]DYNASMART-P does not explicitly report delay but does report travel time and average stopped time.
[h]CORSIM can report queue length only for arterial streets, not freeways.
[i]Performance measure is percent time queued.
[j]User cost can be easily obtained by multiplying simulation total delay output and multiplying by cost figure.
[k]Traffic diversion based on maximum queue or delay assumption—not routing algorithm.

Table 2. Survey of State DOTs on Current Practices for Assessing Work Zone Traffic Impacts [24]

State	Tools Used for Estimating Capacity	Tools Used for Estimating Traffic Impacts: Queues and Delays
Alabama		Oklahoma DOT Spreadsheet
Arizona		QUEWZ
Arkansas		QUEWZ
California	Experience and HCM	Spreadsheet based on HCM
Colorado	Guidelines in the "Lane Closure Policy" document	Synchro/Sim Traffic and HCS
Delaware	HCM	Delaware Transportation Model, HCS, Synchro, CORSIM
Florida	Chapter 10 of FDOT's Plan Preparation Manual and HCS 2000	Chapter 10 of FDOT's Plan Preparation Manual and HCS 2000
Hawaii	HCM	• HCM and experience • QuickZone in the future
Illinois	HCS 2000, SIG/Cinema, HCM, and QUEWZ	HCS 2000, SIG/Cinema, HCM-based spreadsheet, QuickZone and QUEWZ
Indiana	HCM, Past data	QUEWZ, QuickZone, Synchro, CORSIM
Kansas	None Experience, if any	None
Kentucky	Experience, no formal procedure	• No formal procedure • Rare use of CORSIM
Maine	Experience and HCM 1994	• Spreadsheet and Synchro/SimTraffic for partial closures • TRIPS (Travel Demand Model) for full closures of bridges or highways
Maryland	MD-QuickZone (modified QuickZone) using HCM Value or University of Maryland Model or any user defined value	MD-QuickZone (modified QuickZone)
Massachusetts	Start with base capacity value and apply adjustment factors for lane widths, truck percentages, grades, etc. (similar to HCM)	• Spreadsheet model (BASICQUE) based on 'Planning and Scheduling Work Zone Traffic Control' publication of FHWA (Chapter 2, page 15), published in 1981 • Also use QuickZone, TRANPLAN for complex projects
Montana	No estimation	HCM, if used
Nevada	HCM 2000	• Currently Synchro, CORSIM, HCM • QuickZone in the future
New Jersey	HCM 1994	Spreadsheet based on HCM
Ohio	QUEWZ-98	Ohio DOT Spreadsheet
Oklahoma		Spreadsheet based on HCM

Oregon	• Currently experience • Actual traffic counts in future	• Currently CORSIM • Aim to develop graph from CORSIM results and validate it with field data
Pennsylvania		Actively using QuickZone
Rhode Island	HCM 1997	• Mostly HCM and experience • Occasionally QuickZone
Tennessee	Mix of actual traffic counts and HCM procedures	Web-based Queue/Delay Prediction Model under development
Texas	QUEWZ	QUEWZ and CORSIM
Utah		DELAY Software for small projects, MINUTP (comprehensive planning model) for large projects
Washington	Mix of actual traffic counts and HCM procedures	• Primarily QUEWZ • Limited use of QuickZone
Wisconsin	Experience and literature	Mainly spreadsheet based on HCM, but occasionally CORSIM and QuickZone
Wyoming	HCM and Synchro	HCM and Synchro

Based on the survey results, the DOTs' software selection can be summarized as seen in Table 3. HCM based spreadsheets and software take first place among various alternatives for both capacity and queue-delay estimations. However the HCM based spreadsheets or software have limitations for assessing the impact of multiple work zones or long corridor work zones.

Table 3. Software Usage Percentage by State DOTs Included in Table 2

Software	Usage for Capacity	Usage for Queue and Delay
HCM based spreadsheet, HCS	51.7%	48.3%
QuickZone	3.4%	34.5%
QUEWZ	10.3%	20.7%
CORSIM	-	24.1%
SYNCRO	3.4/%	20.7%

Queue and Delay Estimation

If traffic volume exceeds work zone capacity, congestion occurs and then queues and delays will form. Likewise, when the traffic volume is below the work zone capacity, vehicles may travel without congestion but at speeds lower than those travelled on freeways. The additional time needed for vehicles to pass the same length of roadway when there is a work zone can be referred as a traffic delay caused by the work zone.

Moreover, because of the stochastic nature of flow, queues may form at a work zone even if the traffic flow falls below the capacity.

There are various methodologies that can be used to estimate the queue length and delay in work zones. Generally, two types of queuing analyses (summarized in the following sections) are used to analyze the generation and dissipation of queues:

(1) A deterministic queuing analysis, in which the arrivals of the vehicles are assumed to follow a uniform pattern, and

(2), a stochastic queuing analysis. The stochastic analysis assumes that the distribution of the vehicle arrivals follows a probability distribution. Some crude assumptions are taken into account in order to simplify such an analysis.

Deterministic Queuing Analysis

In the deterministic approach, the queuing analysis can be carried out at a macroscopic or microscopic level. While macroscopic traffic models try to explain the relationships among traffic characteristics such as the relationship between flow and density, microscopic traffic models focus on single vehicle-driver units. Service time rates and the arrival of vehicles are seen as continuous at the macroscopic level. For the microscopic level, both the service time rates and the arrival of vehicles are believed to be discrete. While macroscopic analyses are used when the rates of arrival and service time are high, microscopic analyses are regularly carried out when the rates are low.

A deterministic macroscopic queuing model is used to analyze queue lengths and delays created by work zone bottlenecks. The model is built on the conversation of flow principles. Conversation of flow theory proposes that the number of vehicles entering a specific part of a roadway at a particular period of time must equal the number of exiting vehicles at the same time period under homogeneous roadway conditions. When there is a work zone present on the freeway acting as a bottleneck, the number of exiting vehicles may be fewer than the entering vehicles. The difference refers to a queue that has formed upstream. The analysis simply treats the length of the queue as the difference between the arrivals and departures at a specific point.

Figure 5 depicts the change in the traffic flow between 1 pm and 2 pm as result of a hypothetical work zone. This diagram is based on the deterministic queuing theory. The horizontal axis represents time and the vertical axis represents cumulative traffic volume arriving at the roadway link where the work zone is located. The slopes of lines 0-1, 1-2 and 2-3 are the traffic flow rate between 12pm and 1pm, 1pm and 2pm and 2pm and 3 pm, respectively. Because of the capacity reduction due to the work zone, the actual flow rate is reduced to the level of 2'. The slope of line 1-2' represents the flow rate past the work zone. When the work zone is removed, the flow rate increases until it becomes equal to the maximum flow rate, the slope of 2-X. This is also equal to the slope of 0-C (See below for an explanation). When all the delayed traffic passes the work zone location after the work zone has been removed, the traffic flow returns to its normal rate.

In the absence of congestion all arriving cars are served because the line 0-C, which represents the cumulative capacity (maximum departure rate), has a steeper slope than the arrival rate of traffic. At 2', when all the lanes are cleared, traffic starts departing at capacity, thus the cumulative departure rate becomes equal to the maximum cumulative departure rate until the queue is cleared (point X).

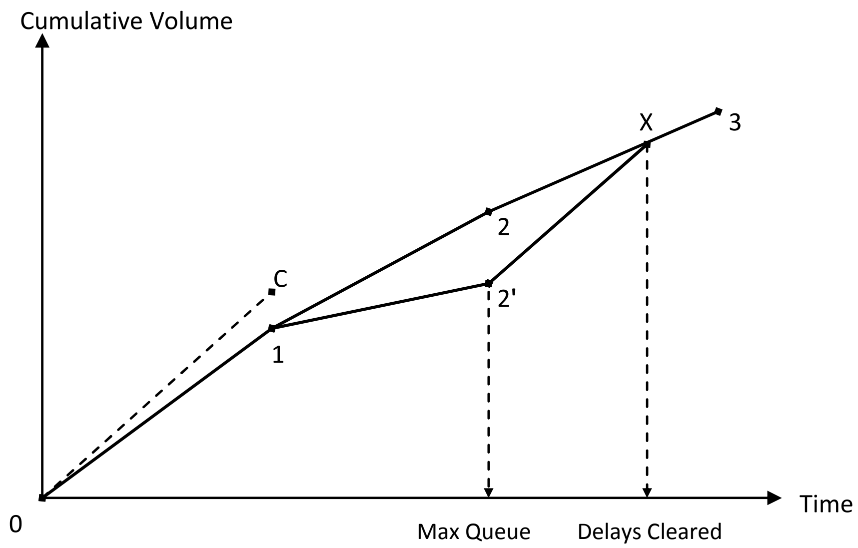


Figure 5. Delay and Queue Formation During Lane Closure

Cassidy and Han [25] estimated the average delay due to work zones on a two-lane two-way highway with one lane closure. They state that a number of different factors influence delay, and that these factors should be kept within acceptable ranges. One of the most important factors in their model was the length of the work-zone. According to Cassidy, delays incurred by motorists can be reduced or increased by changing the length of the work-zone. They estimated delays and queue lengths as a function of work-zone length. The model was also able to institute suitable green times and cycle lengths when there was a signal control on work-zone entrances. Their procedure estimates delay by estimating the right-of-way times in each cycle that takes place in a given time interval. When they predicted green times, they used deterministic queuing techniques to estimate delays. This method is more applicable to work-zone locations in which traffic demands constitute under-saturated conditions.

Jiang [26] developed a model to estimate delays in which the work zone related delays were grouped under several different categories: vehicle deceleration prior to entering work zones, moving delays experienced by vehicles passing through work zones at lower speeds, acceleration delays experienced by vehicles accelerating after existing work zones, and queuing delays caused by the ratio of vehicle arrival to discharge rates. His model uses the vehicle queue-discharge rates to estimate traffic delays instead of the work zone capacity. According to his methodology, the total traffic delay at a work zone can be calculated with this formula [26]:

$$DELAY_I = F_{aI}\ [d_d + d_z + d_a + (1 - t_I)d_w] + D_I \quad (1)$$

where,

F_{aI} = hourly volume of arrival vehicles at hour I,
d_d = delay due to vehicle deceleration before entering work zone,
d_z = delay due to reduced speed through work zone,
d_a = delay due for resuming freeway speed after exiting work zone,
d_w = delay due to vehicle queues during uncongested traffic,
D_I = delay due to vehicle queues during congested traffic.

Chien and Schonfeld [27] proposed a modeling approach that determines how work zone lengths can be adjusted based on significant factors such as vehicle speeds and approaching traffic flow. They used deterministic queue analysis in their study and found that their method provides a useful approach for decreasing both traffic delays and costs. Because the user delay is represented as a constant average cost per vehicle hour, the delay in the model for each vehicle is assumed to be proportional to the time of the delay. The queue delay in the model is formulated as:

$$C_q = \frac{v_d}{2L}\left(1 + \frac{Q - c_w}{c_0 - Q}\right)(Q - c_w)(z_3 + z_4 L)^2 \quad (2)$$

where,
C_q = the queue delay cost per maintained kilometer,
c_w = the zone capacity,
c_0 = roadway capacity in normal conditions,
v_d = the average delay cost,
Q = approaching traffic flow,
z_3 = the setup time,
z_4 = the additional time required per work zone kilometer,
L = the work zone length.

In addition to the queue delay, they also formulated moving delay and the total delay cost per maintained lane kilometer as the combination of these two cost functions:

$$C_v = \left(\frac{1}{V_w} - \frac{1}{V_a}\right) Q(z_3 + z_4 L)v_d \quad when\ Q \leq c_w \quad (3)$$

$$C_v = \left(\frac{1}{V_w} - \frac{1}{V_a}\right) c_w(z_3 + z_4 L)v_d \quad when\ Q > c_w \quad (4)$$

where,

V_w = the average work zone speed,

V_a = the average approaching speed.

Jiang and Adeli [28] also used a deterministic queuing model. Their model is based on the average hourly traffic flow and is appropriate for both short term and long term work zones. Their estimated delay time consists of the upstream queue delay time (t_q), and the moving delay time (t_m) through the work space.

$$t_d = t_q + t_m \tag{5}$$

$$t_q = \sum_{t=t_i}^{t_i+D-1} \left(\frac{T_t + T_{t+\Delta t}}{2} \Delta_t\right) \tag{6}$$

$$t_m = \sum_{t=t_i}^{t_i+D-1} \Delta t_m \tag{7}$$

where
t_i = the starting time at the work zone in hours ranging from 1 to 24,
D = the time period required to complete the maintenance for the work zone,
Δt = the given time period,
T = the cumulative number of vehicles,
Δt_m = the moving delay time.

Stochastic Queuing Analysis

Stochastic queuing analysis methods are usually used for estimating performance characteristics such as delay and queue length [29,30]. Using a stochastic analysis method to estimate vehicle delay is comparatively hard because of the randomness and the uncertainty that take place in traffic flows. Therefore, in order to use these methods, several simplifications should be applied to the models. Two of the more common assumptions used to simplify this method are (1) the arrival of vehicles follows the Poisson process and (2) the mean arrival flow rate is constant.

The stochastic queuing analysis tries to estimate the delay experienced by vehicles at a bottleneck, such as those found at a work zone, by defining the statistical distributions of queue lengths and delays. This analysis is also used for both under-saturated and saturated traffic conditions. The degree of saturation is determined by an intensity equivalent to the volume to capacity ratio.

$$\rho = \frac{\lambda}{\mu} \tag{8}$$

where,
ρ = traffic intensity,
λ = mean vehicle arrival rate,
μ = mean vehicle service rate.

If the traffic intensity is less than 1, then the traffic conditions are undersaturated in this process. Likewise, if the intensity is greater than 1, it can be stated that there is no mathematical solution. In order to estimate the delay experienced by motorists, the queuing process should be converted into a deterministic queuing problem by using several time slices with different mean arrivals and service times.

Since existing deterministic delay formulas are limited, there is an increased need for using stochastic delay models which provide calculations of queue size and delay possibilities that may evolve over time. For that purpose, Brilon and Wu [31] developed a model to compute delays using Markov chain models. They proposed new formulas which are in good agreement with known empirical data. Heidemann [32] developed the probability generation function of the queue length and Laplace-transform of the delay distribution.

Chitturi et al. [33] proposed a step-by-step methodology to estimate capacity, queue length, and delay for stopped queues at work zones. They estimated the total delay experienced by users by adding up the delay time due to queuing and the delay time due to slower speeds. Their model had twelve steps. Some of these steps can be skipped during the application. Steps 1 through 4 deal with speed reduction due to narrow lanes, less than ideal lateral clearance, the intensity of the work, and other factors that may influence speed. In Step 5, the speed that is adjusted in Steps 1 through 4 is used to compute operating capacity. To adjust capacity of the work-zone, a truck adjustment factor is used in Step 6, and an adjusted capacity is computed in the next step. If demand is greater than capacity, the queue length at the end of every hour and the delay due to queuing are estimated in Steps 8 and 9. If demand is less than capacity, one can skip to Step 10, which estimates the delay due to speed reduction. In Step 11, Chitturi et al. estimate the total delay. In the final step they compute user cost. Although there were some adjustment factors that were both taken directly from the HCM and not designed for work zones in this methodology, there was a close similarity between the estimated results and the field data.

Ramezani et al. [34] calculated the total delay for travel times. First they found the number of vehicles moving in the queue and then they found the length of the queue and the speed. From these variables they found travel times and used them to compute the delay. Ramezani and Benehokal [35] recently proposed a methodology for researchers to estimate queue length and delay. In their model, it is taken into consideration that throughout the work space and/or the transition area there may be more than one bottleneck found within the work zones. Their methodology utilizes speed-flow curves of the bottlenecks, the relationship between demand and capacities, and initial queue conditions. When the volume exceeds the transition area and the work zone capacity, there will be active bottlenecks at both locations. Likewise, if the approaching volume stays the same or goes to a higher level the back of the queue will reach the transition area and they will be dependent to one another. Therefore, the bottleneck in the transition area will be neutralized and the only remaining active bottleneck will be the one in work zone. If the volume is less than the capacity, again the work zone will be the only active bottleneck. They estimated queue length at the end of each minute using shockwave theory and then they computed shockwave speed. It was assumed that the vehicle speeds upstream of the queue are the same as the free flow speeds. Arriving volume is taken each minute and shockwave speed is calculated for each minute as well. They multiplied shockwave speed with the interval length and the previous interval’s estimated queue length. Finally, in order to find stable estimation of queue lengths, they used the moving average method.

Ullman and Dudek [36] developed a theoretical approach for estimating queue length during short-term roadwork on urban freeways. They argued that although traditional approaches such as macroscopic work zone analysis tools work well for rural and suburban work zones, they may severely overestimate traffic queues. This overestimation is mainly due to entrance and exit ramps being spaced relatively far apart whereas in urban areas the ramps are closely spaced, which enable users to embark on many diversion opportunities and routes. Their model is based on macroscopic fluid-flow analogies of traffic and considerations of the freeway corridor as a section of permeable pipe. This model was also calibrated to represent the magnitude of traffic queues at work zones on freeways in Texas. They used macroscopic fluid-flow theory to examine the diversion under lane closures using previously found data. The method required needs comparatively extensive inputs to estimate the corridor permeability factor relating to the diversion potential of roadway segments. They used Darcy's Law to represent the relationship between traffic queuing and diversion.

$$q_{side(1)} = KiA = K' \frac{\Delta\overline{p_1}}{TE} \Delta x_i \tag{9}$$

where

$q_{side(1)}$ = the flow permeating out the sides of the pipe through each segment,
Δp_1 = the average traffic stream pressure differential between roadway and the rest of the corridor within Δx_1,
A = area through which flow is occurring,
K = coefficient of permeability,
TE = total energy of the traffic stream, and
i = energy gradient across the permeable medium.

With the help of the hydrodynamic analogy, a shockwave is said to occur when traffic streams of varying stream conditions exist. A cumulative plot is the graphical interpretation of a function that represents the cumulative number of vehicles which pass an observer at a specific time interval, t [37].

These plots are used to examine the flow of vehicles that pass a number of bottlenecks. Newel used these plots in the study of transportation as an examination tool, while Moskowitz introduced the technique to the area [38]. Many researchers have used this analogy from fluid dynamics to characterize traffic flow. Lighthill and Whitham [39] were the first researchers who tried aforementioned analogy. They analyzed the existence of shock-waves and traffic, and their theory demonstrated that one dimensional waves can be applied to transportation in order to estimate the highway traffic flow behavior.

Suppose that Figure 6 shows a traffic stream that is moving on a roadway at a given flow, speed, and density. Assume that a truck comes into the stream and slows down the continuing traffic. The effects of this behavior can be explained by using shock-wave theory. The vehicles that are in the platoon will adjust their spacing and this effect can be seen in the Figure 7. Given conditions, the speed of the shockwave between two conditions are given by [40]

$$w_{AB} = \frac{q_B - q_A}{k_B - k_A} \quad (10)$$

In more general form:

$$q_i = k_j - k_i \quad (11)$$

$$w_{ij} = \frac{q_j - q_i}{k_j - k_i} \quad (12)$$

Where,

w : Speed of the shockwave

q : Flow

k : Density

The first equation above demonstrates the relationship between flow, density, and speed. The second equation defines the speed at the change of traffic conditions, analogous to a shock-wave which propagates along a roadway. Figure 7 shows that the shock waves produced at point B are propagated in the backward direction. These two equations basically represent their model.

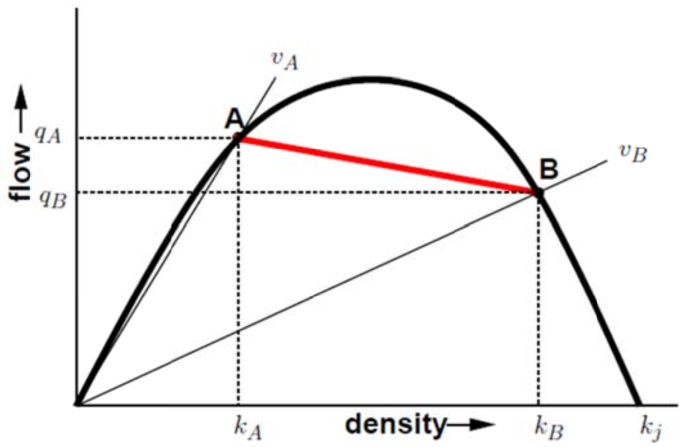


Figure 6. Shock Wave Flow-Density Curve [40]

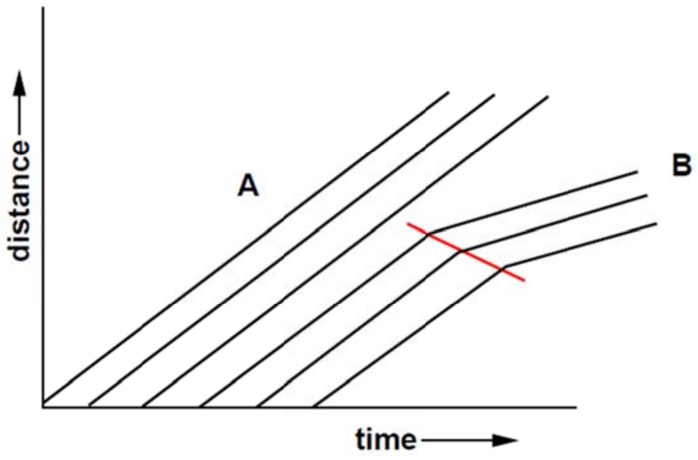


Figure 7. Shock Wave Time-Space Diagram[40]

The major difference between shock-wave and deterministic queuing models is that they use different methods to explain vehicles that are queued upstream of a bottleneck. Shockwave analysis studies the spatial dimension of queues. Therefore, shock-wave analysis captures more realistic behavior of queues and it determines the maximum queue reach.

Work Zone Capacity Estimation

Capacity is defined in the Highway Capacity Manual (HCM) as "*the maximum hourly rate at which persons or vehicles can be reasonably expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions*" [41].

Although there are different approaches in the literature, the majority of the measurement methods used to calculate work zone capacity relies upon queue discharge and maximum flow rates during congested and uncongested conditions. Bham and Khazraee [42] specified that work zone capacity definitions are either conceptual or operational. In their view, the conceptual definition of work zone capacity is based on mean queue discharge or breakdown flow rates. For instance, if capacity estimation is used to schedule a lane closure, then the breakdown flow rate will be the proper definition to avoid traffic congestion. The mean queue discharge is mostly used to estimate the delay and user cost since it reflects the expected average flow rate once queues form under work zone conditions. The operational definition is based upon a volume analysis, calculated by taking vehicle counts in a given time interval in conjunction with vehicle counts at specific measurement locations, such as at the end of a transition or activity area.

Most of the studies covered in this literature review focus on the conceptual definition of work zone capacity. Dixon et al. [43] identified work zone capacity as the 95th percentile value of all 5-minute flow rate observations within queue conditions. Jiang [44] identified work zone capacity as "*the traffic flow rate just before a sharp speed drop followed by a sustained period of low vehicle speed and fluctuating traffic flow rate*". Al Kaisy et al. [45] described work zone capacity as a mean queue discharge rate at the end of the work zone transition area. Maze et al. [46] defined work zone capacity as the average of the 10 highest volumes during the before and after queuing conditions. Benekohal et al. [47] defined work zone capacity as the discharge flow from platooning vehicles within continuous traffic condition. Dudek and Richard [48] stated the work zone capacity is the mean queue discharge rate at a freeway bottleneck.

Factors Affecting Capacity

Base capacity estimation assumes standard conditions such as dry roadway surface, good weather, and familiar drivers. In most cases, however, standard conditions are not applicable. There are several factors which affect capacity, classified by the HCM 2010 as roadway conditions, traffic conditions, traffic control conditions, environmental conditions and technology. Table 4 shows the factors which have an impact on work zone capacity.

Table 4. Conditions Effecting Work Zone Capacity [41]

Roadway	Traffic	Control	Environmental	Technology	Work Zone
-Number of lanes -Road type -Lane and shoulder width -Speed limit -Grade -Ramp -Lateral distance	-Vehicle type -Lane distribution -Driver population -Heavy vehicle ratio	-Traffic signals -Traffic signs -Turn restrictions	-Weather (rain, snow) -Light (daylight, dark)	-ITS strategies -Ramp metering	-Work zone layout -Intense of activity -Working time -Duration of project -Reduced speed limit -Lane, shoulder closure -Lane closure location, and time

Weng and Meng [50] defined work zone capacity as a function of sixteen different factors, which are shown below in Figure 8. Several studies were conducted to find out the individual or combined effect of each factor on work zone capacity. According to studies performed by Al-Kaisy and his colleagues, there was a 7 percent reduction in work zone capacity during off-peak hours compared to peak hours and a 16 percent reduction during weekend days compared to days during the week [45, 51]. Work activity reduced capacity by 6 percent at the work zone sites they studied. Left lane closures caused a 5.7 percent reduction in work zone capacity. Similarly, they found a 5 percent decrease in work zone capacity at darkness compared to the light conditions during the day time. Regarding the impact of adverse weather conditions, HCM suggests that capacity reduces during heavy rain by at least 10 to 20 percent on freeways. Venugupal and Tarko [52] found a 10 percent reduction and Al-Kaisy and Hall [53] found a 4.4 to 7.8 percent reduction in capacity due to rain conditions at observed work zones. Potentially, adverse weather conditions have a negative effect on work zone capacity.

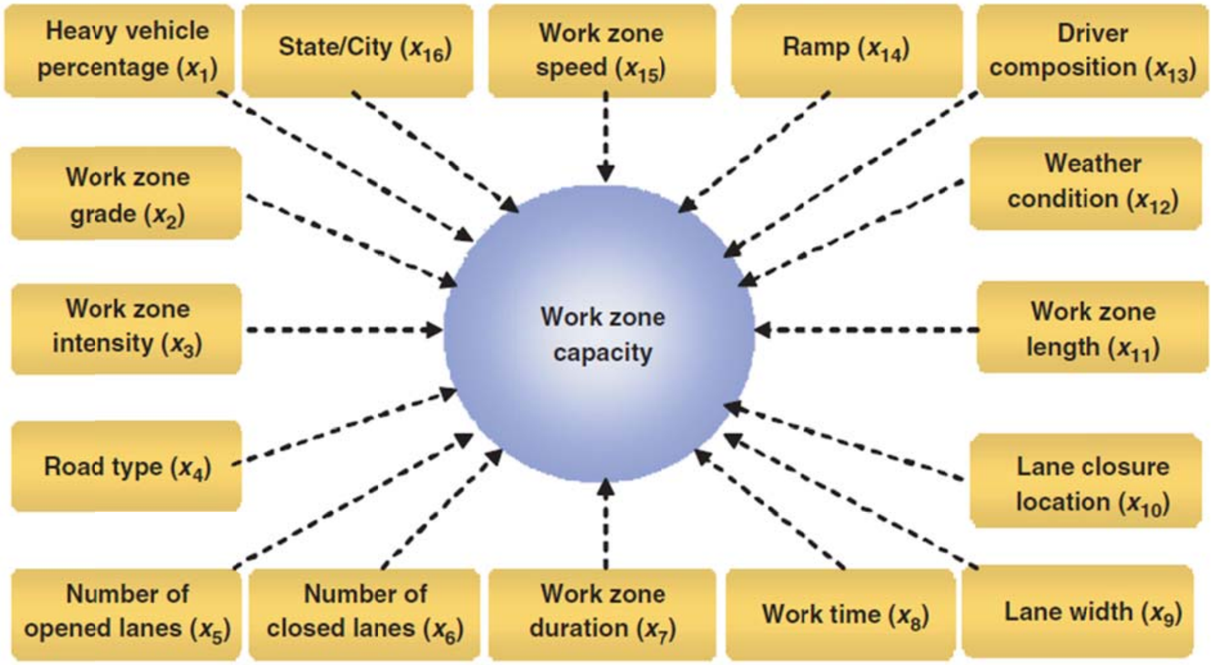


Figure 8. Factors Affecting Work Zone Capacity [50]

Estimation of Work Zone Capacity

The majority of work zone capacity estimation methods are based on modifying the base capacity with several of the factors mentioned in the previous section. Multiplicative, additive, and mixed models which incorporate linear and multivariate linear regression, have been developed [53,54,55]. To obtain more precise capacity estimations, different combinations of affecting factors have been used. Besides linear models, the Neuro-Fuzzy Logic Model has been used to estimate work zone capacity by incorporating various factors that affect work zone capacity [56]. The ensemble tree approach, as shown in Weng and Meng [50], is one of the more recent techniques used to develop work zone capacity estimation models.

In several studies the estimation of remaining capacity at work zones was based on factors including the ratio of heavy vehicles, number of lanes closed, and intensity of work zone activity.

Table 5 summarizes some of the previous studies on work zone capacity and the corresponding capacity estimations.

The capacity estimation model developed by Krammes and Lopez (54) was adopted by HCM 2000 (41). According to this model, capacity is estimated by the multiplication and interaction of reduction factors with base capacity, which is assumed to be 1,600 vehicles per hour per lane (vphpl) regardless of any conditions. Several adjustments were made to the base capacity value, including adjustments for the intensity of the work activity, the effect of heavy vehicles, and the presence of ramps in specific work zone locations.

$$f_{HV} = \frac{1}{1+P_T(E_T-1)} \tag{13}$$

$$C_a = [1600 - I - R] * f_{HV} * N \tag{14}$$

where,
f_{HV} = adjustment for heavy vehicles as defined
P_T= proportion of heavy vehicles,
E_T= passenger car equivalent for heavy vehicles,
C_a = adjusted mainline capacity (veh/hr);
I = adjustment factor for type, intensity, and location of the work activity (±160 pc/h/ln),
R = adjustment for ramps,
N = number of lanes open through the short-term work zone.

A study by Dixon et al. (43) estimated work zone capacity values for rural and urban freeways in North Carolina. This study found that both the intensity of the work zone activity and the type of study site, i.e., rural or urban, had strong effects on work zone capacity. For example, for two-lane to one-lane configurations in rural sites with heavy work intensity, the capacity was 1,210 vehicles per hour per lane in the activity area. For urban areas with the same lane operations under moderate and heavy work zone intensity, the activity area capacity was 1,560 vehicles per hour per lane and 1,490 passenger cars per hour per lane, respectively. This study also reported an activity area capacity of 1,440 vehicles per hour per lane for three to one lane operation with moderate work intensity in urban sites (See Table 5).

Jiang (44) assessed vehicle speeds and queue-discharge rates at work zones in addition to traffic capacity. The traffic data used in this study was collected from four different work zones on four-lane freeways in Indiana. Jiang (44) used low vehicle speeds and fluctuating traffic flow rates as the indicators of congestion at work zones. Therefore, work zone capacity was defined as the traffic flow rate just before a sharp speed drop, followed by a sustained period of low vehicle speed and fluctuating traffic flow rate. Study results indicated that capacity at work zones varied between 1,258 and 1,689 passenger cars per hour per lane (pcphpl), and that a heavy vehicle ratio had an effect on capacity.

Table 5. Studies on Work Zone Capacity

Study	Year	Location	Road Type	#of Work Zones	Length of Study	Capacity at Work Zone
Krammes and Lopez (54)	1992	Texas	Freeway	33	4 years	1,600 pcphpl
Dixon et al.(43)	1996	North Carolina	Rural, Urban Freeway	24	9 months	1,440 vphpl
Jiang (44)	1999	Indiana	Freeway	4	19 months	1,258-1,689 pcphpl
Maze et al. (46)	2000	Iowa	Rural Freeway	1	19 days	1,400-1,600 pcphpl
Al-Kaisy et al. (45)	2000	Ontario	Freeway	2	3 days	1,750-2,150 pcphpl
Kim et al. (55)	2001	Maryland	Freeway	12	Not reported	1,228-1,790 pcphpl
Schnell et al.(58)	2002	Ohio	Interstate, State	4	Not reported	866-2,982 vphpl
Al-Kaisy, Hall (53)	2003	Ontario	Urban Freeway	6	Different for sites	1,853-2,252 pcphpl
Sarasua et al. (59)	2004	South Carolina	Interstate	23	1 year	1,460 pcphpl
Benekohal et al. (47)	2004	Illinois	Interstate	11	1 day	597-1,294 vphpl
Lee et al. (60)	2008	Wisconsin	Urban Freeways	8	4 months	1,134-2,643 pcphpl
Heaslip et al. (61)	2008	Florida, Massachusetts	Interstate	2	7 and 10 days	1,245-1,992 vphpl
Benekohal et al. (57)	2010	Illinois	Interstate	3	AM, PM	868-1,604 vphpl
Bham and Khazraee (42)	2011	Missouri	Interstate	1	4 days	1,194-1,404 vphpl
Weng and Meng (50)	2012	Maryland, North Carolina, California Indiana, South Carolina, Ontario, Texas Toronto,Florida	Rural, Urban Freeway	182	Not Reported	1,180-2,090 vphpl
Edara et al. (24)	2012	Missouri	Urban Interstate	2	2 day	1,149-1,301 vphpl

Note: vphpl = vehicles per hour per lane; pcphpl = passenger car per hour per lane.

Al-Kaisy et al. [45] investigated freeway capacity at a reconstruction site with long-term lane closures. They also considered the effect of important control and extraneous variables like temporal variation, grade, the day of week, and weather conditions. They used data from a construction site on Gardiner Expressway, for both directions, in Ontario. The normal three-lane configuration was reduced to two lanes at the construction zone in each direction and the approximate length of the work site in each direction was 1,640 feet. The study found that the capacity varied within a wide range, between 1,750 pcphpl and 2,150 pcphpl, and with a mean value of 1,943 pcphpl. Later, Al-Kaisy and Hall [53] added four more Ontario construction sites to this dataset. Individual investigations were used to estimate a base capacity for freeway reconstruction sites and determine the effect of important factors including heavy vehicles, driver population, rain, site configuration, and work zone activity. A generic work zone capacity model (R2=0.63) was created for freeway reconstruction sites using a base capacity value of 2,000 pcphpl. The model was expressed using the following equation:

$$C = C_b * f_{HV} * f_d * f_w * f_s * f_r * f_l * f_i \qquad (15)$$

where,

$C_b =$ base capacity (2000 pcphpl),

$C =$ work zone capacity,

$f_{HV} =$ heavy vehicle adjustment factor,

$f_d =$ driver population adjustment factor (1.0 for peak hours-weekdays, 0.93 for off-peak weekdays, 0.84 for weekends),

$f_w =$ work activity adjustment factor (1.0 for no work activity, 0.93 for work activity at site),

$f_s =$ adjustment factor for side of lane closure (1.0 for closure of right lanes, 0.94 for closure of left lanes),

$f_r =$ rainy weather adjustment factor (1.0 for no rain, 0.95 for light or moderate rain, 0.90 for heavy rain),

$f_l =$ light conditions adjustment factor (1.0 daytime, 0.96 nighttime), and

$f_i =$ interactive effect (1.03 for left-lane closures during weekday-off peak, 1.08 for weekends when work activity is present, 1.02 for left-lane closures during weekends, 1.05 for rain during weekends, 1.0 for all other conditions).

Maze et al. [46] conducted an investigation of a work zone on a rural interstate highway (I-80) in Iowa. They measured the number of vehicles that passed through a work zone lane closure prior to and during congested operations, with the intention of understanding driver behavior at the work zone. They collected data for 19 days at the work zone; to find the maximum work zone capacity they calculated the average volume of the ten highest volumes immediately before and after the queue was measured. They found that the capacity at the work zone varied between 1,400 pcphpl to 1,600 pcphpl.

Kim et al. [55] developed a new freeway work zone capacity estimate methodology that uses various independent factors, which contribute to capacity reduction. These independent factors are: the number of closed lanes, location of closed lanes, proportion of heavy vehicles, lateral distance to open lanes, work zone length, work zone grade, and intensity of work zone. Data was collected in Maryland at 12 work zone sites with four to one and four to two lane closures in one direction. A work zone capacity estimate multiple regression model was developed to establish a functional relationship between work zone capacity and several key independent factors including the number of closed lanes, proportion of heavy vehicles, grade, and intensity of work activity. The stepwise regression analysis of the proposed model was promising with an R^2 value of 0.993. Model results were also compared with existing capacity models using the root mean square (RMS) error. The new capacity model is depicted by the following equation:

$$Capacity = 1857 - 168.1\,NUMCL - 37.0\,LOCL - 9\,HV + 92.7\,LD - 34.3\,WL - 106.1\,WI_H - 2.3WG * HV \quad (16)$$

where,
NUMCL = number of closed lanes,
LOCL = location of closed lanes,
HV = proportion of heavy vehicles,
LD = lateral distance to open lanes,
WL = work zone length
$\mathrm{WI_H}$ = work zone intensity
WG = work zone grade.

Schnell et al. [58] studied the feasibility of using commercially available traffic simulation and prediction tools to estimate queue lengths at work zones for the Ohio Department of Transportation. The simulation and prediction tools used in the study included HCS, Synchro, CORSIM, NetSim and QueWZ92. They collected field data from 4 different work zones (2 interstate and 2 in-state) at highways in Ohio. The values obtained from the field data were compared with the outputs of each tool. They found that, although they were visually appealing simulation packages, Synchro and CORSIM had inaccuracies in their queue length predictions. They concluded that none of the tools except QueWZ92 and ODOT Spreadsheet were designed to adequately model work zones operating at or above capacity.

Karim and Adeli [62] developed an adaptive computational model for estimating work zone capacity, queue length, and delay. In their model, they proposed various factors that affect work zone capacity, including the number of lanes, number of open lanes, work zone layout, length, lane width, percentage of trucks, grade, speed, work intensity, darkness factor, and the proximity of ramps. A radial-basis function neural network (RBFNN) model was used to determine the mappable quantifiable and non-quantifiable factors which described the work zone traffic control problem in relation to the associated work zone capacity. To test the network model they created look tables of 40 examples of work zones and ODOT estimated work zone capacities. The network was tested with 27 work zone capacity values that had been observed in previous studies. The network model was implemented for three different scenarios. These examples illustrated the significance of accurately estimating work zone capacity, the demand reduction factor, and the work scheduling on queue delay and length. Based on the RBFNN model, the root mean square error was estimated as 165 vph, which is an acceptable range for practical purposes.

Sarasua et al. (59) investigated various factors affecting the capacity of short-term lane closures at interstate work zones in South Carolina. In their study they organized a survey to assess current practices for short-term work zone closures on the Interstate system. They distributed this survey to all of the State DOTs, Puerto Rico, and the District of Columbia. Eleven returned surveys provided information about the threshold lane volume used by transportation agencies. Over half of the survey respondents used threshold lane volume to decide the suitability of lane closures. Table 6 shows the formally adopted threshold lane volume by several state DOTs. Later, Sarusa et al. collected one year field data (for flow, speed, and queue length) at 23 work zone sites on 2, 3 and 4 lane roadways, with a different number of lanes closed at each site. By using the passenger car equivalent flow and speed data, they developed a model which can estimate the capacity at work zones based on the vehicle make up, number of lanes open at the work zone, and work zone intensity. The final model is as follows:

$$C_{WZ} = (1460 + I) * f_{HV} * N \tag{17}$$

where,

C_{WZ} = work zone capacity (veh/hr),
I = work zone intensity (ranges from –160 to +160 pc/h/ln),
f_{HV} = heavy-vehicle adjustment factor as defined in HCM (41), and
N = number of open lanes.

Table 6. Threshold Lane Volumes Adopted by DOTs (59)

State	Threshold Lane Volume
Connecticut	1,500 to 1,800 vphpl
Missouri	1,240 vphpl
Nevada	1,375 to 1400 vphpl (7% trucks)
Oregon	1,400 to 1,600 pcphpl
South Carolina	800 vphpl
Washington	1,350 vphpl
Wisconsin	1,600 (rural) and 2,000 pcphpl (urban)

Benekohal et al. (47) presented a methodology for estimating speed and capacity in freeway work zones. The underlying principle of this methodology is that operating factors in work zones, which include work intensity, lane width, lateral clearance, and other factors, cause motorists to reduce their speed. The collected video data included 11 Illinois interstate two-to-one work zone lane closures with eight long-term and three short-term work sites. Work zone intensity was quantified and correlated with consequent speed reduction using field data for long-term work zones and driver survey data for short-term work zones. Based on these relationships an anticipated work zone operating speed was computed using a speed-flow relationship developed from the project data. The model is represented by the following equation:

$$C_{adj} = C_{U_O} * f_{HV} * PF \tag{18}$$

where,
C_{adj} = adjusted capacity,
C_{U_O} = capacity at operating speed U_O,
f_{HV}= heavy – vehicle adjustment factor as defined in HCM [41], and
PF = platooning factor.

In this study, a step by step approach was defined to estimate work zone capacity. These steps can be summarized as follows: estimating speed reductions due to narrow lane width and clearance, work intensity, and any other factors. The operating speed (U_O) is calculated by subtracting the estimated speed reductions from the free flow speed. Based on operating speed, C_{U_O} is defined by the speed-flow curve. By estimating the heavy – vehicle adjustment factor (f_{HV}) and deciding the platooning factor (PF), the adjusted work zone capacity can be found by Eq.(18).

Weng and Meng (50) used an ensemble tree approach to develop a work zone capacity model. They describe their model as a set of decision trees which determine the affecting factors on work zone capacity. 182 sets of data were used to develop models for the following states: Maryland, Texas, North Carolina, California, Indiana, Ontario, Toronto, South Carolina and Florida. They observed that in comparison to the decision tree method, the ensemble tree yielded stable results. More specifically, the reproduced ensemble tree approach outperformed the existing capacity estimation methods by providing more accurate results.

Besides numerical methods, field data can also be used to estimate work zone capacity. HCM 2000 [41] suggested that the capacity definition should be the maximum flow rate at sustainable conditions for 15 minutes. Benekohal et al. [57] developed a technique called the “h-n” or “h minus n” method to estimate work zone capacity by using field data. The model’s main idea is to estimate the missing capacity caused by the underutilization of roadways. H denotes headway in seconds and n denotes headway threshold for free flow traffic. If the observed headway is higher than 8 seconds then this value is replaced with a reduction of 4 seconds from the observed headway. Capacity values estimated by the “h-n” method were greater than the ones estimated by the HCM 2000 method.

Lee et al. [60] developed a tool to predict delays and queues for short-term lane closures. In order to evaluate and enhance their tool, they collected field data that contained information on the traffic flow and the queuing patterns during work zone operations on selected urban freeways. The field data showed that the roadway capacity varied between 1,134 pcphpl and 2,643 pcphpl, depending on the number of lanes closed and the intensity of the work zone activity.

Heaslip et al. [61] proposed an enhanced methodology for measuring the capacity at work zones. They investigated the impact of driver behavior at work zones and found that driver behavior influences flow quality when drivers encounter changing roadway conditions and lane configurations. This study used data collected from two highways, one in Florida for 10 days and the other in Massachusetts for 7 days. The data indicated that the average capacity was 1,992 vphpl for the Florida site and 1,245 vphpl for the Massachusetts site. Using field observations they also calculated the driver behavior factor, which was based on the assessment of factors including driver familiarity, driver adaptability, driver aggressiveness, and driver accommodation tendencies that are unique for different demographic groups.

Bham and Khazree [42] recorded a video stream of the traffic in the presence of a work zone at I-44 in Missouri. They used an Autoscope software package to count the number of vehicles traversing the work zone area. Both breakdown flow and maximum sustained flow rates methods were used to estimate the work zone capacity. The averages of 15-minutes maximum sustained flow rates were observed to be 1,307 vphpl and 1,406 vphpl for westbound and eastbound directions, respectively. The average of 11 breakdown flow rates (range of 1,194-1,404) was estimated to be 1,295 vphpl. It was found that the mean discharge queue rate 1,072 vphpl was significantly smaller than the observed breakdown flow rate.

Edara et al. [24] estimated the work zone capacity for four different short-term work zones in Missouri. Maximum sustained flow, rescaled cumulative flow, and the 85th percentile flow techniques were all used to estimate work zone capacity. The capacity values estimated by the queue discharge flow methods were found to be more accurate when compared to other methods. They conducted a nationwide survey with several State DOTs. The estimated capacity values by Edara et al. were close to the capacity values estimated by the HCM method for Missouri. The survey results showed that the work zone capacities used by the other state DOTs were higher than the estimated values. Table 7 shows values of the work zone capacity by different State DOTs.

Table 7. Work Zone Capacity Values Adopted by State DOTs [24]

State	2 to 1	3 to 1	3 to 2	2 Two-way one-lane (TWOL)	Two-way one-lane (with median crossover)
Florida	1,800 vph	—	3,600 vph	1,400 vph	—
Wisconsin	1,500 pcphpl	1,500 vph	1,500 pcphpl	—	1,400 pcphpl
Nevada	1,500–1,600 pcphpl	1,500–1,600 pcphpl	1,500–1,600 pcphpl	1,500–1,600 pcphpl	1,500–1,600 pcphpl
Massachusetts	1,500 vph	1,500 vph	3,000 vph	850–1,100 vph	
Hawaii	1,600 pcphpl	1,600 pcphpl	1,600 pcphpl	600-800 pcphpl	
Iowa	1,450 vphpl	—	1,450 vphpl	—	—
New York	1,800 pcphpl	1,600 pcphpl	1,700 pcphpl	—	1,800 pcphpl
New Jersey	1,300–1,400 vphpl	1,200–1,300 pcphpl	3,000–3,200 vph	600–750 vphpl	1,200–1,500 vphpl

Note: vph = vehicle per hour; vphpl = vehicles per hour per lane; pcphpl = passenger car per hour per lane.

CURRENT STATE OF PRACTICE IN COORDINATING PROJECTS

Significant Projects

The National Cooperative Highway Research Program (NCHRP) Report on *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan* [8] lists various strategies for transportation agencies to improve coordination, planning and scheduling of work zone activities. Coordination may involve county and local highway agencies and contractors as well as highway agency personnel representing different divisions such as maintenance, construction, design and surveying, traffic operations. Some of the strategies recommended in the NCHRP [8] report are:

Coordinating activities so that they can be scheduled to overlap, or not overlap, as appropriate.

- Work zones on two parallel corridors can reduce the alternative route choices for travelers, which could increase congestion caused by work zones. Such projects need to be scheduled at different times.
- Separate projects on the same route (resurfacing, surveying, and utility) should be scheduled to occur at the same time or as close together as possible to minimize disruption to traffic and to take advantage of the already deployed work zone traffic control.

Coordinating work zone activities and improving communication among agencies have already been practiced by various State DOTs. The Oregon Transportation Investment Acts was passed in 2001 and 2002 and dedicated $2.5 billion over a 10-year period to upgrade Oregon's highways, interchanges, and bridges. Oregon DOT (ODOT) recognized the need for the coordination of projects with the objective of managing and minimizing traffic operational impacts at the network level [9].

With more than 100 active work zones to manage during each summer period, ODOT created a Statewide Traffic Mobility Manager and Mobility Operations Center. The purpose of the Center was to follow the current congestion due to active work zones and coordinate the work zone lane closures to reduce delays. All project schedules were loaded into a common project database by each district and the project schedules and mobility impacts were then evaluated by the Mobility Operations Center, which had the authority to command a reschedule of work zone activities if acceptable delay thresholds were exceeded. They coordinated projects on different corridors by using a "Region Mobility Schedule" to see conflicts between the work affecting critical route pairs and coordinated activities [10]. Figure 9 shows a snapshot of the Region Mobility Schedule spreadsheet.

Region Mobility Schedule

ID	Key No.	Contract No.	Task Name	Mile Post Begin	Mile Post End	PM	Start	Finish
1	**2**	0	**I-5 Projects**	**283.21**	**306.73**		**Thu 5/6/10**	**Fri 6/28/13**
2	14949	14225	I-5: Iowa Viaduct	298.09	298.39	Statler	Thu 5/6/10	Fri 6/28/13
3	15140	14304	I-5: Holladay-Marquam & I-405: Fremont Bridge	300.92	301.98	Beeson	Thu 2/10/11	Thu 9/27/12
4								
5	**6**	0	**I-84 Projects**	**5.5**	**82.08**		**Wed 2/24/10**	**Mon 11/30/15**
6	14032	14165	Bundle 210 - Sandy River Bridge EB/WB	17.68	17.68	OBDP - Barnh	Wed 2/24/10	Fri 11/29/13
7	11017	14401	HCRH State Trail: JB Yeon - Moffett Creek	37.52	39.02	Beeson	Thu 10/27/11	Fri 10/18/13
8	17168	0	I-84: Bridge Deck Overlays	35.06	42.05	Beeson	Thu 10/18/12	Mon 9/30/13
9	16267	0	I-84: MLK Blvd. - I205	0.40	5.60	Earlywine	Thu 11/8/12	Fri 5/31/13
10	16846	0	I-84 EB to I-205 NB Aux Lane	5.5	6.6	Frietag	Thu 3/7/13	Wed 5/28/14
11	17541	0	I-84 at Troutdale Interchange	16.58	17.35	Beeson	Thu 11/14/13	Mon 11/30/15
12								
13	**6**	0	**US26 (East) Projects (Route Exceptions Req'd)**	**3.52**	**40.01**		**Thu 10/6/11**	**Thu 8/22/13**
14	17483	14393	US26: MP 22.5 - Luzon Ln.	22.5	26.33	Beeson	Thu 10/6/11	Thu 10/11/12
15	13717	0	US26: MP 49.60 - MP 50.00 (Rockfall)	49.20	50.00	Statler	Thu 5/10/12	Wed 11/28/12
16	15051	0	US26: SE 122nd - SE 136th	7.21	7.0	Beeson	Thu 7/26/12	Tue 11/13/12
17	15773	0	US26: Springwater Intersection	16.24	16.24	Beeson	Thu 11/1/12	Wed 7/31/13
18	1504713717	0	US26: MP 49.20 - MP 57.45 (Pavement Preservation)	49.20	57.45		Thu 8/22/13	Thu 8/22/13
19	15052/13717	0	US26: MP 49.20 - MP 51.00 (Downhill passing lane/mec	49.20	51.00		Thu 8/22/13	Thu 8/22/13
20								
21	**7**	0	**US26 (West) Projects**	**24.13**	**67.0**		**Wed 5/12/10**	**Wed 12/31/14**
22	14070	14228	US26: 185th - Cornell Rd.	64.30	67.0	Larson	Wed 5/12/10	Thu 6/28/12
23	16141	14429	US26: Sylvan - I405	71.53	73.94	Statler	Thu 3/29/12	Fri 5/31/13
24	14838	14459	US26: West Fork Dairy Creek Bridge #02673	46.2	46.4	Larson	Thu 5/17/12	Wed 7/11/12
25	16842	0	US26: Shute Interchange	61.07	61.07	Larson	Thu 3/8/12	Thu 12/26/13
26	12885	0	US26: Glencoe Road Interchange	56.94	57.22	Larson	Thu 4/12/12	Wed 12/31/14
27	17991	0	US26 (SW Kelly Ave): Ross Island Br - OR99W (Naito Pl	0	0.31	Earlywine	Tue 10/16/12	Fri 6/28/13
28	16137	0	US26: Jefferson St - Highland Interchange	73.12	73.31	Statler	Thu 3/28/13	Thu 10/31/13
29								
30	**2**	0	**I-205 Projects**	**0**	**27.18**		**Thu 2/9/12**	**Mon 4/28/14**
31	16847	14417	I-205: SE Foster Rd - SE 82nd Drive	15.87	17.80	Earlywine	Thu 2/9/12	Wed 10/31/12
32	14856	0	I-205 @ NE Airport Way Interchange	24.65	24.65	Freitag	Thu 7/18/13	Mon 4/28/14
33								
34	**1**	0	**US30 (East) Projects**	**9.0**	**13.0**		**Thu 5/24/12**	**Thu 10/31/13**
35	15068	14471	US30B: NE 122nd Ave. - MP 13.54	12.0	13.0	Beeson	Thu 5/24/12	Thu 10/31/13
36								
37	**4**	0	**US30 (West) Projects**	**1.93**	**69.95**		**Thu 1/6/11**	**Mon 9/30/13**
38		0	Lewis and Clark (Longview) Bridge	48.68	48.68	OR/WASH	Thu 1/6/11	Fri 1/4/13
39	11196	0	US30: "B" Street Bike/Ped Path	46.62	47.34	Weatherford	Thu 3/22/12	Wed 12/26/12
40	16151	0	Lower Columbia River @ Cornelius Pass Rd.	13.05	13.32	Larson	Thu 8/9/12	Wed 7/31/13
41	17566	0	US30: McNamee Rd. - MP 17.93	13.03	17.93	Larson	Thu 9/13/12	Mon 9/30/13
42								
43	**6**	0	**OR99 (West) Projects**	**7.0**	**10.8**		**Thu 1/6/11**	**Tue 12/31/13**

Page 1 Tue 9/18/12

Figure 9. Region Mobility Schedule Spreadsheet used by ODOT (10)

Washington State DOT (WSDOT) uses a computer tool for coordinating mid- to long-term construction projects and events. The project team interviewed WSDOT Construction Traffic Management group via phone conversation and a web-meeting in June 2013. The Construction Impact Analysis (CIA) tool is a web-based application that tracks the estimated traffic impacts of multiple years of future construction, maintenance and special events (sports games, marathons, concerts, etc.) at the state and local level. The tool is currently being used for mid- to long-term coordination only. A snapshot of CIA tool is shown in Figure 10.

The tool is used by the WSDOT staff who do not have closure permitting authority and who are not routinely managing day-to-day traffic impacts. They look at construction projects/schedules from a traffic perspective. The tool helps them manage the overwhelming amount of data including: when, where and what construction closures are happening in the region for all jurisdictions. The use of this tool brings together the agencies responsible for the construction, maintenance, and operations. The CIA tool uses hot spots to help project teams communicate with each other while projects are still in design and before contracts are awarded. The main advantage of this tool is that it gets project teams to start talking early.

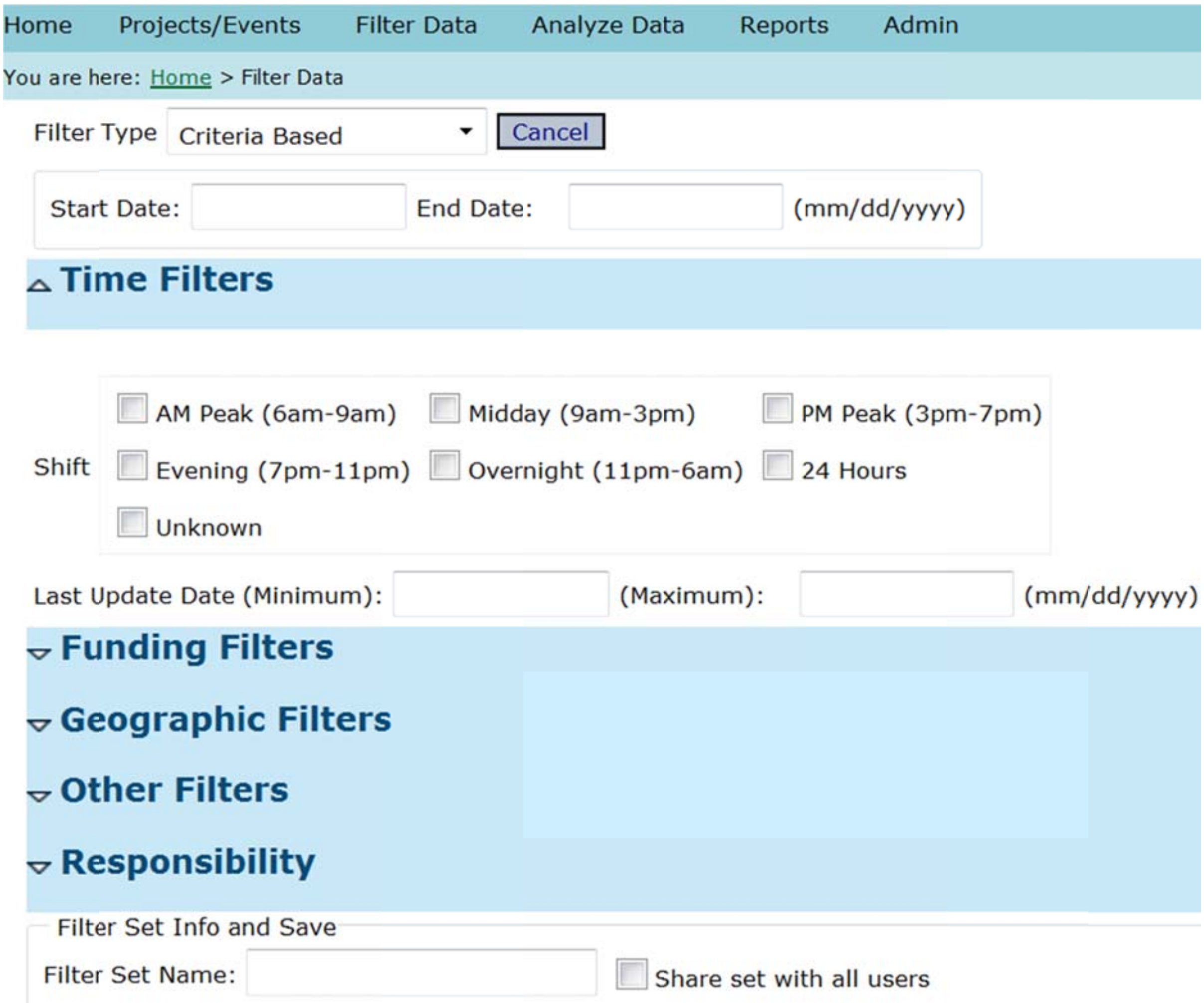


Figure 10. WSDOT's CIA Tool Interface

The Great Lakes Regional Transportation Operations Coalition (GLRTOC) includes the member agencies that extend from Minnesota through Wisconsin, Illinois, Indiana, Michigan, and Ontario. They hold an annual work zone preview during the first week of February in Chicago, where the planned work zones are shared between the member agencies. With the vast amount of data being shared, there was an apparent need for a map on which all the work zones could be placed with detailed information. Given that the objective was to improve coordination across agencies, they needed to be able to visually see where conflicts or opportunities existed. Figure 11 shows a sample from the GLRTOC visual work zone review [11].

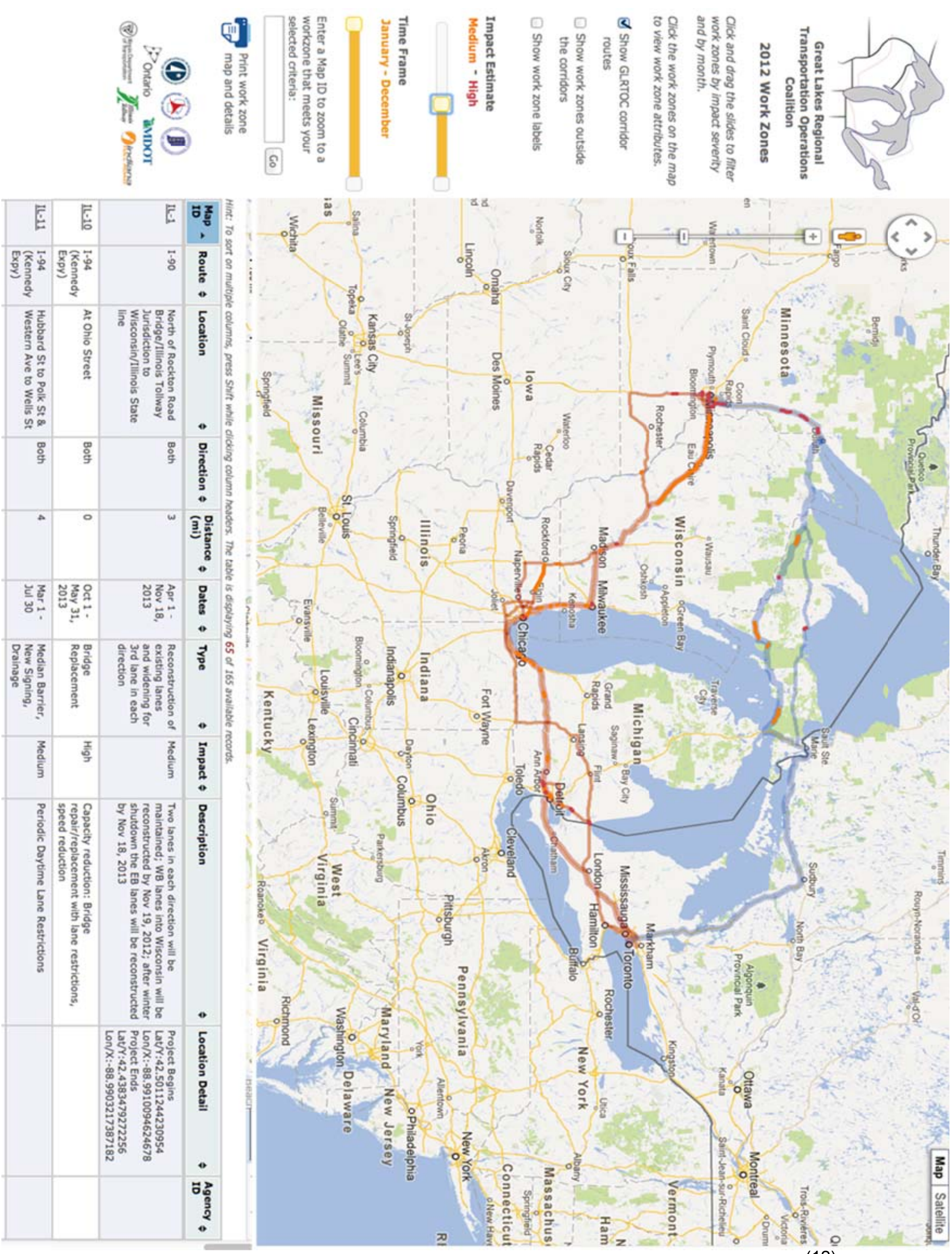
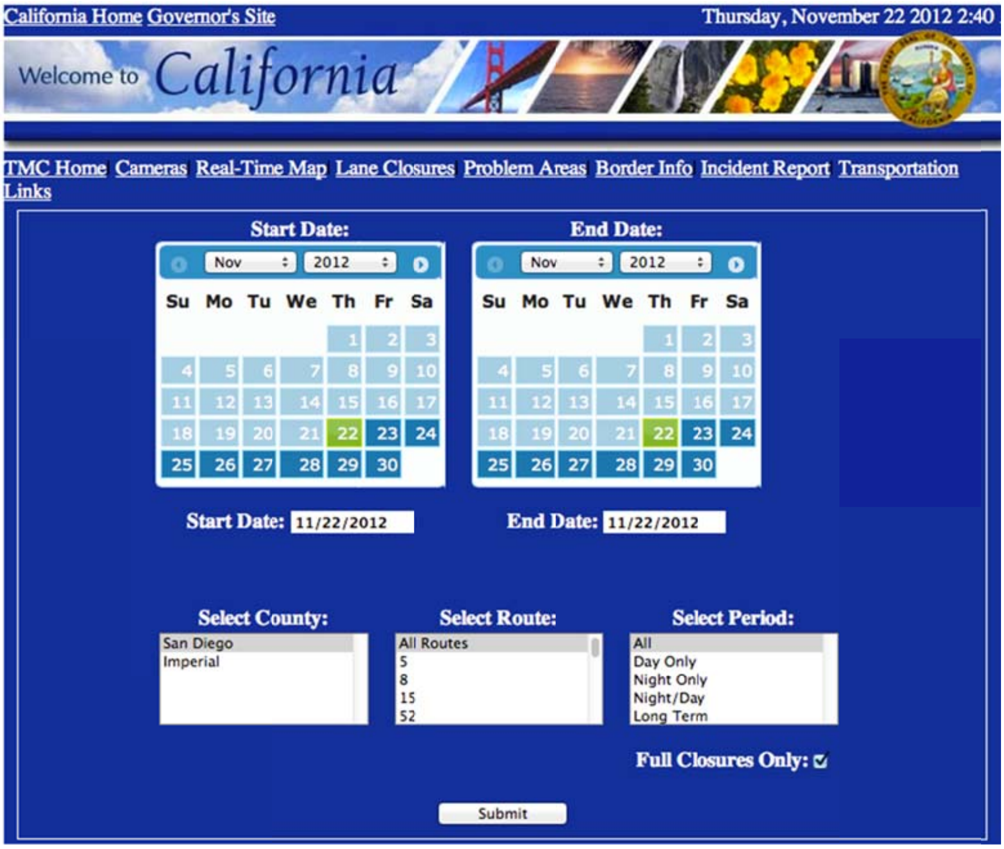


Figure 11. Snapshot of GLRTOC Work Zone Review Tool [12]

Caltrans coordinates multiple construction and maintenance projects within a corridor. For maintenance projects, a complete corridor can be closed off to traffic during the night while the maintenance teams perform the required work. They also coordinate construction projects that are much longer in duration with different projects in one corridor (13).

Caltrans develop a single corridor or regional TMP when multiple projects are in the same corridor or on corridors within the same traffic area. The TMP Manager coordinates the development and implementation of corridor and regional TMPs. The TMP team includes representatives from the Department's Divisions of Construction, Maintenance, Project Management, and Traffic Operations for each of the affected Districts and local law enforcement, transit, and emergency services agencies (14). They use a web-based lane closure system (LCS) to review the details of a lane closure request, check for potential conflicts, approve or mitigate requests, ensure that the closure is consistent with any corridor TMPs, and monitor closure progress. Figure 12 shows a snapshot for the Caltrans web-based LCS system.

As an example of the Caltrans work zone consolidations strategy, a 10-mile stretch of I-405 and four () miles of the southbound lanes were closed for 53 hours, from July 15 to July 17, 2011. The closure enabled workers to demolish half of the Mulholland Drive Bridge so they could widen the expressway between the Westside and the San Fernando Valley. For the weekend of September 29th, 2012, the same stretch of I-405 was fully closed so workers could demolish the northern side of the bridge during phase 2. Multiple agencies (maintenance, utility, survey, and others) took to the closed 10-mile section of highway to perform their work. Figure 13 shows the full lane closure for both ways during the Mulholland Drive Bridge construction.



Day Closures

Total Closures: 5
Start Time: >= 6:01 AM - < 6:01 PM
End Time: > 6:01 AM - <= 6:01 PM

Route	Direction	Facility	Start Date	End Date	Begin Location	End Location	Work Type	Lane Closed	Total Lanes
11-22-2012 , Total:5									
5	SB	Off Ramp	11-22-2012 06:01 AM	11-22-2012 08:01 AM	Route 76 / Coast Hwy		Special Event		2
76	WB	Mainline	11-22-2012 06:01 AM	11-22-2012 08:01 AM	Route 76	Loretta St	Special Event	1	3
163	NB	Off Ramp	11-22-2012 06:30 AM	11-22-2012 08:30 AM	Route 163	Quince St	Special Event		1
163	NB	Off Ramp	11-22-2012 06:30 AM	11-22-2012 09:30 AM	Route 163	Richmond St	Special Event		1
163	NB	Off Ramp	11-22-2012 06:30 AM	11-22-2012 09:01 AM	Route 163	Robinson St	Special Event		1

Longterm Closures

Total Closures: 2
24+ hour closures

Route	Direction	Facility	Start Date	End Date	Begin Location	End Location	Work Type	Lane Closed	Total Lanes
78	N/A	Surface Street	01-29-2012 09:01 PM	01-31-2013 05:01 AM	SB Mission Rd OH	@ Rte 78	Highway Construction	2	2
78	N/A	Surface Street	01-29-2012 09:01 PM	01-31-2013 05:01 AM	NB Mission Rd OH	@ Rte 78	Highway Construction	2	2

Figure 12. Caltrans LCS Web-based Lane Closure System [15]

Figure 13. CALTRANS Work Zone Consolidation (Mulholland Drive Bridge) [15]

Similar to Caltrans, the Michigan DOT (MDOT) attempts to identify all scheduled construction work in a corridor so that a contract might be able to deal with all of them, especially in the Detroit area. The principle that the MDOT is applying is “get in, get out and stay out.” The MDOT have also implemented a weekend closure within a long term contract project and invited road maintenance, utility and survey forces to work on the interest within that time period [13].

The Missouri DOT (MoDOT) coordinates lane closures across district boundaries, and considers the statewide impact of work zones on traffic. Each district of the MoDOT has a work zone coordinator that coordinates work zone activities within the district and communicates and coordinates with other districts. The district coordinators are also responsible for scheduling multiple tasks in a single work zone rather than scheduling multiple lane closures in the same area, and proper coordination to avoid scheduling work zones on parallel routes at the same time [13].

The Oklahoma DOT found that, in many instances, when a maintenance job was completed a newly installed utility crossing then ruined the recent improvements. Then, in 1998, the Oklahoma DOT started coordinating its projects and activities with the local highway agencies, utility contractors, and maintenance forces during the project planning phase to minimize traffic delays [13]. Table 8 summarizes the work zone coordination efforts by selected state DOTs.

Table 8. Work Zone Coordination Practive of Selected State DOTs

Agency	Description	Computer Tool
Caltrans	Reviews the details of a lane closure request, check for potential conflicts, approve or mitigate requests.	Web-based lane closure system (LCS)
WSDOT	Coordinates mid to long term events including construction, maintenance and special events	CIA tool
Indiana	Follows a lane closure policy that includes a statewide lane closure map and close-up lane closure maps for each of the four major urban areas in the State.	-
Ohio	Follows a policy that includes the queue analysis methodologies for determining the lane closure restrictions and suggestions for mitigation strategies.	Web-tool to calculate estimated queue length and determine permitted lane closure hours
Missouri	Coordinates lane closures across district boundaries, considering the statewide impact of work zones on traffic	-
Oklahoma	Coordinates its projects and activities with the local highway agencies, utility contractors and maintenance forces during the project planning phase	-
GLRTOC	Coordinates various types of roadway projects via a Google Maps based interactive computer tool.	Web-based computer tool that shows various types of work zones
Oregon	Coordinates all work zone lane closures to reduce delays	MS Outlook

In summary, there are no universal DOT policies that address how agencies should coordinate or consolidate projects. In addition, only a few states utilize computer tools specific to regional or corridor based work zone coordination. State DOTs mostly coordinate significant and long-term projects. There are more maintenance operations (M&O) and utility work projects than significant and long-term projects. FHWA rule requires agencies to consider the planning and coordinating of M&O activities. According to this requirement, the following efforts are suggested:

- Overall system-wide impacts of M&O activities are minimized and better managed.
- Coordinate and combine multiple M&O activities into a single larger project.
- Perform M&O activities as part of planned construction projects (whenever possible) as opposed to M&O work being completed individually.
- Coordinate, implement, and manage M&O and construction activities at the regional/district/corridor level to minimize overall impacts.

Short Term and More Frequent Work Zones

The majority of roadway projects include minor repair, roadway maintenance, bridge maintenance, surveying, landscape and utility work that require relatively short term work zones. Based on the USDOT report [5], there are more maintenance and minor repair projects than major overhaul or expansion projects, as shown in Figure 14.

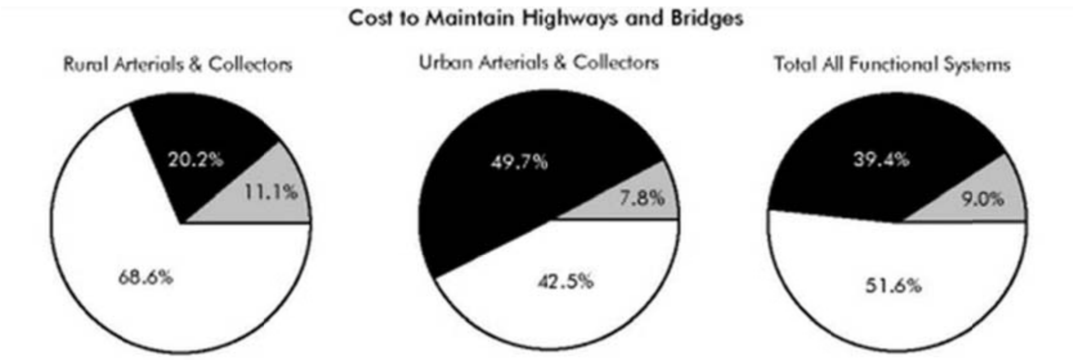


Figure 14. Status of the Nation's Highways, Bridges and Transit [5].

It would be beneficial for NJDOT to effectively coordinate, plan and quantify the impact of these relatively short-term yet frequent projects with each other and also with long-term projects. Despite the lack of computer tools for regional work zone coordination, there are several state DOTs and local agencies utilizing computer tools to coordinate activities that affect right-of-way. For local/urban work zone coordination purposes NYCDOT, PennDOT, RIDOT, Baltimore, District of Columbia, Sacramento, Colorado Springs, and Santa Barbara developed computer tools.

In October 2011, NYCDOT unveiled an online mapping system to minimize the number of times streets are dug up, reduce construction congestion, and extend the life of resurfacing projects. The map shares monthly list of "protected streets" (recently repaved/reconstructed streets) and future work zones (See Figure 15).

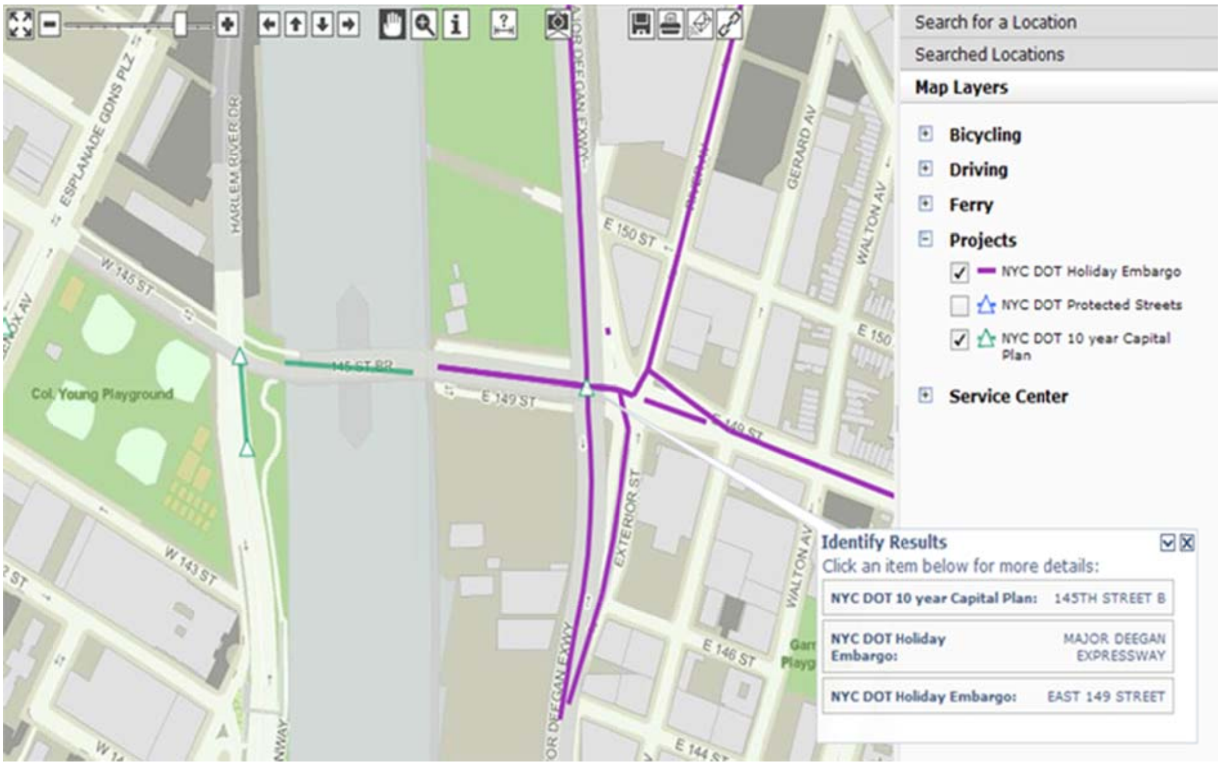


Figure 15. NYCDOT Work Zone Map http://gis.nyc.gov/doitt/nycitymap/

Current NJDOT Work Zone Practice

This subsection reviews the types of projects undertaken by NJDOT and reviews the current practice of work zone coordination on NJ roadways. The information presented below is based on the interviews conducted by NJDOT experts. Table 9Table 9lists the interviewees and the dates of each interview.

There are various types of projects that NJDOT allocates budget for:

- Capital Program Management (CPM) Projects
- Maintenance Engineering Projects
- Local Aid Projects
- Transportation Systems Management Projects

Among these projects, CPM and Maintenance Engineering projects together constitute the majority of the allocated budget.

Table 9. List of NJDOT Interviews

Interviewee	**Date**
Dave Lambert, *Manager, Capital Program Management*	April 15, 2013
Andrew Tunnard, *Director, Maintenance Operations*	April 16, 2013
John Gahwyler, *Regional Maintenance Engineer, Region North*	June 25, 2013
Harish Bhanderi, *Manager, Roadway Maintenance and Engineering Operations*	July 2, 2013
Thomas Saylor, *Manager, Capital Program Management*	July 2, 2013
Mark Hauske, *Engineer, Capital Program Supporter*	July 2, 2013
Scott Thorn, *Project Manager, Capital Program Management*	July 3, 2013
Jim Hadden, *Transportation Systems Management*	July 8, 2013
Jeevanjot Singh, *Transportation Systems Management*	July 8, 2013
Sheryl Grant, *Supervisor, Bureau of Program Systems Management Division of Capital Program Support*	October 16, 2013
Maintenance Operations - Andrew Tunnard, Harish Bhandari, Ahmad Ghorbani, Parth Oza, Gerald Oliveto and Jaime Oplinger.	March 11, 2014
Ahmad Ghorbani, Maintenance Operations	April 22, 2014

CPM Projects

Several management groups in NJDOT can hand down a decision for determining CPM projects' needs. These management entities can be from safety, bridge, pavement management or they can be from planning division, a metropolitan planning organization or external stakeholders. The process of screening problems and awarding projects takes about 2 to 4 years (Limited scope projects can take one year to award). There are approximately 50 CPM projects per year and these are bid to contractors. Their duration may vary between 6 months to several years.

Coordination of CPM projects plays an important role in the impact of work zones to the traffic. NJDOT already combines capital project work zones that are in close proximity at the problem screening stage. For instance, if there is a major work zone planned on a specific route, project management team finds out about other necessary work planned (e.g. overpass improvements, resurfacing, etc.) and combines them at the planning stage. Each CPM project requires an extensive traffic impact analysis. Based on the interviews, it can be stated that the CPM project managers are in close communication during the project screening process, and therefore they are well aware of any other conflicting CPM projects in close proximity.

For project reporting, NJDOT has been using a program called Project Reporting System (PRS) since 2001 to track CPM project updates. The tool is developed and maintained by Michael Baker Consulting. The tool is used by managers and it includes:

- Projects in Concept Development and Feasibility Assessment
- Projects in Design
- Projects in Construction

During the Concept Development phase of CPM project selection, projects are entered into the CPM Project Reporting System (PRS) tool and the anticipated construction start date and the anticipated traffic impacts are known. This information is then updated throughout various phases of the project delivery timeline, as shown in Figure 16.

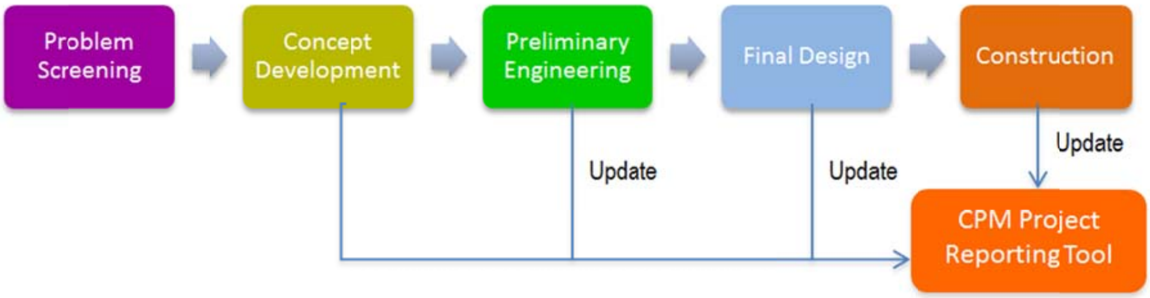


Figure 16. CPM Projects in PRS Database

The database includes information such as program manager contract information, detailed project information, and progress of work by date. Figure 17 shows a screenshot of the CPM PRS tool.

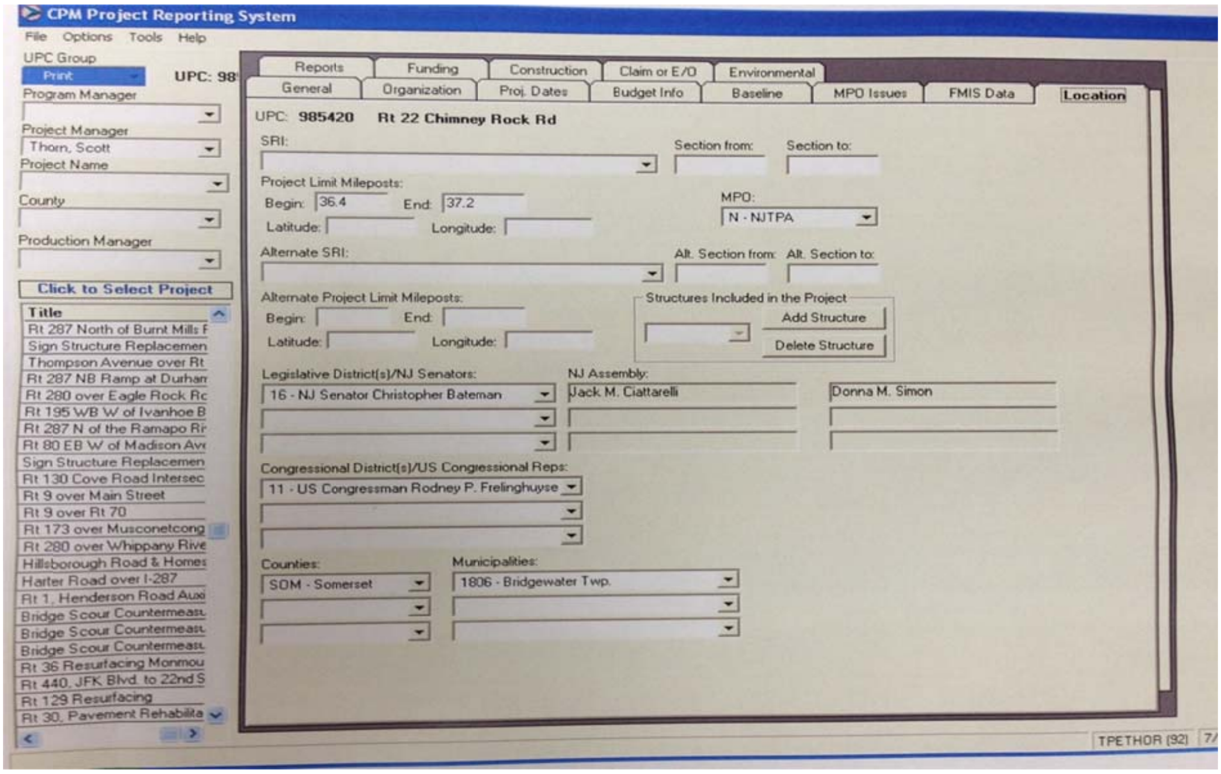


Figure 17. Screenshot of the CPM Project Reporting System

Maintenance Engineering Projects

Maintenance engineering projects include maintaining roadways, equipment and bridges to extend the service life of these infrastructures. These projects usually address a list of pre-defined roadways and bridges and delay the need for more extensive and expensive projects. Compared to CPM projects, they are not location specific. In other words, work can be performed at certain locations, sometimes in different counties. These projects are conducted by:

(1) On-call contractors who are awarded for a specific umbrella project (e.g. northern NJ resurfacing program)

(2) NJDOT maintenance personnel, they usually conduct smaller scale project such as pothole repairs, crack sealing, landscaping, etc.

Once a project is awarded to an on-call contractor, Operations division requests them to finish the project in a given time period which takes between 4 to 6 weeks. Work zone locations and lane closures are usually scheduled several months in advance. Contractors need to request a permit from the Mobility and Systems Engineering division two weeks prior to the proposed work. The same permit is needed every time a contractor works on a roadway. Based on our interviews, we were told that there is some kind of communication between the Operations projects and CPM projects. However, there are not any efforts to coordinate these two different project types. Coordination would highlight the conflicts between these projects and allow managers to take critical decisions that might result in time and money savings.

Majority of maintenance engineering projects are conducted by NJDOT personnel. These work zones are performed on need-basis. Maintenance projects are more frequent than any other types of projects. However, they are relatively harder to coordinate since they are scheduled within a couple of days.

Local Aid Projects

Local aid projects are the projects funded partially by the NJDOT, bid and awarded by the local agencies primarily on non-state roadways and streets. NJDOT usually does not have prior knowledge of these projects. Although these projects are on local roadways, they can also affect the connecting state roadways. If a list of these local projects were available to NJDOT, a better communication with the local agencies can lead to coordination of work zones.

CPM projects are planned years in advance, and coordination with other CPM projects is already being done in NJDOT. However, the relation between CPM projects and other types of projects should be improved. For this purpose, better information exchange between CPM projects, traffic operations, utility and local aid projects should be established. Maintenance engineering projects with on-call consultants are relatively easier to coordinate than daily works conducted by NJDOT maintenance crews.

Transportation Systems Management Projects

Transportation systems management projects are funded by NJDOT Mobility and Systems Engineering division. These projects are few and far between and usually involve the installation of intelligent transportation systems equipment such as radar detectors, cameras, tag readers, electronic displays on roadways.

BENEFIT COST ANALYSIS

Expected benefits of coordinating work zones are the reductions in direct costs such as travel time and delay costs, accident costs and vehicle operating costs. Congestion cost values will be obtained from the Road User Cost manual to be in accordance with the current NJDOT cost calculations. Accident costs and vehicle operating costs will be adopted from the previous studies conducted by the research team, and will be updated for the current year values. Costs associated with work zone coordination are the costs of modifying project schedules, design and penalty costs.

Congestion Costs

The monetary value of travel time (VOT) plays a crucial role in determining cost changes since all these cost categories are related to travel time. Travel time costs may consist of time devoted to waiting, accessing vehicles and the actual travel time depending on the mode choice of the traveler. Apogee Research estimated congestion costs in a study in Boston and Portland (63) areas using VOT as the 50% of the average wage rate for work trips and 25% for other trip purposes. K. Gwilliam (64) concluded that work travel time should be valued at 100% wage rate based on a review of international studies. He also pointed out that non-work travel time should be valued at 30% of the hourly wage rate.

Likewise, USDOT (65) suggests value of travel time should be between 50% and 100% of the hourly wage rate depending on travel type such as personal and business. These VOT studies did not include user characteristics, mode of travel, or time of day choices in the estimation process. To consider these issues, some studies conducted stated preference surveys to estimate VOT for different modes of travel and trip purposes (66,67,68).In this report, it is assumed that the VOT ranges based on average hourly wages as recommended by the USDOT (65).

Two vehicle types: passenger cars and trucks were considered. For passenger cars, the VOT range, based on the hourly wage, is assumed to be between 80% and 120% of the average hourly wage within peak period, and between 35% and 60% of the average hourly wage within off-peak periods, respectively. For trucks, the VOT range, based on the hourly wage, is assumed to be 100% within both off-peak and peak periods. U.S. Department of Labor (69) stated average hourly wages for all jobs in New Jersey. The report specifies that, in 2012, the average hourly wage for all employments was $25.00 per hour. The hourly wage for trucks in transportation and warehousing was $21.37 per hour. Table 10 shows the VOT ranges, as suggested by the USDOT (65), used in our analysis.

Table 10. Value of Time Ranges [65]

Time Period	Passenger Cars	Trucks
Peak	$20 - $30	$21.37
Off-Peak	$8.75 - $16.25	$21.37

The Bureau of Public Roads travel time function was used to calculate time loss. Thus, the total cost of congestion between a given origination-destination (OD) pair can be calculated by the time loss of one driver along the route, multiplied by total traffic volume (Q) and the average value of time (VOT).

Vehicle Operating Costs

There are many contributing factors to the operating costs of a vehicle. Some of these factors are the type of vehicle, environmental conditions, road, design, and flow speed of traffic. The factors are more specifically, the depreciation cost, cost of fuel, tires, oil, insurance and parking/tolls. While some costs are unit costs per mile, the depreciation cost is defined by a function of mileage and vehicle age. The depreciation cost function, which is estimated in an early NJDOT project conducted by Ozbay [75], is utilized in this report. From the American Automobile Association (AAA) and USDOT reports, the other categories aforementioned; cost of fuel, oil, tires, insurance, parking and tolls are obtained.

Accident Costs

The costs associated with an accident can be separated into two distinct groups, where it is defined as accident costs as the economic value of damages caused by a vehicle accident/incident (Table 11). The first group is the cost of foregone production and consumption, which can be converted into monetary values. Life-injury damages compose the second group, which require more elaborate techniques in order to convert into monetary values. The accident cost function is used to convert the estimated number of accidents into a dollar value. It accomplishes this by estimating this number of accidents that occur over a period of time and then multiplying the number of accidents by their unit cost values. Although the cost of each individual accident varies with its own circumstances, similar accidents tend to have costs that correspond to the same range.

Table 11. Components of Accident Costs [74]

Pure Economic Costs	
Major costs	Description
Medically related costs	Hospital, Physician, Rehabilitation, Prescription
Emergency services costs	Police, Fire, ambulance, helicopter services, incident management services
Administrative and legal costs	Vehicle repair and replacement, damage to the transportation infrastructure
Life Injury Costs	
Employer costs	Wages paid to co-workers and supervisors to recruit and train replacement for disabled workers, repair damaged company vehicles, productivity losses due to inefficient start-up of substitute workers
Lost productivity costs	Costs due to pain, suffering, death and injury
Travel delay costs	Productivity loss by people stuck in crash related traffic jams

The accidents are separated into the three categories of fatal, injury, and property damage. The traffic accident database of New Jersey was used to develop the accident occurrence rate functions for each of these three types. Annual accident rates by accident type are closely related to the characteristics of traffic volume and roadway geometry.

Traffic volume is represented by the average annual daily traffic, while the roadway geometry of a highway section is based on engineering design. The possibility of accident occurrence is closely affected by the many features of roadway geometric design. The various features are too detailed to be considered in a function, so highways are classified function type. These functional types are Interstate, freeway-expressway, and local-arterial-collector, where it is assumed that each type has its own unique roadway design features. By classifying the types in this way, it is possible to work with only two variables: road length and number of lanes.

Nine different functions were developed corresponding to the three accident occurrence rate functions for each accident type for each of the three highway function types. These functions were found through regression analysis. The number of accidents in a given year is reported for each highway function type, using the available data obtained from detailed accident summaries for the years 1991 to 1995 in New Jersey. The statistical results of the estimation of accident occurrence rate functions can be found in Ozbay et al [76].

The unit cost of each type of accident directly affects the cost estimates. The National Safety Council [(70)] reported the average unit cost per person for three accident types, as shown in Table 12. These values are comprehensive costs that include a measure of the value of lost quality of life which was obtained through empirical studies based on observed willingness to pay by individuals to reduce safety and health risks.

Table 12. Average Comprehensive Cost by Injury Severity [(71)]

Accident Type	Cost
Death	$4,459,000
Incapacitating injury	$225,100
Nonincapacitating evident injury	$57,400
Possible injury	$27,200
No injury	$2,400

This accident cost estimation can only be approximated as the studies in relevant literature show varying unit costs. One National Highway Traffic Safety Administration (NHTSA) study [(71)] study reports that each fatality produces a lifetime economic cost of $977,000, where over 80% of this cost is a direct result of lost workplace and household productivity. Additionally, this study quotes the cost of a critically injured survivor as $1.1 million [(71)]. A study by FHWA [(72)] reported the comprehensive cost of each accident by severity, as shown in Table 13.

Table 13. Average Comprehensive Cost by Accident Type FHWA [(72)]

Accident Type	Cost
Fatal	$4,156,490
Incapacitating	$287,757
Evident	$57,551
Possible	$30,374
Property Damage Only	$3,197

Note: All costs are in 2016 dollars, converted from 1994 values using 2.5% discount rate.

A recent poll conducted by American Association of State Highway and Transportation Officials (AASHTO) [(73)] reported accident costs by severity. The reported values shown in Table 14 reflect the average accident costs used by 24 states for prioritizing safety projects.

Table 14. Average Cost by Accident Type AASHTO [(73)]

Accident Type	**Cost**
Fatality	$2,435,134
Major Injury	$483,667
Incapacitating Injury	$245,815
Minor Injury	$64,400
Injury	$59,898
Possible or Unknown Injury	$23,837
Property Damage	$6,142

The unit accident costs reported by the FHWA [72] are used for the purpose of this report (see Table 11). In order to align the cost estimates based on the accident types available in NJDOT accident database, we regroup accident types in FHWA [72] into fatality, injury (incapacitating), and property damage accidents.

The accident cost functions are presented in Table 14. These functions are based on unit accident cost for each accident type. The accident cost functions used in this study were first developed by Ozbay et al. [74], and later improved by Ozbay et al.[74,75] with a new accident database.

Maintenance Costs

A Total of 61 resurfacing projects between 2005 and 2006 in New Jersey were considered [6]. Here, roadway infrastructure costs and resurfacing costs are equated. The average number of lanes, length in miles and total project costs formed the data, while roadway traffic volume was not included. Consequently, a simple resurfacing cost function based on number of lanes and length was developed.

Table 15 summarizes the cost functions used in the analysis.

Table 15. Cost Functions [75]

Cost	Total Cost Function		Variable Definition	Data Sources
Vehicle Operating	$C_{opr} = 7208.73 + 0.12\left(\frac{m}{a}\right) + 2783.3a + 0.143m$		a: Vehicle Years	AAA [77] USDOT [78] KBB [79]
Congestion	$C_{cong} = \begin{cases} Q\frac{d_{a,b}}{V_0}\left(1+01.15\left(\frac{Q}{C}\right)^4\right)VOT & if\ Q \le C \\ Q\frac{d_{a,b}}{V_0}\left(1+01.15\left(\frac{Q}{C}\right)^4\right)VOT + Q\left(\frac{Q}{C}-1\right)VOT & if\ Q \ge C \end{cases}$		Q= Volume (veh/hr) d= Distance (mile) C= Capacity (veh/hr) VOT= Value of time ($/hr) V_0= Free flow speed (mph)	Mun[80] Small and Chu [81]
Accident	Category 1: Interstate-freeway	$C_{acc} = 127.5Q^{0.77}.M^{0.76}.L^{0.53}$ $+114.75Q^{0.85}.M^{0.75}.L^{0.49}$ $+198{,}900Q^{0.17}.M^{0.42}.L^{0.45}$	Q= Volume (veh/day) M= Path length (miles) L= no of lanes	FHWA [72] USDOT [82]
	Category 2: principal arterial	$C_{acc} = 178.5Q^{0.58}.M^{0.77}.L^{0.43}$ $+18{,}359Q^{0.45}.M^{0.63}.L^{0.47}$		
	Category 3: arterial-collector-local road	$C_{acc} = 229.5Q^{0.58}.M^{0.77}.L^{0.77}$ $+9{,}179.96Q^{0.74}.M^{0.81}.L^{0.75}$		
Maintenance	$C_M = 800{,}950N^{0.384}L^{0.403}$		N: Number of lanes L: Length of project	Ozbay et

		(miles) T: Time between each resurfacing cycles (hour) t: Travel time of one additional vehicle (hour)	al. [74]

Cost Saving Analysis

This subsection describes the cost-benefit analysis approach adopted for the Work Zone Coordination Spreadsheet (WCS) tool developed as part of this research project. Details on the WCS tool are presented in the Work Zone Coordination Spreadsheet Tool section.

The cost of work zone coordination is the penalty of delaying one work zone or integrating it in another work zone. The numbers used to quantify penalty are not only readily available but also are different from work zone to work zone. Cost estimates will be obtained from the project managers, since they will have the most accurate numbers.

On the other hand, the benefit of coordinating work zones will be obtained from the WCS tool. The following subsections describe the two likely scenarios of work zone coordination and the resulting benefits.

<u>Benefit Cost Analysis Scenarios</u>

Scenario 1: Conflicting Work Zones on the Same Roadway

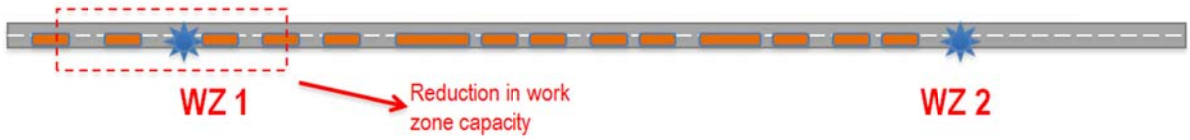


Figure 18. Two Work Zones on the Same Roadway

Figure 18 shows two work zones adjacent to each other. In the analysis, if the conflicting projects are less than a mile apart and they are both in conceptual design phase, then it is assumed that there is a possibility of consolidating these two projects into a single one. The benefit of a possible consolidation scenario is removing one work zone and therefore the delays it imposes on traffic. WCS tool estimates the delays that each work zone imposes on traffic and converts them into monetary values using VOT.

The benefit of consolidating work zones is the value of total delay of the work zone that is removed, assuming that the length of the consolidated work zone is no longer than the maximum of the two separate work zones. The effect of work zone length on delay was considered small here. Occasionally, it is not possible to consolidate two projects for various reasons. In that case, WCS tool allows users to determine the benefit of re-scheduling one of the work zones to another time period. During this process, the WCS analysis depends on the expertise of users during this process. If one of the work zones is easier to re-schedule, the computerized tool estimates the reduction in cost of delay by re-scheduling one of the projects during another time period.

Scenario2: Conflicting Work Zones on Different Roadways

Based on the proximity work zones, the user can decide whether one of the work zones should be re-scheduled.

Figure 19. Proximity of Two Work Zones

WCS tool allows users to estimate the delays when the selected project is rescheduled and when it is status-quo. The benefit of rescheduling is the reduction in total delay costs. The tool also provides an estimated percentage of traffic diversion between roadways, and estimate benefits accordingly.

Running a traffic assignment algorithm is another method of traffic diversion when work zone exists on a roadway. However, traffic assignment requires a network-wide origin-destination matrix along with other specific input as calibrated link travel times. Thus, this process of performing traffic assignment to estimate diversion volumes for a specific work zone coordination scenario will be extremely time consuming and costly. For example, the Work Zone Impact and Strategy Estimator (WISE) Software developed by SHRP 2 follows this approach [(83)]. It can either import an existing travel demand model or let users create a new network. This tool is tested by Rutgers / NYU researchers. It is observed that the tool has significant problems in both importing an existing travel demand model and creating a new network. Therefore, the proposed benefit cost analysis approach is a more practical method that incorporates the expertise and rationality of the users.

PROPOSED WORK ZONE COORDINATION FRAMEWORK

The goal of advance coordination is to reduce the number of work zone conflicts in New Jersey highways. This chapter brings together the concept of work zone coordination, interviews, review of project times and their timeline from the beginning to completion, and the NJDOT's already available databases. It should be noted that NJDOT, contractors and engineering companies are responsible partners in order for coordination to be effective.

NJDOT experts informed the project team that adding at least Maintenance Engineering projects in the CPM PRS database would highly increase the long-term coordination process. The coordination can be possible only if the maintenance engineering projects were visible in the PRS database along with their respective information such as their approximate locations, estimated start and completion dates and work zone duration, long before they are bid out to contractors. However, this would require modifying the CPM PRS tool which is not cost effective. Therefore, a database with a similar format used for CPM projects is needed for the maintenance projects through the CPM PRS tool. The desired workflow of the two databases and their integration with the work zone coordination tool is shown in Figure 20.

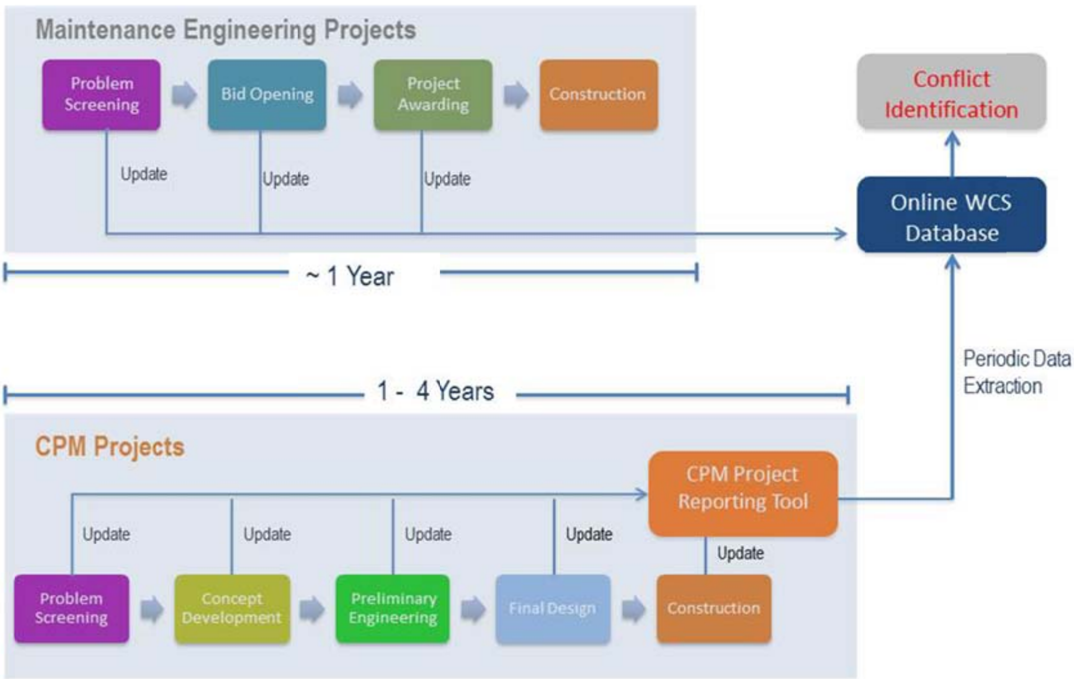


Figure 20. Stage 1 Timeline

Although this is an ideal work flow for improved long-term coordination of CPM and maintenance projects, it is not practical because of the need to create, update information for each project continually throughout the project delivery and maintain a relatively complex database. It requires additional manpower and coordination from the maintenance operations department, which is not always straightforward to obtain.

As an alternative solution, the research team focused on the short-term (e.g. less than a month) coordination, as suggested by the NJDOT Mobility and Systems Engineering division during the quarterly project meeting on January 29, 2015. In order to realize this objective, the research team utilized the OpenReach database.

OpenReach is a web-based, multi-modal, regional (NY/NJ/CT) inter-agency tool that (84):

- Links dozens of transportation & police operations centers
- Provides direct access for decision makers
- Integrates incidents/construction/travel times/video
- Includes variable message signs/HAR
- Serves as database for travel info systems (e.g. NJ 511 System)

It includes three independent but integrated systems of TRANSCOM Region, NJ Statewide and Delaware Valley Regional Planning Commission (DVRPC). OpenReach is used by the Traffic Management Centers in NJ for their daily traffic management activities. It includes not only active and dormant work zones in the state but also work zones in the TRANSCOM database, and also includes incidents and infrastructure assets. OpenReach is being used on a daily basis by the Traffic Management Centers in NJ for their daily traffic management activities, and it includes all events including information on historical work zones such as the time and date of work zone, how many lanes closed, description of work zone and type of project. Information in OpenReach is used to populate Daily Construction Report that is sent out to involved parties and information for the NJ 511 System.

In addition, the Mobility and Systems Engineering division requested that the OpenReach database be fed in the WCS tool automatically without having to import the database manually by the staff.

Based on the suggestions from the research panel, the team updated the work zone coordination framework as shown in Figure 21.

Based on this updated coordination framework, the OpenReach database and CPM PRS database is fed into an extended online database, called Work Zone Coordination Spreadsheet (WCS). OpenReach database is obtained through TRANSCOM via periodic XML feeds and updates itself automatically, and CPM PRS database is obtained from NJDOT manually. It should be noted that for short-term coordination, the inclusion of the entire CPM PRS database is not necessary, since the OpenReach database already includes the work zone information of these projects. Therefore, the team imports only the CPM projects that are in their final design or earlier phases to avoid double counting in the WCS.

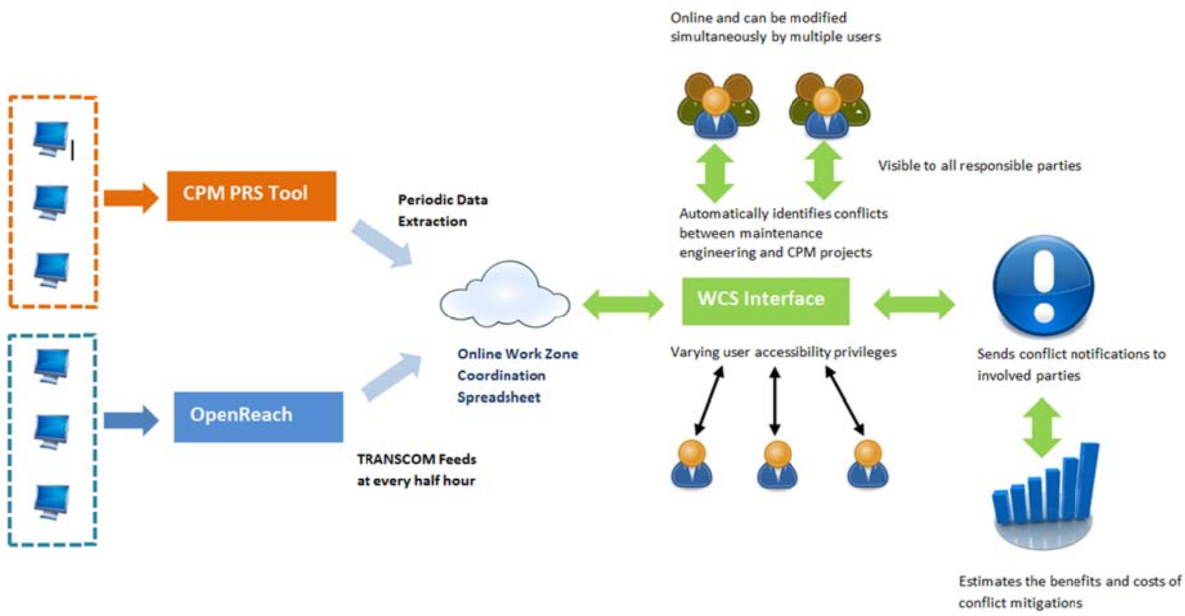


Figure 21. Work Zone Coordination Framework

Once the WCS is established, the database is used by the WCS Tool developed by the research team. The details of this tool are presented in the next section. Using the combined database, WCS tool allows user to identify work zone conflicts, alert involved parties, and conduct a benefit cost analysis of coordinating the conflicting work zones. The decision process of whether to coordinate work zones is depicted in the decision flowchart shown in Figure 22.

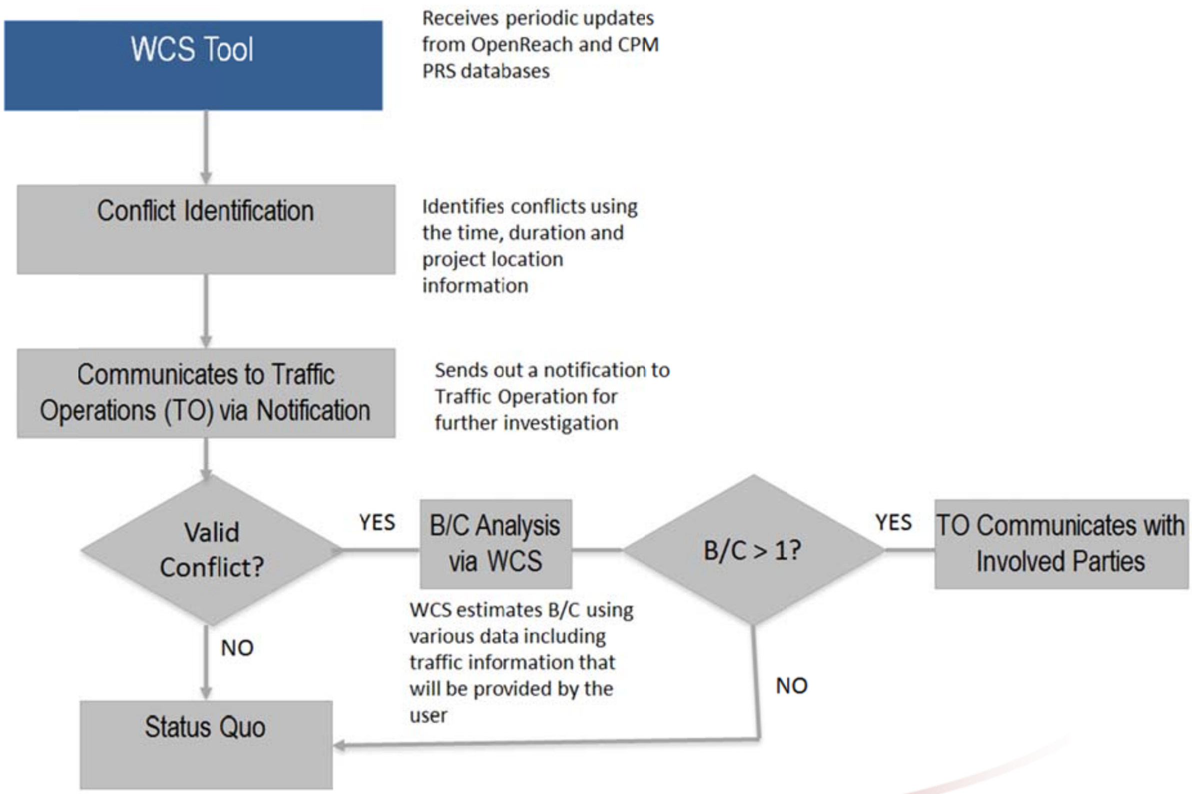


Figure 22. Decision Making Process for Work Zone Coordination using WCS Tool

The following section presents how to use the WCS tool.

WORK ZONE COORDINATION SPREADSHEET (WCS) TOOL

Work Zone Coordination Spreadsheet (WCS) tool is an online computer tool developed for NJDOT. This user-friendly tool is aimed at providing NJDOT with an easy-to-use way to evaluate the feasibility and effectiveness of coordinating short and long term work zones and measure the benefits of various combinations of projects relative to each other and the status quo.

The WCS tool was distributed to 15 NJDOT traffic operations and CPM division staff on November 17, 2015. The tool was then updated based on the comments / suggestions received on December 21, 2015.

The key functional requirements of the tool can be listed as follows:

- Integrates all scheduled and active construction projects and planned CPM projects.
- Available online and can be modified simultaneously by multiple users.
- Identifies conflicts between work zone projects.
- Sends conflict notification to involved parties.
- Visible to all responsible parties.
- Offers varying user accessibility privileges.
- Estimate the benefits of conflict mitigation.
- Ability to save the analyses in a report format.

The interactive tool is developed using Javascript as the main development environment. It provides users the following applications:

- **Project Visualization**: Users can either add various types of projects, or query projects based on various criteria, such as project status, SRI number, time frame, milepost range, county, project manager and structure. Users can map the project location on Google Maps on the same window. Users can also view project timeline as a Gantt chart.
- **Lane Closure Analysis**: Users can estimate the queue and delay estimation of lane closures for any selected project from the list.
- **Conflict Analysis**: Once the WCS tool determines the list of projects that are in conflict with any selected project, users can click on a conflicting project from the list and view a Gantt chart that show the project timeliness of both project on the same chart.
- **Benefit Cost Analysis**: Users can estimate the benefit of coordinating / consolidating projects that are in conflict with each other.
- **Link and Volume Characteristics** (such as number of lanes, hourly volume and AADT.
- **Reporting**: Users can save / print the selected analyses in a report format.

Figure 23 shows the application flowchart of the WCS tool. Details of each module will be presented in the next sections.

“Lane Closure Analysis” and “Benefit Cost Analysis” modules of the WCS tool depend on hourly volumes and link capacities. In particular, the benefit of coordinating work zones will be realized through reducing the economic costs of vehicular queues. Hourly vehicular delays and queue lengths can only be estimated using roadway volumes.

In order to determine hourly volumes on each link of NJ highways the research team gathered three different databases from NJDOT. These are:

- ESRI shape file of NJ Straight Line Diagrams
- Sensor Counts Database
- Sensor Information Database.

ESRI Straight Line Diagrams Database: The research team obtained the ESRI shape file of the New Jersey Straight Line Diagrams (SLD) from NJDOT. The database behind the SLD shape file includes information on the links of major highways and county roads in NJ, such as link length, number of lanes, annual average daily traffic (AADT), zip code, etc. The dataset contains 51,190 unique roadway links. Details of the ESRI shape file of NJ SLD are given in the Appendix.

Sensor Counts Database: Sensor counts database includes short term sensor counts of the last five years. It has directional 48-hour duration hourly volumes collected at various highway locations in the state. The dataset shows the sensor ID, direction, begin and end hour of volume counts and hourly volumes in each direction of traffic flow. Each sensor has multiple days of data with varying start and end hours. However, this dataset does not have the information about the highway which the sensor is located.

Sensor Information Database: Sensor information dataset includes information on all the sensors that are used for collecting hourly volumes on NJ highways. The available information includes sensor ID, sensor type, highway SRI number, sensor milepost, zip code, and X and Y coordinates.

In short, the necessary data to obtain hourly volumes are available in these three databases separately. A C programming code is used to parse the data and create links between each dataset. Estimation of hourly link volumes is shown in Figure 24.

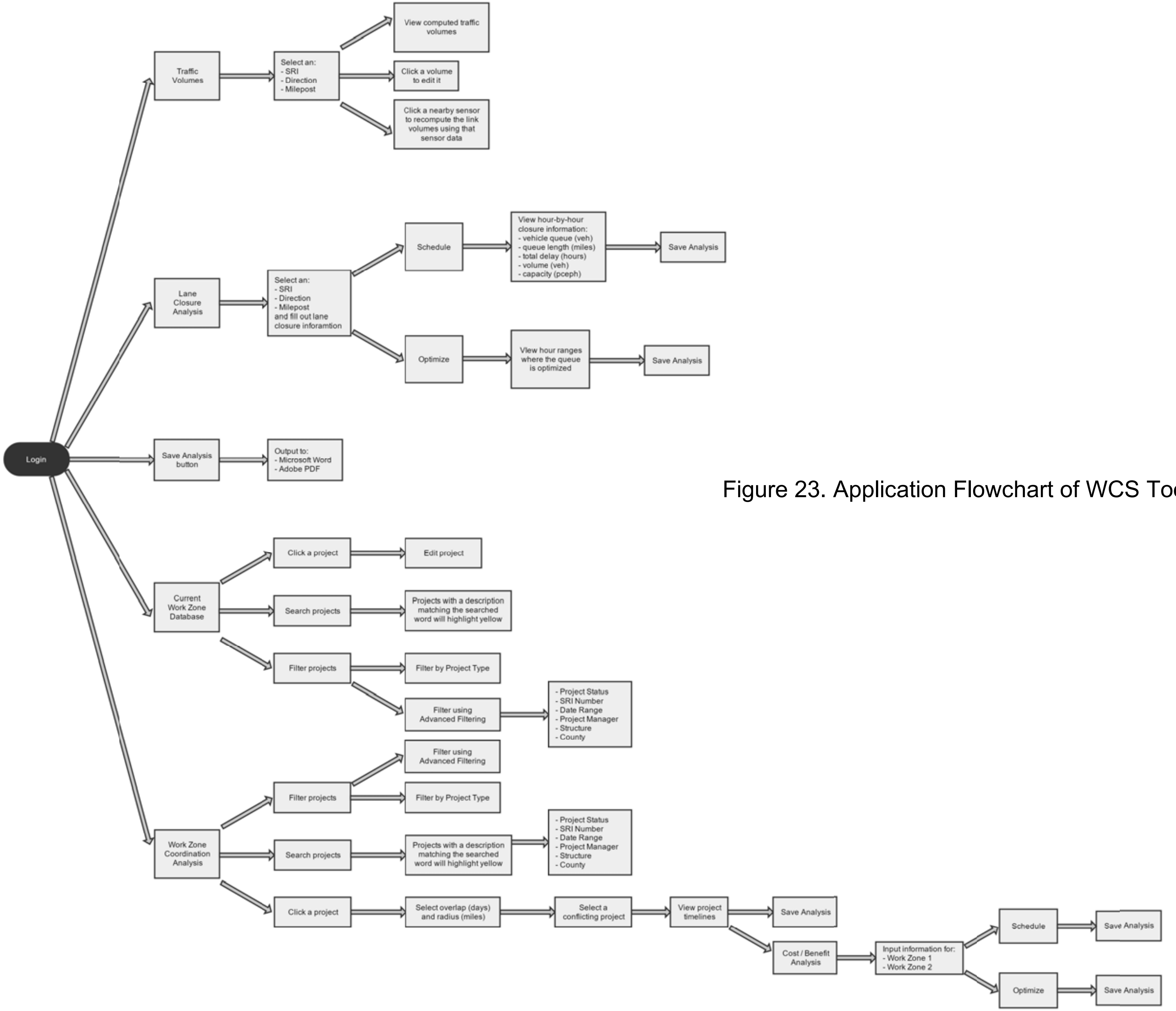


Figure 23. Application Flowchart of WCS Tool

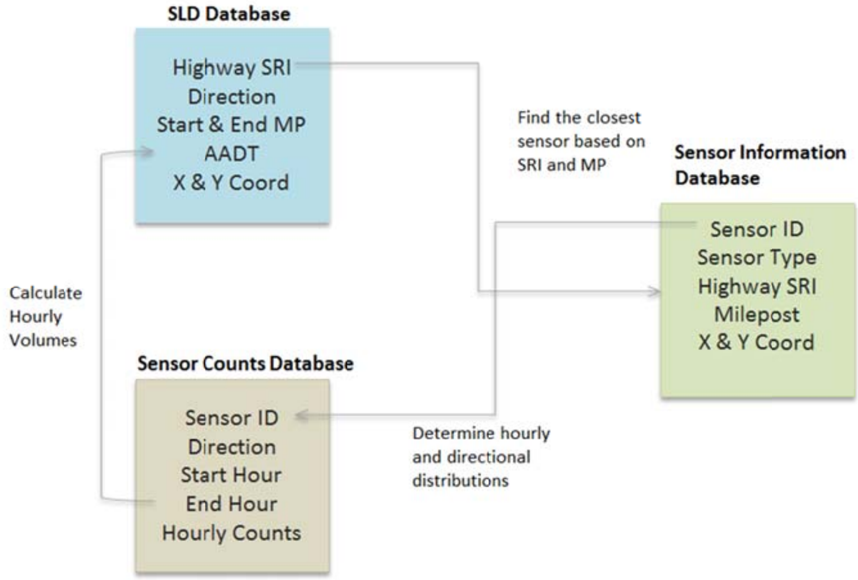


Figure 24. Flowchart of Hourly Link Volume Estimation

The C programming code developed by the research team finds the closest sensor to each highway link in the SLD database by using the X & Y coordinates in SLD database and Sensor Information database. After identifying the sensor ID, the code then matches the sensor ID in the Sensor Counts database and extracts the hourly counts, and determines the directional flow and hourly distribution. AADT information available in the SLD dataset is converted to hourly volumes by:

$$Hourly\ Volume\ [i] = AADT * Directional\ Flow[i] * Hourly\ Distribution[i] \qquad (19)$$

Where i stands for hour of the day, i =1, … , 24.

Several assumptions were used to generate hourly volumes:

- If the highway does not have any sensor data then obtain hourly and daily factors from a closest highway that contains a sensor in the same direction.
- Weekdays (Monday-Friday) have the same hourly factor distributions; Weekends (Saturday and Sunday) have the same hourly factor distributions.
- There are only two daily factors that represent the change in daily traffic volume for weekdays and weekends. Therefore, the daily volume for any given weekday is the same.
- Since traffic counting stations have AADT values obtained in various years, these values are converted for year 2014 using an annual traffic increase of 2%.

The research team calculated the hourly volumes for each highway segment in the NJDOT SLD database. This information is input into the WCS tool. It should be noted that the validity of hourly volumes in the WCS tool depends on the accuracy of sensor counts and the AADT values in the SLD database. WCS tool, as explained in detail below, allows users to use second or third closest sensor to the selected highway link, in case the closest one has faulty or unreliable counts, or allows users to replace the estimated hourly volumes with observed ones. In addition, the tool also flags link volumes that have excessively high traffic volumes (e.g. 2500 vehicles per hour per lane).

The following subsections present a step-by-step guidance on how to use the WCS tool.

Getting Started

In order to access the WCS tool, enter http://128.6.237.242/WorkZone/login.php on your browser's address bar. The following log on screen will appear.

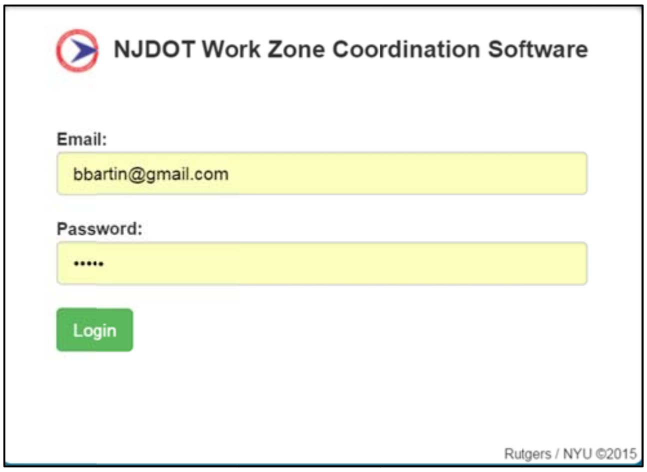


Figure 25. Log on Screen

Once the correct credentials are entered, the start screen as shown in Figure 26 will appear. The start screen includes the four key modules of the WCS tool, namely

- Traffic Volumes,
- Lane Closure Analysis,
- Current Work Zone Database,
- Work Zone Coordination Analysis.

The next subsections describe each module.

In addition, on the home screen, there is a tray icon, , which indicates the number of reports generated by the user, and a Feedback link, when clicked it takes image of the screen and allows users to comment on any issue that they seem problematic. Any issues raised by users using the Feedback link are sent directly to the Rutgers / NYU research team via e-mail.

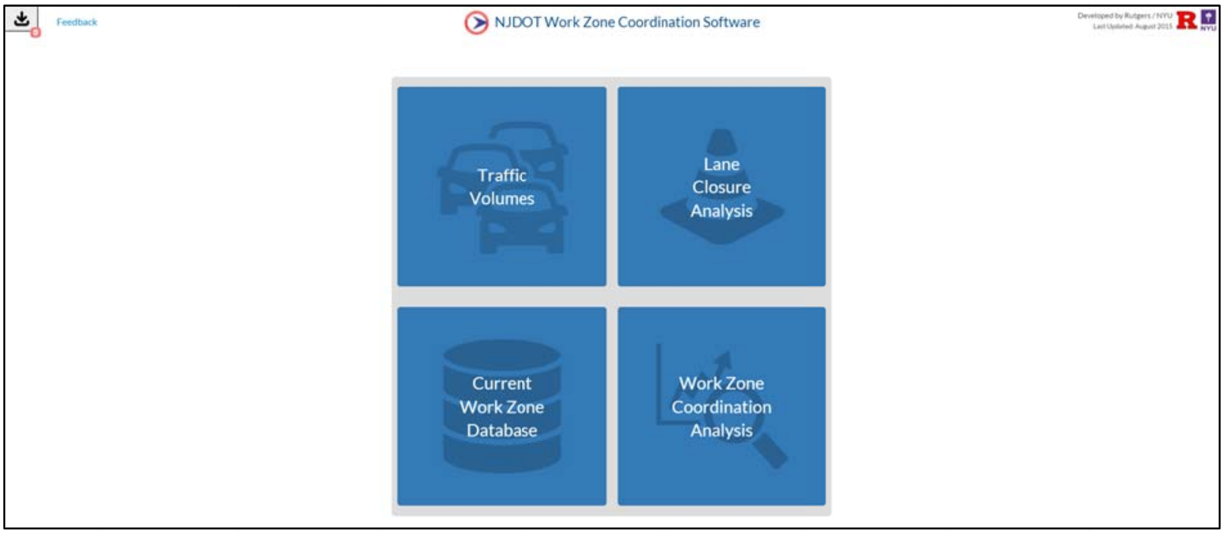


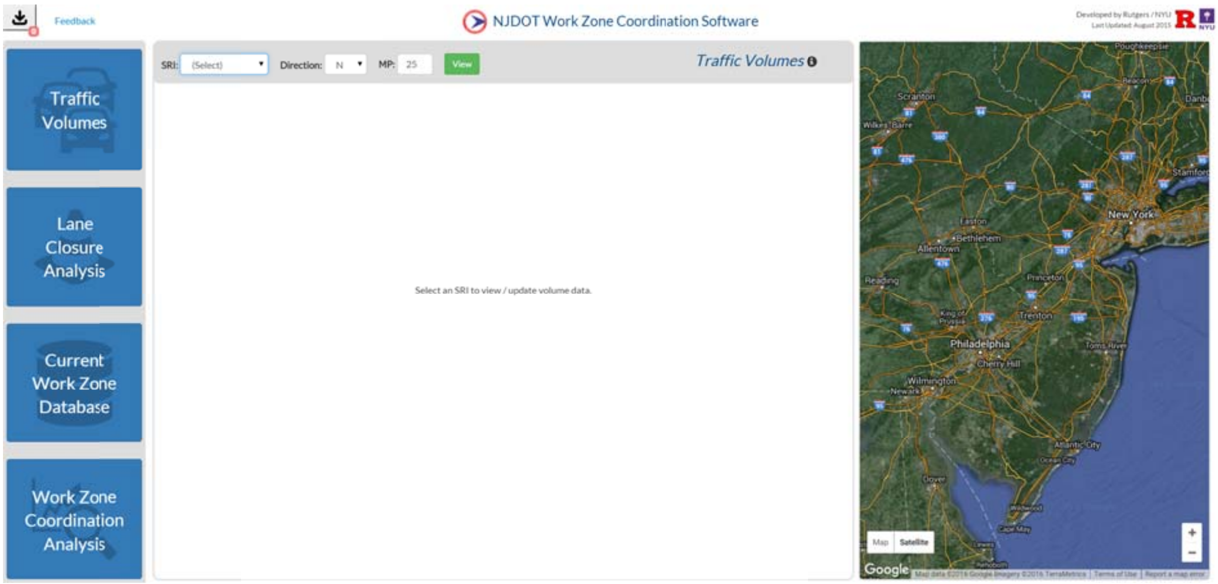
Figure 26. WCS Home Screen

Traffic Volumes

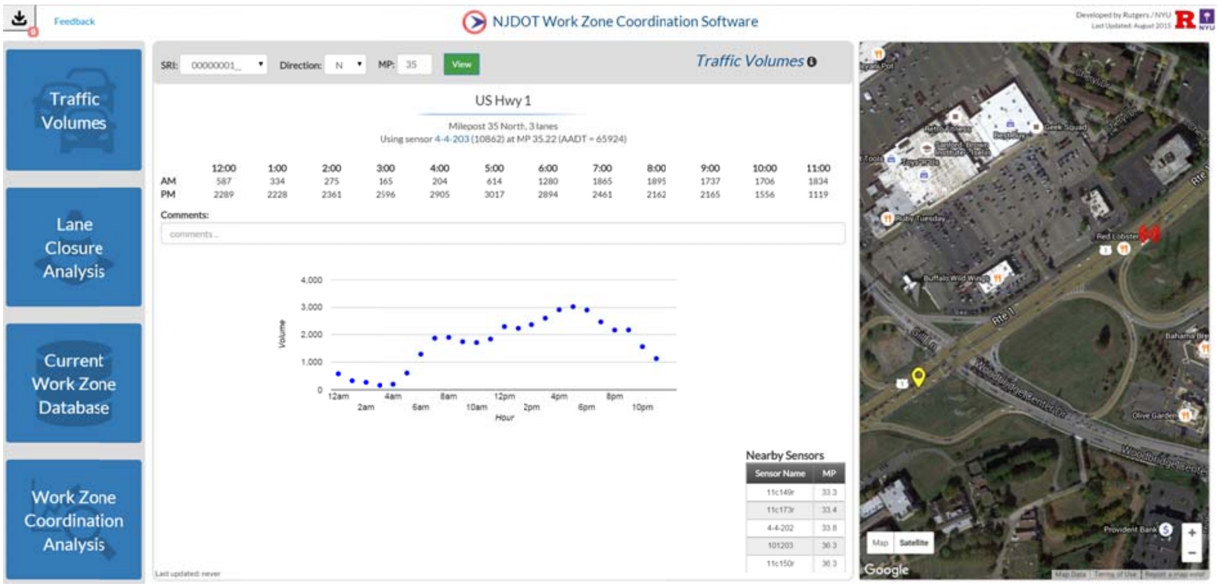
This module is used to find the hourly volumes on NJ highways. As mentioned before, hourly traffic volumes are calculated using the AADT values shown in each link within the SLD database and the short term sensor count database.

Figure 27a shows the start screen when the Traffic Volumes module is selected. As shown, the buttons for the four key modules are lodged to the left of the screen for easy access. From the dropdown menu, users can select any highway using the SRI number, travel direction and specify the milepost number. When the View button is clicked, hourly volumes on the selected location are shown along with the location of the link in Google Maps. Figure 27b shows the case when milepost 35.0 on Route 1 northbound is selected from the dropdown menu.

Several remarks are needed at this point. First, there are two items shown in the Google Maps window: one is the location of the selected link, shown by the pushpin, and the other one is the sensor that is closest to the selected link. The name of this sensor is shown above the hourly volumes table as 4-4-203 with ID number 10862, located at milepost 35.22. Also, the AADT and the number of lanes of the link are shown as 65,924 and 3-lanes, respectively. These values are imported from the SLD database.



(a)



(b)

Figure 27. (a) Traffic Volumes Start Screen (b) Traffic Volumes for Selected Highway Link

The actual sensor readings can be reached by simply clicking on the name of the sensor, 4-4-203 in this case. Once clicked, a pop-up window with the hourly sensor counts will appear. As explained earlier, these sensor readings are used to calculate the hourly percentages and directional distributions in equation (19).

At the bottom right of the results window, there is a list of nearby sensors. These are the other close sensors to the selected link, sorted in ascending order based on proximity. For example, if users would like to calculate the hourly volumes based on the second closest sensor, 11c149r in this case, then they can simply click on the name, and the results will update themselves based on the readings of this selected sensor.

As mentioned before, the validity of the hourly volumes for the selected locations depend on the accuracy of the link's AADT value and the sensor readings. For some reason, if the hourly values seem out of the ordinary, users can include their comments at the bottom of the hourly volumes table. In addition, if up-to-date hourly volume data is available for the selected link, users can change the contents of the table simply by clicking on each cell and changing the values.

Lane Closure Analysis

This module of the WCS tool is used to generate the delays and queues resulting from a particular lane closure scenario. The estimation of delay and queue due to lane closure is based on the Road User Cost Model developed by Urban Engineers, Inc. for the NJTA, as shown below:

If a particular lane is closed, the capacity is calculated using the calculations specified in the Road User Cost Model developed by Urban Engineers, Inc. Capacity is calculated as follows:

Work Zone Capacity = Normal Operating Capacity * (1 - (12 - *lane width*) * (0.1)) * *number of lanes*

For a given hour the queue and delay are calculated as follows:

If Volume > Capacity
  Queue = (Volume – Capacity) + Queue

If Capacity > Volume
  Queue = 0

Delay = (Delay+ (Queue / Capacity))*0.5

Figure 28 shows the start window for this module. As done in the Traffic Volumes module, the SRI number, the direction of travel and the milepost for the desired link is input, and the details for the proposed lane closure is inserted in the respective boxes. Users can either schedule a lane closure between pre-set hours using the Schedule option, or find the optimal start and end hours using the Optimize option.

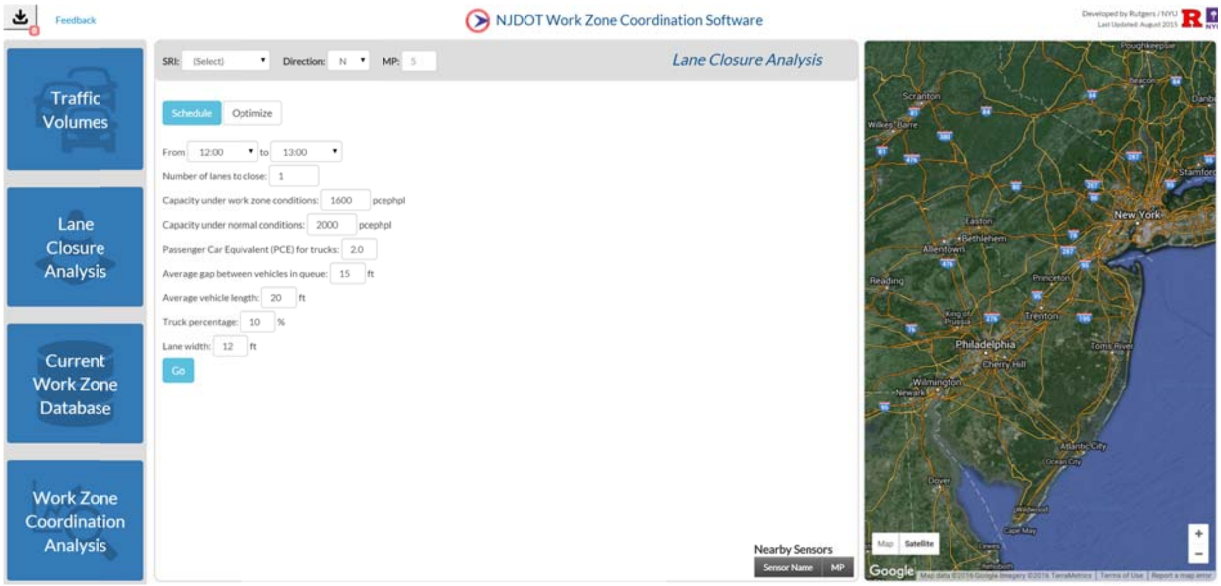


Figure 28. Lane Closure Analysis Start Window

The required parameters for lane closure analysis include the start and end time of lane closure, number of lanes closed, capacity under normal and work zone conditions, passenger car equivalency, average gap between vehicles, average vehicle length, truck percentage and lane width. These parameters are used to estimate delay and vehicle queue lengths.

For example, if we select Route 1 northbound at milepost 10.0 and close 1 lane for work zone between 7 am and 8 am, using the default parameters, we get the estimated impact as shown in Figure 29. The scatter plot in the figure shows hourly volumes on the selected work zone. The highlighted dot(s) represent the work zone hours. The capacity difference between signalized and un-signalized roadways was not considered here and can be developed in future enhancement of tool.

Results show that one lane closure between the selected hours result in a vehicle queue length of 4.5 miles due to reduced capacity, and the queue dissipates between 8 am and 9 am. Results also show the estimated total delay due to lane closure.

The Optimize button is used when users prefer determining the optimal time period to conduct a lane closure. Figure 30a shows the parameter window for this application. Users can input the work zone duration, which periods the lane closure should not take place, maximum allowable queue lengths, etc. For the same example above, suppose that we would like to find out the optimal 1-hour of lane closure at Route 1 northbound at milepost 10, and specify that the maximum allowable queue is 2 miles, we simply enter these values as shown in Figure 30a, and click on the Go button.

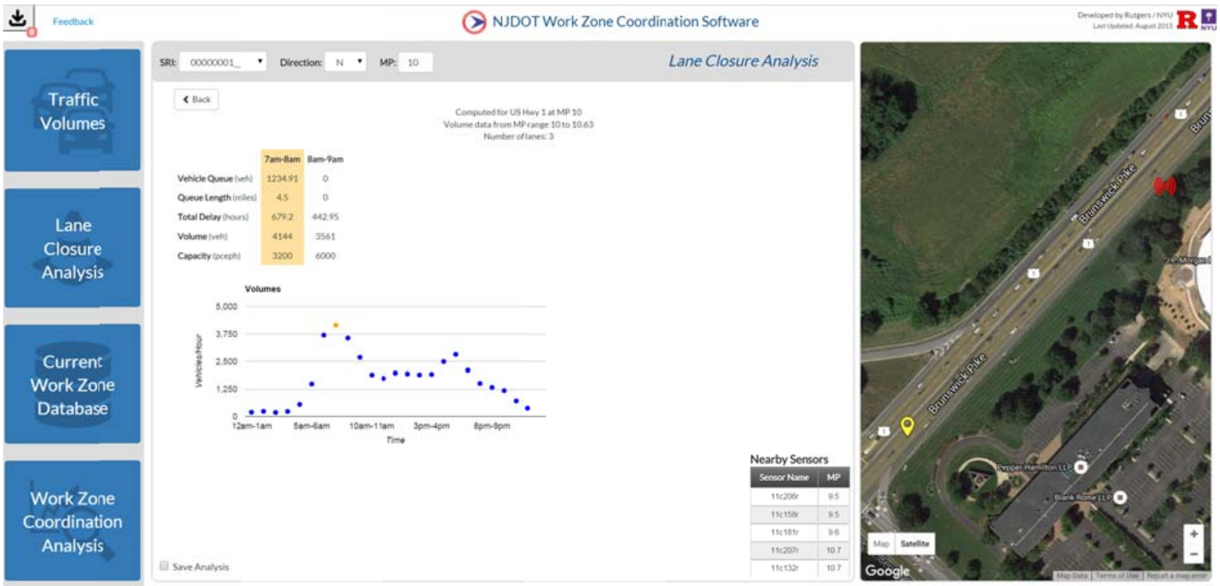


Figure 29. Results of a Hypothetical Lane Closure Analysis

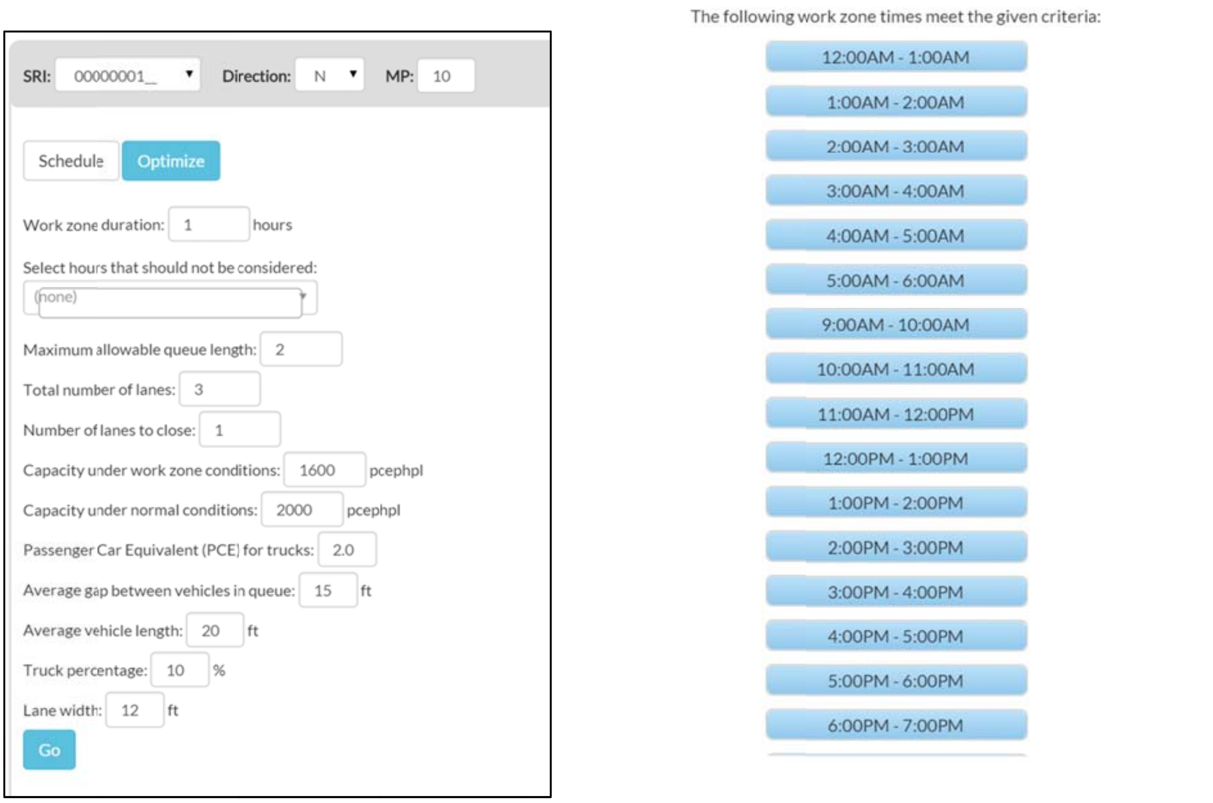


Figure 30. Optimization of Lane Closure Analysis (a) Input Window (b) Results Window

The optimal hours are calculated by the program and displayed as shown in Figure 30b. Users can click on each alternative to see the delay and queue results. It should be noted that the number of alternative hours will decrease as the restrictions, such as the maximum allowable queue length is reduced and / or allowable work zone hours.

Users can check the Save Analysis box located at the bottom left of the screen, as shown in Figure 29 to save the results. Once this checkbox is selected, the number located on the tray icon will increase by one. Users can click on the tray icon anytime to report the results in PDF or MS Word format.

<u>Current Work Zone Database</u>

This module is to visualize the current WCS database that includes not only the up-to-date OpenReach database provided by TRANSCOM, but also the CPM PRS tool, as depicted in Figure 21, the work zone coordination framework. It should be iterated that the OpenReach database is updated automatically via XML feeds from TRANSCOM, and the PRS database is updated manually at every month. One month period is sufficiently up-to-date for the CPM projects because, compared to other type of projects CPM projects are not updated frequently.

The start screen of this module shows a list of projects and their locations on the Google Map, located to the right of the project list, as shown in Figure 31. In the large scale view of the NJ map, the projects that are nearby are clustered, and the number on each circle represents the number of projects in each cluster. Once zoomed in, each project location can be seen separately. Users can hold the cursor over each circle and read project display titles.

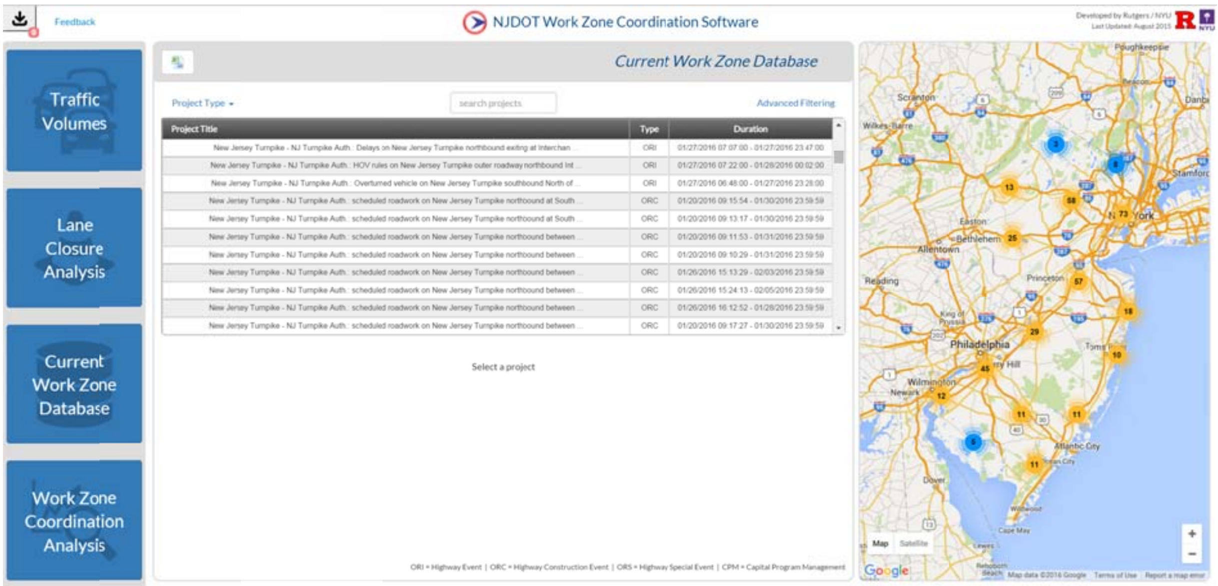


Figure 31. Current Work Zone Database Start Window

Users can select any project from the list by clicking on the project title. Description of the selected project will appear below the project list table, and the map will zoom in to the location of the selected project. Description of the project includes general information such as the display title, project description, notes/updates, the responsible NJDOT division and the location and duration information.

The listed projects have four (4) types:

ORI: Highway Event, ORC: Highway Construction Event, ORS: Highway Special Event, and CPM: Capital Program Management. The first three types are imported from OpenReach database, and the latter is imported from the PRS database.

Users can sort the project list based on these project types simply by selecting the desired project type from the Project Type dropdown menu. User can also search a keyword within the project description of the listed projects, or use the Advanced Filtering link, as seen in Figure 32. Users can filter the project list based on SRI number, project status (CPM projects only), date range, project manager (CPM projects only), structure number, and county.

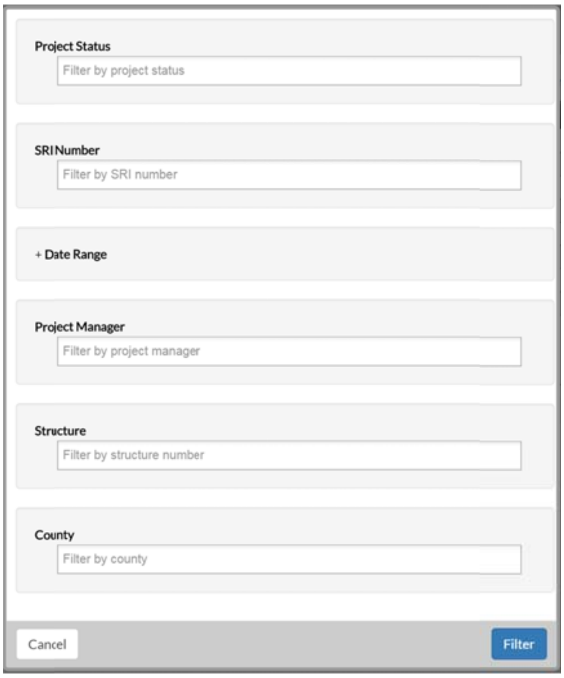


Figure 32. Advanced Filtering of Projects

Users can also download the up-to-date project list simply by clicking on the MS Excel icon located at the top left corner of the screen, as shown in Figure 31.

Work Zone Coordination Analysis

This module is used to determine if a work zone is in conflict with another work zone in its vicinity. The start window of this module is the same of Current Work Zone Database module shown in Figure 31.

Once a project is selected from the project list, it prompts a conflict analysis window, as shown in Figure 33. Conflict analysis is conducted by using two parameters: (a) Overlap period and (b) Radius. In searching conflicting projects, the tool finds out if two projects are closer to each other than the radius distance and overlap by more than the specified number of days. For instance if days overlapped is 3 days and radius is 10 miles, it determines if there any projects within 5-mile radius of the selected project that overlaps at least 3 days. These parameters can be adjusted simply by moving the sliding bar. It should also be mentioned that the details of the selected project can be viewed by hovering the mouse on the project display title within the conflict analysis window.

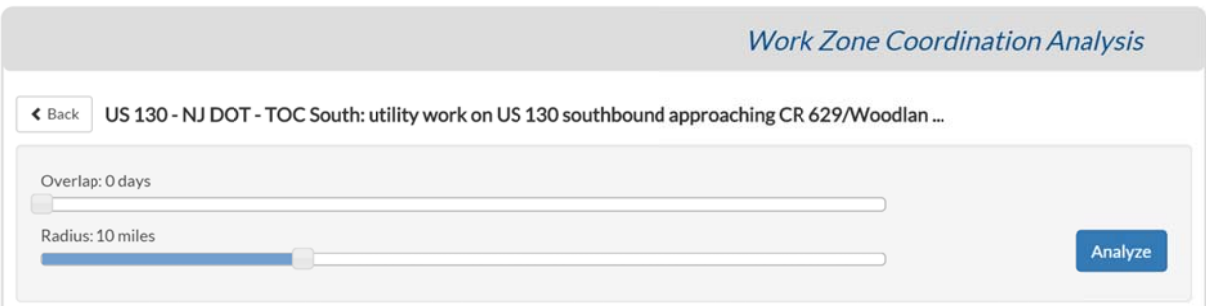


Figure 33. Conflict Analysis Window

After selecting the two conflict parameters, the user can click on the Analyze button located at the bottom right corner of the conflict analysis window, as shown in Figure 33. This prompts the tool to search the existing project list and determine, based on the days overlapped and radius parameters, if any of the other projects is possibly in conflict with the selected project.

If any work zones that are possibly in conflict are detected these are listed in a table format. Figure 34 shows the list of conflicting projects based on the selected project and the parameters selected in Figure 33.

The list shows which work zones are in conflict with the selected one, how many days they overlap, how far they are from the selected work zone, and their start and end dates. These projects can be either on the same roadway or on alternative roadways, as explained in Cost Saving Analysis section.

The validity of these potential conflicts needs to be verified by the user. WCS tool simply identifies the presence of other work zones in the vicinity of another work zone. It is up to the users' expertise to determine if one of the listed work zones in fact is an actual conflict. For example, two work zones can be on the same roadway and very close to each other, but on different traveling directions. Then the user would eliminate this work zone as a conflict. For example, in Figure 34, the last project on the list is the same work being conducted on the opposite direction of US 130. Similarly, two projects can be on different roadways yet close to each other. It is not possible for the tool to determine if these two roadways are alternative routes to a destination, but an experience user can identify this easily using his/her expertise.

Project	Overlap	Distance from Start	Distance from End	Duration
New Jersey Turnpike - NJ Turnpike Auth.: Construction, construction on New Jersey Turnpike inner roadw ...	3 days	7.69 miles	7.69 miles	01/27/2016 18:09:00 - 02/11/2016 14:15:40
New Jersey Turnpike - NJ Turnpike Auth.: scheduled roadwork on New Jersey Turnpike northbound between ...	4 days	7.77 miles	7.77 miles	01/20/2016 09:10:29 - 01/31/2016 23:59:59
New Jersey Turnpike - NJ Turnpike Auth.: scheduled roadwork on New Jersey Turnpike northbound from Inn ...	3 days	7.69 miles	7.69 miles	01/26/2016 12:37:22 - 01/28/2016 23:59:59
NJ 38 - NJ DOT - TOC South: roadwork on NJ 38 both directions West of CR 615/Marter Rd (...	4 days	6.18 miles	6.18 miles	12/31/2015 08:18:45 - 08/16/2016 23:59:59
US 130 - NJ DOT - TOC South: utility work on US 130 northbound at CR 629/Woodlane Rd (Edg ...	3 days	0 miles	0 miles	01/26/2016 10:43:05 - 01/28/2016 23:59:59

Figure 34. List of Conflicting Projects

Once the user is sure that any of the listed work zones is a valid conflict, then the potential work zone is selected from the list. When a project is selected from the list, a pop up window is prompted as shown in Figure 35. Here, the user can view the details of each work zone by hovering on the project display title. For example, in this specific case, the first project is a utility work on US 130 in the southbound direction that requires a right lane closure between 9 am and 3 pm from January 26, 2016 till January 29, 2016. The second one is construction work on NJ 38 that requires one-lane closure on both directions between 6 am and 3 pm from December 31, 2015 until August 16, 2016.

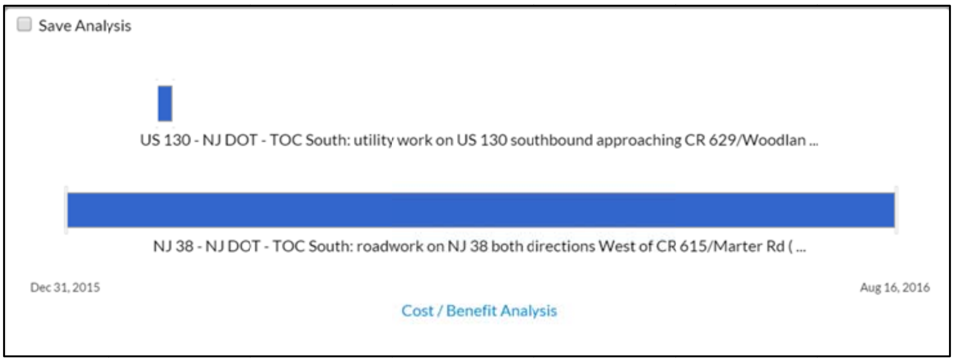


Figure 35. Time Table of Two Conflicting Work Zones

As mentioned above, the tool cannot determine if these two roadways are alternative routes to a certain destination(s). However, if the user decides that they are in fact alternative routes, this specific case constitute a good example for coordination purposes. The first project is a short term utility project, and the second one is a long term construction project that takes place between overlapping hours for four days. If the user decides that the two projects are in conflict with each other, the short term project can move to another hour. However, in order to make a decision, the user needs to find out if this coordination has potential benefits or not. Cost benefit analysis is required to assess the benefits of such coordination.

Cost benefit analysis window is prompted when the Cost / Benefit Analysis link, shown in Figure 35, is selected. This application starts with the first work zone, namely the utility work on US 130 southbound in this example. This window is similar to the input parameter window in the Lane Closure Analysis module, where the user is asked to input the number of lanes closed, percentage of trucks, value of time for passenger cars and trucks, duration and time period of the work zone, capacity under work zone and normal conditions, etc. Note that number of lanes and work zone duration information for work zone 1 are included in the window as a reminder, as shown in Figure 35. Here, the complete project information can be viewed by hovering on the Work Zone 1 link.

It should be mentioned that in Figure 36 the Lanes Closed is shown automatically as zero (0), yet the *number of lanes closed to traffic* parameter is filled as one (1). This is because of the fact that when the project details are input in OpenReach, lanes closed section is sometimes left empty but the number of lanes closed information is written in project description text. Therefore the user should pay attention to the information within the text as well.

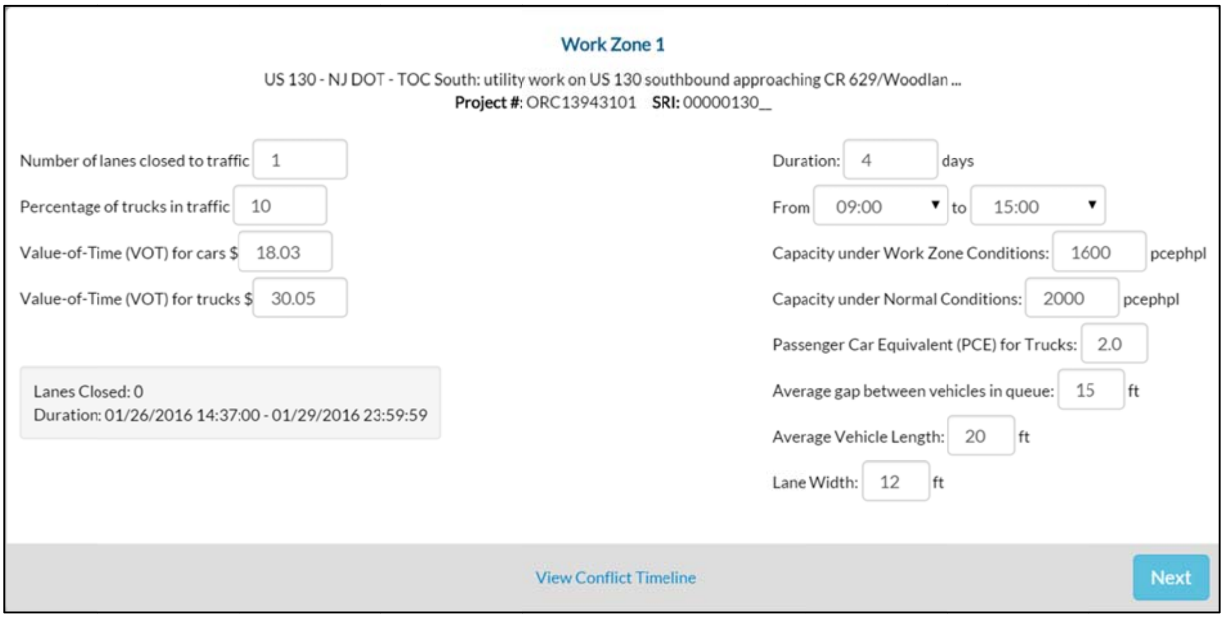


Figure 36. Cost Benefit Analysis Input Window for Work Zone 1

When the user clicks on Next, input for Work Zone 2 is asked, as shown in Figure 37. After entering the required information in this window, the user clicks on Next to view the summary of both work zones, and asked if there is any opportunity for coordination between these two projects, as shown in Figure 38.

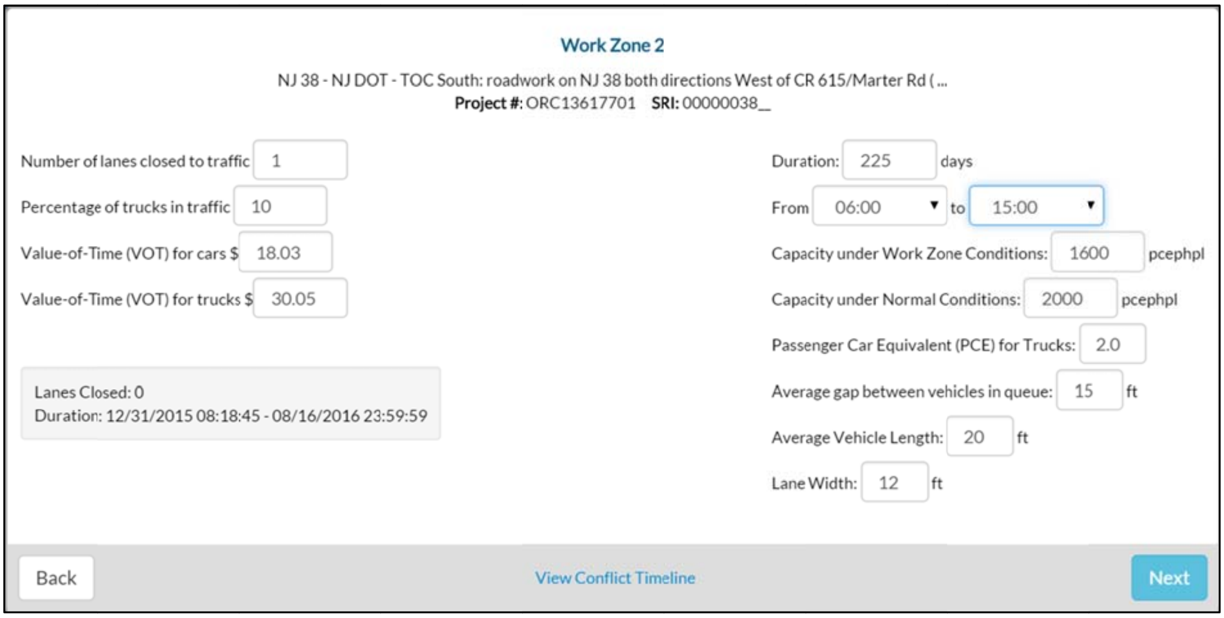


Figure 37. Cost Benefit Analysis Input Window for Work Zone 2

If the user decides that there is an opportunity for coordination of the two work zones and selects Yes from the dropdown menu, the tool prompts another question, asking "Which project do you want to reschedule?" In this specific example, it is more feasible to change the work hours of Work Zone 1, namely US 130 utility work, since it is a short term work zone, the user selects US130-NJDOT from the menu. The next question that appears after is if the user assumes a diversion from NJ 38 to US 130, now that there will be no work zone on US 130 when there is a work zone on NJ 38, and familiar drivers can divert to US 130 if congestion occurs. If the user assumes a diversion then an assumed diversion percentage is entered, as shown in Figure 38.

Here, the user can either reschedule US 130 project manually using the Reschedule button, or let the tool find the best hours automatically by pressing the Optimize button. This option is similar to the one in the Lane Closure Analysis module.

When Reschedule button is pressed, the tool allows the user to change the work zone hours, as shown in Figure 39.

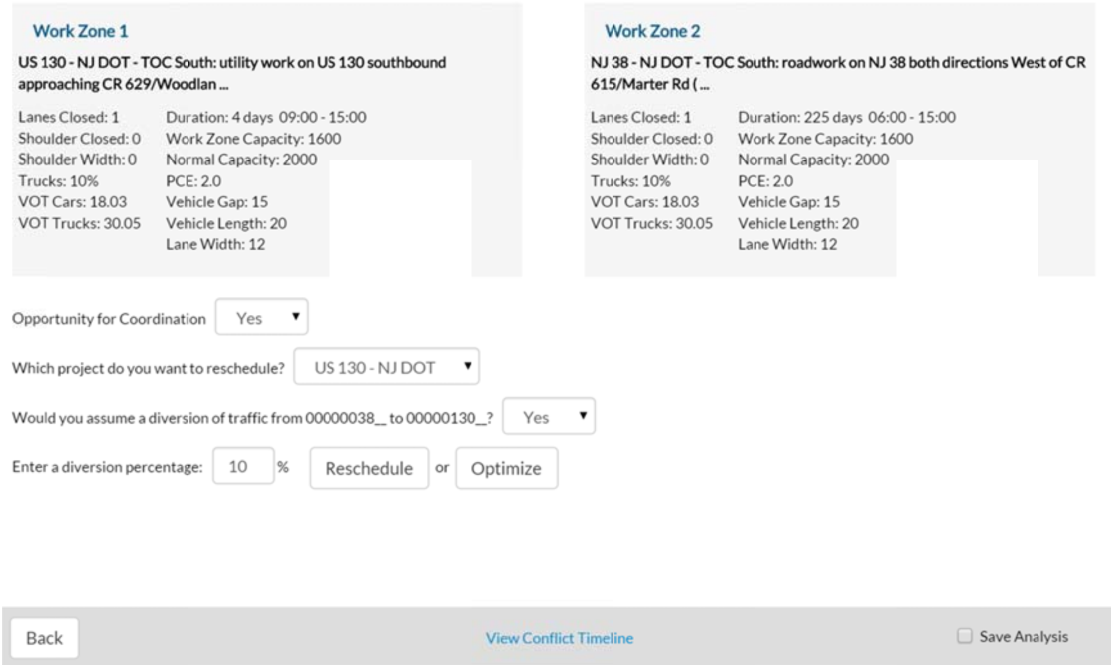


Figure 38. Cost Benefit Analysis Coordination Decision Window

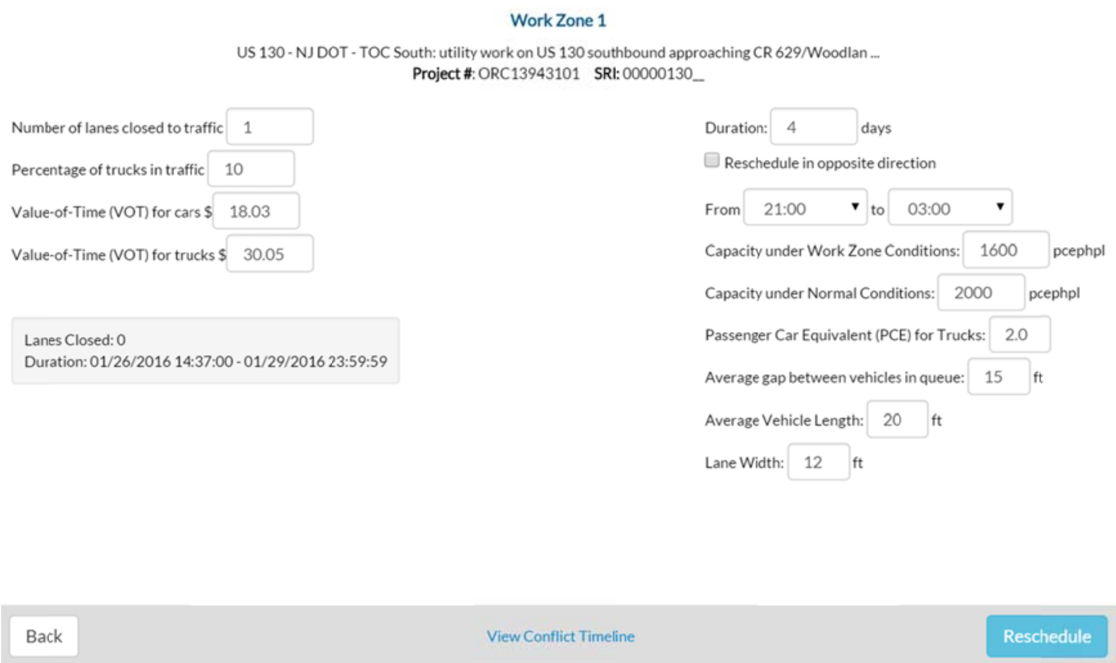


Figure 39. Cost Benefit Analysis Rescheduling Window

In the rescheduling window, the user must select the same number of work zone hours as the original. For example, the original work hours for the US 130 project is from 9 am to 3 pm, so the rescheduled hours should be six hours in total. As shown in Figure 39, the rescheduled hours for Work Zone 1 are set as from 9 pm to 3 am. Once the user clicks the Reschedule button, the tool calculates the estimated benefit of rescheduling the US 130 project to another selected period, as shown in Figure 40.

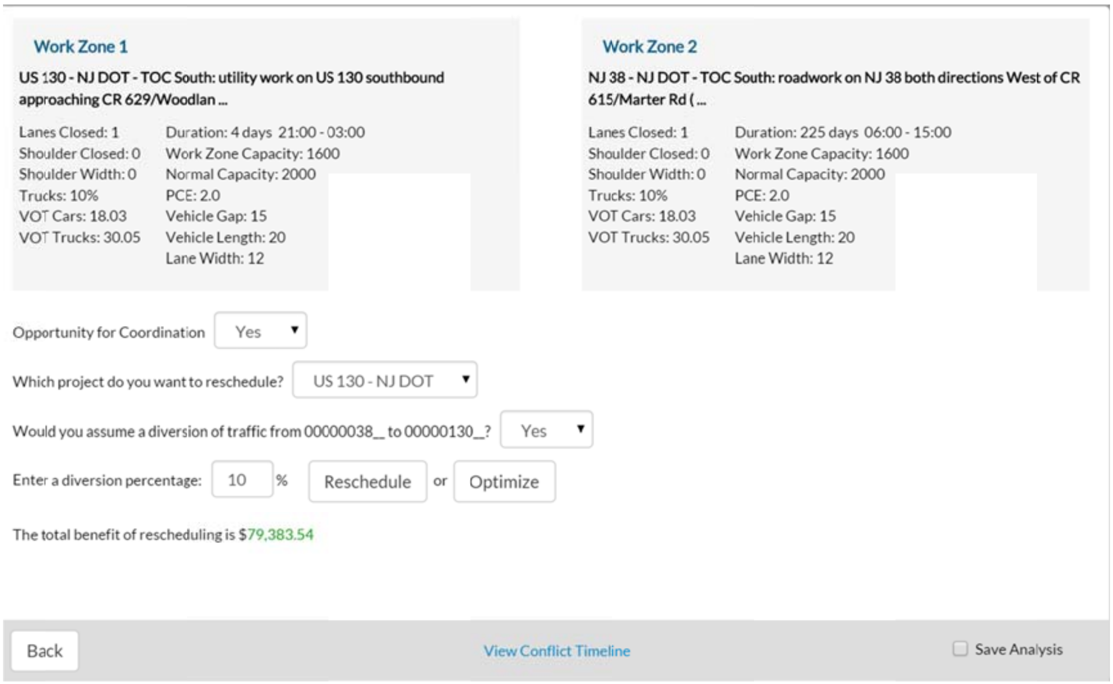


Figure 40. Cost Benefit Analysis Result Window

The benefit, $79,383 shown in the cost benefit analysis result window is calculated based on the delay estimation procedure shown in the Appendix and the value of time unit costs shown in Table 10.

One would expect that rescheduling a work zone comes with a cost. The **cost** of work zone coordination is the “penalty” of rescheduling one work zone (coordination) or integrating it in another work zone (consolidation). These costs are not readily available as they might from work zone to work zone. This estimate will be obtained from the project managers, since they will have the most accurate cost of rescheduling work zones.

If the estimated cost is less than the estimated benefit of coordination, the user can decide to “initiate” communication between the involved parties.

SUMMARY AND CONCLUSIONS

The increasing number of work zones adversely affects the mobility and safety of travelers on already congested roadways. Drivers are constantly faced with unfavorable road conditions and unexpected delays due to work zones. Faced with growing number of work zones, the challenge for transportation agencies is to effectively manage the impacts of work zones to alleviate congestion and maintain the safety of motorists without disrupting project schedules.

A review of work zone coordination by other states is presented in the Current State of Practice section of this report. It was found that there are no universal DOT policies that address how agencies should coordinate or consolidate projects. In addition, only a few states utilize computer tools specific to regional or corridor based work zone coordination. State DOTs mostly coordinate significant and long-term projects. However, the majority of roadway projects include minor repair, roadway maintenance, bridge maintenance, surveying, landscape and utility work that require relatively short term work zones. There are more maintenance and minor repair projects than major overhaul or expansion projects.

The research team carefully reviewed the NJDOT state-of-practice. The review is based on the interviews with NJDOT experts. Based on the interviews, it can be stated that the CPM project managers are in close communication during the project screening process, and therefore they are well aware of any other conflicting CPM projects in close proximity. However, because there is no combined and accessible-to-all database of work zones, it is not a straightforward task for all divisions to coordinate with each other.

The project team, after consulting with the project panel and the NJDOT Mobility and Systems Engineering division, devised a work zone coordination framework that utilizes one common work zone database. Initially, the coordination framework involved two stages: Stage 1 included long-term coordination and Stage 2 included short-term coordination. Stage 1 takes advantage of the fact that Maintenance Engineering projects are known in the beginning of the each year. These projects get awarded and completed within less than a year. In this stage, it was initially proposed to create a database for aforementioned projects and make them visible to the decision makers and coordinate Maintenance projects around CPM projects. Stage 2 aimed to coordinate all work zones including CPM projects and maintenance projects in the short term.

The research team developed the Work Zone Coordination Spreadsheet (WCS) tool. WCS is an online user-friendly computer tool that is developed for providing NJDOT with an easy-to-use way to evaluate the feasibility and effectiveness of coordinating short and long term work zones and measure the benefits of various combinations of projects relative to each other and the do-nothing scenario.

The key functional requirements of the tool identified as a result of the review of the current state of practice in the US, interviews with NJDOT experts and a number of meetings with prospective users of the tool can be listed as follows:

- Integrate all scheduled and active construction projects in the OpenReach Database and planned CPM projects.
- Implement as an online tool that can be modified simultaneously by multiple users
- Identify conflicts between work zone projects
- Send conflict notification to involved parties
- Be visible to all responsible parties
- Offer varying user accessibility privileges
- Estimate the benefits of conflict mitigation
- Have the ability to save the analyses in a report format to be shared with the decision makers.

Details on how to use the WCS tool are presented in the Work Zone Coordination Spreadsheet Tool section of the report. The tool is operational and being used by NJDOT. Rutgers / NYU team will continue to provide technical support to the users of the tool. This includes providing access to new users, fixing minor bugs, and ensuring that the tool remains available throughout this initial testing period.

Future work is needed to continue the day-to-day maintenance and development of the tool based on the actual experiences of its users. One improvement will be automated the acquisition of all work zone project data from NJDOT in addition to the OpenReach database. Similarly, the acquisition of traffic data can be improved to incorporate different on- and off-line databases maintained by NJDOT. This can be done given the current flexible database architecture of the WCS tool. Finally, additional coordination and consolidation related tasks can be added based on the needs of the users of the tool to enhance the effectiveness of work zone operations in New Jersey.

REFERENCES

1. U.S. Department of Transportation, Federal Highway Administration, *Moving Ahead: The American Public Speaks on Roadways and Transportation Communities*. FHWA-OP-01-017. Washington, D.C., 2001.
2. Bureau of Transportation Statistics "National Transportation System" http://www.bts.gov/publications/national_transportation_statistics/, Accessed on December 3, 2011.
3. U.S. Department of Transportation, Federal Highway Administration, *Developing and Implementing Transportation Management Plans for Work Zones. FHWA-HOP-05-066.* Washington, D.C., 2005.
4. National Cooperative Highway Research Program. *Highway Construction Coordination to Minimize Traffic Impacts*. Project No: 08-36, Task 56. August 2006.
5. U.S. Department of Transportation, 2006 Status of the Nation's Highways, Bridges, and Transit: Conditions & Performance, Report to Congress. Washington, D.C., 2006.
6. New Jersey Department of Transportation (NJDOT) Website. www.state.nj.us/transportation.
7. U.S. Department of Transportation, Federal Highway Administration Website http://ops.fhwa.dot.gov/trafficanalysistools/
8. National Cooperative Highway Research Program. *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan. Volume 17: A Guide for Reducing Work Zone Collisions*. NCHRP Report 500, 2005.
9. Federal Highway Administration. Synthesis of Procedures to Forecast and Monitor Work Zone Safety and Mobility Impacts, 2005.
10. Tony Coleman. FHWA Webinar. "ODOT Work Zone Project Coordination." Oregon Department of Transportation, September 24, 2012.
11. Welke B. and Rafferty P. "Work Zone Project Coordination Michigan's I-94 Corridor and the Great Lakes Megaregion." Great Lakes Regional Transportation Operations Coalition, September 24, 2012.
12. GLRTOC Website, http://www.glrtoc.org/workzones/wzim/
13. Federal Highway Administration. Work Zone Best Practices Guidebook. Available online at http://ops.fhwa.dot.gov/wz/practices/practices.htm. Accessed on December 3, 2011.
14. Scriba T. "Implementation of Transportation Management Plans (TMPs)." Federal Highway Administration AASHTO Design Meeting, July 15, 2008.
15. CALTRANS Website, http://www.dot.ca.gov/dist11/d11tmc/sdmap/speeds/laneclosures.html
16. H. Ramezani, R. F.Benekohal and K. A. Avrenli. "Determining Queue and Congestion in Highway Work Zone Bottlenecks." Report No 046IY02. NEXTRANS Center, Purdue University, West Lafayette, IN, 2011.
17. Hardy, M. H., Larkin, J. J., and Wunderlich, K. E., *QuickZone A Work Zone Delay* Estimation and Analysis Tool, ITS America Annual Meeting, April 2002.
18. Website, http://ops.fhwa.dot.gov/wz/traffic_analysis/quickzone/

19. Lee C. and Noyce A. D. “Work Zone Capacity and Analysis Tool (WZCAT) Calibration/Validation”. Report No. 200700, Wisconsin Department of Transportation Statewide Traffic Operations Center, Milwaukee, WI, 2007.
20. Ozbay, K. and Bartin, B. (2008) “Development of Uniform Standards for Allowable Lane Closure” New Jersey Department of Transportation Research Report FHWA-NJ-2008-014.
21. Bartin, B., Ozbay, K. and Mudigonda, S. (2012)“ Interactive Lane Closure and Traffic Information Tool Based on a Geographic Information System.” *Transportation Research Record: Journal of the Transportation Research Board*. Vol. 2272. pp. 44–55.Jiang, X. and Adeli, H. (2004), "Object-Oriented Model for Freeway Work Zone Capacity and Queue Delay Estimation." Computer-Aided Civil and Infrastructure Engineering. 19(2), pp. 144-156.
22. Schroeder B. J. and Rouphail N. M. “Estimating Operational Impacts of Freeway Work Zones on Extended Facilities”. Transportation Research Record: Journal of the Transportation Research Board, No. 2169, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 70–80.
23. Bartin B., Ozbay K., and Mudigonda S. “Interactive Lane Closure and Traffic Information Tool Based on a Geographic Information System” Transportation Research Record: Journal of the Transportation Research Board, No. 2272, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 44–55.
24. Edara, P., Kianfar, J., and Sun, C. “Analytical Methods for Deriving Work Zone Capacities from Field Data”. Journal of Transportation Engineering, Vol. 138, No. 6, June 1, 2012, pp. 809-818.
25. M. J. Cassidy and L. D. Han, "A Proposed Model for Predicting Motorist Delays at Two-Lane Highway Work Zones," *Journal of Transportation Engineering,* vol. 119, no. 1, pp. 27-42, 1993.
26. Y. Jiang, "Traffic Characteristics and Estimation of Traffic Delays and User Costs at Indiana Freeway Work Zones," Indiana Department of Transportation, 1999.
27. S. Chien and P. Schonfeld, "Optimal Work Zone Lengths for Four-lane Highways," *Journal of Transportation Engineering,* vol. 127, no. 2, pp. 124-131, 2001.
28. X. Jiang and H. Adeli, "Freeway Work Zone Traffic Delay and Cost Optimization Model," *Journal of Transportation Engineering,* vol. 129, no. 3, pp. 230-241, 2003.
29. G. F. Newell, "Traffic Flow in the Morning Commute," Transportation Science, vol. 22, no. 1, pp. 47-58, 1988.
30. G. Weiss and A. Maradudin, "Some Problems in Traffic Delay," *Operations Research,* vol. 10, pp. 74-104, 1962.
31. W. Brilon and N. Wu, "Delays at Fixed-Time Traffic Signals under Time-Dependent Traffic Conditions," *Traffic Engineering and Control,* vol. 31, no. 12, pp. 623-631, 1990.
32. D. Heidemann, "Queue Length and Waiting-Time Distributions at Priority Intersections," *Transportation Research B,* vol. 25B, no. 4, pp. 163-174, 1991.
33. M. V. Chitturi, R. F. Benekohal and A. Z. Kaja-Mohideen, "Methodology for Computing Delay and User Costs in Work Zones," *Journal of the Transportation Research Board,* no. 2055, pp. 31-38, 2008.

34. H. Ramezani, R. F. Benekohal and K. A. Avrenli, "Methodology to Analyze Queue Length and Delay in Work Zones," in *Presentation at the 90th TRB Annual Meeting*, 2010.
35. H. Ramezani and R. F. Benekohal, "Work Zones as a Series of Bottlenecks," *Journal of the Transportation Research Board,* vol. 2272, pp. 67-77, 2012.
36. Ullman, G. L., Dudek, C. L. "Theoretical Approach to Predicting Traffic Queues at Short-Term Work Zones on High-Volume Roadways in Urban Areas." Transportation Research Record: Journal of the Transportation Research Board, No. 1824, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 29-36.
37. C. F. Daganzo, Fundamentals of Transportation and Traffic Operations, Elsevier Science Ltd., 2000.
38. K. Moskowitz and L. Newman, "Notes on Freeway Capacity," Highway Research Board, 1963.
39. M. J. LightHill and G. B. Whitham, "On Kinematic Waves: A Theory of Traffic Flow on Long Crowded Roads," Proc. of Royal Society, vol. 229, no. A, pp. 317-345, 1995.
40. Transportation Reseach Board (1975) “Special Report 165: Traffic Flow Theory”. Washington, D.C.
41. Transportation Research Board. (2000). Highway Capacity Manual, Washington, DC.
42. Ghulam H. Bham, PhD; S. Hadi Khazraee. “Missouri Work Zone Capacity: Results of Field Data Analysis”. Report No, TPF-5-(081) & DOT #09810. Missouri, 2011.
43. Dixon, K. K., Hummer, J. E. and Lorscheider, A. R. "Capacity for North Carolina Freeway Work Zones." (Transportation Research Record) 1529 pp. 27–34 (1996).
44. Jiang, Y. "Traffic Capacity, Speed, and Queue-Discharge Rate of Indiana’s Four-Lane Freeway Work Zones." Transportation Research Record 1657, 1999: 10-17.
45. Al-Kaisy, A., Zhou, M., and Hall, F. "New Insights into Freeway Capacity at Work Zones." Transportation research Record 1710, 2000: 154-160.
46. Maze, T. H., Schrock, S. D., and Kamyab, A. "Capacity of Freeway Work zone Lane Closures." Mid-Continent Transportation Symposium 2000 Procedings. 2000.
47. Benekohal, R. F., Kaja-Mohideen, A. Z., Chitturi, M. V. "Methodology for Estimating Operating Speed and Capacity in Work Zone." Transportation Research Record 1833, 2004: 103-111.
48. Dudek, C. L. and S. H. Richards. Traffic Capacity Through Urban Freeway Work Zones in Texas. In Transportation Research Record: Journal of the Transportation Research Board, No. 869, TRB, National Research Council, Washington, D.C., pp. 14-18.
49. Transportation Research Board. (2010). Highway Capacity Manual, Washington, DC.
50. Weng, J. and Meng, Q. “Ensemble Tree Approach to Estimating Work Zone Capacity”. Transportation Research Record: Journal of the Transportation Research Board, No. 2286, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 56–67.

51. Al-Kaisy, A., and F. Hall. Examination of Effect of Driver Population at Freeway Reconstruction Zones. In Transportation Research Record: Journal of the Transportation Research Board, No. 1776, TRB, National Research Council, Washington, D.C., 2001, pp. 35–42.
52. Venugopal, S., and A. Tarko, “Investigation of Factors Affecting Capacity at Rural Freeway”. Transportation Research Board 80th Annual Meeting, 2001.
53. Al-Kaisy, A., and F. Hall. Guidelines for Estimating Capacity at Freeway Reconstruction Zones. Journal of Transportation Engineering,Vol. 129, No. 5, 2003, pp. 572–577.
54. Krammes, R. A. and G. O. Lopez. Updated Short-Term Freeway Work Zone Lane Closure Capacity Values. Report FHWA/TX-92/1108-5, Federal Highway Administration, U.S. Department of Transportation, and Texas Department of Transportation, Austin, Texas, 1992.
55. Kim, T., D. J. Lovell, and J. Paracha. A New Methodology to Estimate Capacity for Freeway Work Zones. Paper No. 01-0566, submitted to the Transportation Research Board Annual Meeting, 2001.
56. Adeli, H. and X. Jiang. Neuro-Fuzzy Logic Model for Freeway Work Zone Capacity Estimation. Journal of Transportation Engineering, September/October 2003.
57. R. F.Benekohal, H. Ramezani K. and A. Avrenli. “Queue and User’s Costs in Highway Work Zones.” Report No ICT-10-075. Illinois Center for Transportation, Illinois, 2010.
58. Schnell, T., Mohror, J. S., and Aktan, F. "Evaluation of Traffic Flow Analysis Tools Applied to Work Zones Based on Flow Data Collected in the Field." Transportation Research Record 1811, 2002: 57-66.
59. Sarasua, W. A., Davis, W. J., Clarke, D. B., Kottapally, J., and Mulukutla, P. "Evaluation of Interstate Highway Capacity for Short-Term Work Zone Lane Closures." Transportation Research Record 1877, 2004: 85-94.
60. Lee, C., Noyce, D. A., Qin, X. "Development of Traffic Delay Assessment Tool for Short-Term Closures on Urban Freeways." Transportation Research Board Annual Meeting CD-ROM, 2008.
61. Heaslip, K., Louisell, C., Collura, J. "Driver Population Adjustment Factors for the Highway Capacity Manual Work Zone Capacity Equation." Transportation Research Board Annual Meeting CD-ROM, 2008.
62. Karim, A. and Adeli, H. "Radial Basis Function Neural Network for Work Zone Capacity and Queue Estimation." Journal of Transportation Engineering, 2003.
63. Apogee Research. “The Costs of Transportation”, Conservation Law Foundation (Boston; www.clf.org), 1994.
64. K. Gwilliam. The Value of Time in Economic Evaluation of Transport Projects; Lessons from Recent Research. World Bank (Washington DC), January 1997.
65. USDOT. Departmental Guidance on the Evaluation of Travel Time in Economic Analysis”, Memo, USDOT Available online at http://ostpxweb.dot .gov/policy/safety/VOT_Guidance_ Revision_1.pdf, April 9, 1997.
66. Mayeres, I., Ochelen, S. and Proost., S. (1996) “The Marginal External Cost of Urban Transport”, Transportation Research Part D, No.2, pp. 111-130.

67. Booz Allen Hamilton, ACT (2003). “Transport Costing Study”, Canberra Department of Urban Services Available online at http://www.actpla.act.gov.au/plandev/tp-intro/tp-archive/transportstudy.pdf.
68. I.T. Transport. “The Value of Time in Least Developed Countries”, Department for International Development, UK under its Knowledge and Research (KaR) Programme, available online at www.transport-links.org /transport_links, Accessed June 2005.
69. U.S. Department of Labor (2007). "State Occupational and Wage Estimates New Jersey". Available online at http://www.bls.gov/oes/2007/may/oes_nj.htm#b00-0000. Accessed December 2008.
70. National Safety Council (2011). "Estimating the Costs of Unintentional Injuries." Available online at http://www.nsc.org/news_resources/injury_and_death_statistics/PagesEstimatingthe Costsof UnintentionalInjuries.aspx. Accessed on July 10, 2013.
71. National Highway Traffic Safety Administration, US Department of Transportation (2000). "The Economic Impact of Motor Vehicle Crashes". Available online at http://www.nhtsa.dot.gov. Accessed on July 9, 2013.
72. Federal Highway Administration (1994). "Motor Vehicle Accident Costs." Available online at http://www.fhwa.dot.gov/legsregs/directives/techadvs/t75702.htm. Accessed July 2013.
73. American Association of State Highway and Transportation Officials (2007) "Poll Results: Crash Costs used for Prioritizing Safety Projects." Available online at http://www.scote.transportation.org/Documents/CrashCostPoll1-07.xls. Accessed on June 22, 2013.
74. Ozbay, K., Bartin, B. and Berechman, J. (2001). “Estimation and Evaluation of Full Marginal Costs of Highway Transportation in New Jersey”, Journal of Transportation and Statistics, Vol. 4, No.1, April 2001. (With Ozbay, K. and Berechman, J.)
75. Ozbay, K., Bartin, B., Yanmaz-Tuzel, O., Berechman, J. (2008) “Alternative Methods for Estimating Full Marginal Costs of Highway Transportation”, Transportation Research A, Vol. 41, pp. 768-786.
76. Ozbay, K., Yanmaz-Tuzel O., Mudigonda S., Bartin B., and Berechman J.Cost of Transporting People in New Jersey-Phase II. New Jersey Department of Transportation Final Report, Report No FHWA/NJ-2007-003, 2007.
77. American Automobile Association, Your Driving Costs 2003, American Automobile Association (www.ouraaa .com), 2003. Based on Runzheimar International data.
78. US Department of Transportation. Cost of Owning and Operating Automobiles, Vans and Light Trucks, 1999.
79. Kelly Blue Book Website, 2006. Available online at http://www.kbb.com/.
80. Mun, Se-IL. Traffic Jams and Congestion tolls. Transportation Research B, Vol. 28, 1994, pp. 365-375
81. Small K., and X. Chu. Hypercongestion. Journal of Transport Economics and Policy, Vol. 37 2003, pp 319-352
82. US Department of Transportation. Crash Records, 2005, Available online at http://www. state.nj.us/transportation/refdata/accident/rawdata01-03.shtm

83. Transportation Research Board (2014) “Strategic Approaches at the Corridor and Network Level to Minimize Disruption from the Renewal Process” S2-R11-RW-1.
84. Coval Systems “What is OpenReach?” http://www.covalsystems.com/latest/openreach/automation.html. Accessed on March 4, 2015.
85. NJ Geographic Information Network Website. Accessed on March 4, 2015. Available at https://njgin.state.nj.us/NJ_NJGINExplorer/jviewer.jsp?pg=ROADS

APPENDIX

ESRI STRAIGHT LINE DIAGRAMS SHAPE FILE [85]

New Jersey Road Centerlines Data

An enhanced version of New Jersey Road Centerlines Data is available for download on the New Jersey Geographic Information Network (NJGIN) web site. The data set is downloadable in ESRI File Geodatabase 9.3 format and ArcView Shapefile format. These databases include the following files:

File geodatabase: Roads_NJ

- Feature Class: Road_Centerlines_NJ
- Alternate Names table: Road_Altnames_NJ
- Labeling table: Road_Labeling_NJ
- Linear Referencing Systems table: Roads_LRS_NJ

DATA OBJECTS

Feature Class Attributes – Road_centerline_NJ

Current road geometry.

- Segment identifier (SEG_GUID, replaces SEG_ID from previous version of road centerlines)
- Highest order highway route or local road designation (highway route takes precedence over local road in this field)
- Address ranges
- ZIP codes (numeric) and ZIP names (text)
- Municipality codes (GNIS)
- State
- Primary local road or highest order highway route name (local road name take precedence over highway route name in this field)
- Local road names
- Highway route names
- Highway route shields and subshields (includes modifiers for alternate, business, etc.)
- Highway route numbers
- Status (active, under construction, planned)
- Surface (improved, unimproved)
- Platform levels (at grade-separated interchanges/overpasses)
- Travel direction (both, increasing)
- Access (restricted, non-restricted)
- Jurisdiction (public, private)
- Feature Status (draft, final)
- Update Date (date of most recent update)

TABLES
Roads_LRS_NJ Contains information about linear referencing systems supported by route measures applied to the Road_centerlines_NJ feature class geometry. The table includes fields for the Standard Route Identifier (SRI), Route Type (ROUTE_TYPE, as defined by NJDOT) and five separate linear referencing system (LRS) route measures. These LRSs enable dynamic display of data based on distance along a route as well as measure-based calculations about features. These fields are maintained by NJDOT except for New Jersey Turnpike and Garden State Parkway LRS measures, which are maintained by the New Jersey Turnpike Authority (not available in current release).

Standard Route Identifier (SRI)
The SRI is a 17 character code that identifies the full length of each highway route or local road using the following convention: CCMMRRRRSD-QIPPPPP. CC stands for two-digit county code (00-21). The value is 00 for Highway Authority Routes, Interstate Routes, US Routes, and State Routes. MM stands for the two-digit municipality code (00-99). The value is 00 for Highway Authority Routes, Interstate Routes, US Routes, State Routes, County 500 Series Routes and Other County Routes. RRRR is the four-digit route number. For numbered routes (Interstates, State and US routes and most County and Other County routes), this number is the posted route number. S is the route suffix if one exists (B - Business; A - Alternate; S – Spur, etc.). If a suffix does not exist, the "_" character is used. D is the primary direction in which the route runs. For undivided routes, or the primary direction of divided routes, the "_" character is used. Secondary directions on divided highways will use the appropriate directional abbreviation (N, S, E, W). Ramps will include the 'suffix' portion, denoted as QIPPPPP.

Route Type
Interstate, US Highway and State Highway designations are considered higher order routes than Highway Authority Routes by NJDOT. The full hierarchy follows in descending order:

1. Interstate
2. US Highway
3. State Highway
4. Highway Authority Route
5. 500 Series County Route
6. Other County Route
7. Local Road
8. Ramp
9. Alley
10. Park / Military

Linear Referencing Systems (LRS)
The various LRSs are separated by a three-character prefix to the milepost fields. The table can be joined to the Road_centerline_NJ based on the SEG_ID field with a one-to-one relationship.

- SLD (Straight Line Diagram): This LRS was developed to support many systems internal to DOT. The SLD mile posting schema for divided roads (multiple centerline representation) increases in the direction of travel on the segment. For example, mile posting the Garden State Parkway primary segments (northbound, or 'south to north' direction of travel) begins at zero in Lower Township, Cape May County. The secondary segments (southbound, or 'north to south' direction of travel) begins at zero in Montvale Borough, Bergen County.
- For undivided, or single centerline routes, mileposts generally follows the convention of 'south to north' or 'west to east', though this is not absolute. Milepost values for this system are based on field inventories of route lengths and may differ from physical milepost marker locations observed in the field.
- PAR (Parent): It correlates milepost values between non-primary segments of divided routes and the analogous primary segment, or between a ramp and the primary route segment that the ramp serves.
- MMS (Mile Marker Signs): This was derived from the field locations of mile marker signs, and has been developed for Interstate, US, and State highways.
- TPK (Turnpike): The Turnpike Authority has developed a highly detailed LRS that supports their specific operations for the Turnpike and Garden State Parkway.

Roadway Features Database

Another database related to the centerlines data is the roadway features database. This database contains 112 tables for different roadway features such as bridge locations, AADT, lane count, median width, speed limits, etc. For each segment-based feature, SRI, start milepost, and end milepost of the segment is defined. Using this three fields in any of the feature tables, it is trivial to relate the selected feature to the centerline data (shape file).

For the purposes of this study, lane counts and AADT features are extracted from the database related to the corresponding geographical segments in the centerline data.