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Evaluation of Traffic Simulation Models for Work Zones in the New England Area

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EVALUATION OF TRAFFIC SIMULATION MODELS FOR WORK ZONES IN THE NEW ENGLAND AREA

A Thesis Presented

by

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ABSTRACT

EVALUATION OF TRAFFIC SIMULATION MODELS FOR WORK ZONES IN THE

NEW ENGLAND AREA

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There are many traffic simulation modeling packages in existence, some of which are designed specifically for work zone analyses. These packages include, for example QUEWZ, Quick Zone, CORSIM and VISSIM. This research evaluates the capabilities of these simulation packages to determine whether or not these packages produce reasonable impact estimates. The research concludes with a set of recommendations to assist transportation professionals in selecting the most appropriate simulation package for a particular work zone project.

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CHAPTER I

<u>INTRODUCTION AND RESEARCH GOAL</u>

As the National Highway System (NHS) continues to age and reach it serviceable life, the focus of road work had shifted from new construction to rehabilitation and maintenance of existing roads. This increasing need to rehabilitate the roadway infrastructure has placed an emphasis on improving our ability to understand, anticipate, and predict work zone traffic conditions, patterns, and other impacts to mitigate long delays.

An average of 23,745 miles of roadway per year had federal aid for improvement from 1997 to 2001. An estimated 3,110 work zones were on the National Highway System (NHS) during the peak summer road work of 2001. These work zones caused congestion to increase from 34% to 58%. The increase in congestion is due to the fact that over the past twenty years, route-miles of highway have increased approximately 3 percent while vehicle-miles of travel have increased 79 percent during the same period [1].

With the staggering increase in vehicle-miles of travel, motorists are increasingly exposed to work zones; 11 billion vehicle-miles of travel have been estimated to pass through active work zones. On average, motorists encounter an active work zone one out of every 100 miles traveled on the National Highway System (NHS), representing loss of 60 million vehicles per hour per day of capacity. Fifty percent of all highway congestion is attributed to non-recurring delay, 24 percent of which is attributed directly to work zone activity [2].

As a part of planning and design for work zone projects, transportation engineers and analysts have used computer based techniques to assess the expected traffic flow conditions and other impacts of candidate work zone strategies. A survey of State DOTs showed that QUEWZ and Quick Zone were the most widely used software packages for the estimation of queue lengths and delays in work zones. FHWA's Quick Zone provides high-level estimates of delay reduction for candidate work zone management strategies. Other current traffic simulation tools attempt to estimate delay and other impacts at a more micro level such as CORSIM.

The main goal of the research is to evaluate the capabilities of several software packages designed to assess impacts of the work zone strategies. These packages have the potential to provide decision makers the information needed to make informed decisions on the best work zone implementation with respect to the prevailing conditions.

CHAPTER II

REVIEW OF LITERATURE

During the last 20 to 30 years many sophisticated traffic simulation models have been developed. Advances in computer technology and traffic flow theory have led to the widespread creation and use of traffic simulation models by traffic engineers and transportation planners involved in the planning, operations, and design of transportation facilities.

Computer simulation is more practical than a field experiment for the following reasons:

- It is less costly.

- Results are obtained quickly.

- The data generated by simulation include several measures of effectiveness that cannot be easily obtained from field studies.

- The disruption of traffic operations, which often accompanies a field experiment, is completely avoided.

- Many schemes require significant physical changes to the facility, which are not acceptable for experimental purposes.

Traffic simulation models create the opportunity for the development of new and innovative transportation systems management concepts and designs. Planners and engineers are now having a means to test ideas prior to the field demonstration. Because these models allow the

designer to identify weaknesses in concepts and designs, they provide a basis for identifying the optimal form of candidate approach. Finally, because the results generated by the model can form a basis for selecting the most effective candidate among competing concepts and designs, the eventual field demonstration will have a higher probability of success.

In addition to their usefulness in analyzing a unique set of conditions, some of the new traffic simulation models include highly sophisticated displays that allow visual demonstration of traffic operations on a computer screen. Traffic conditions could be described only in words in certain simulation models like QUEWZ and Quick Zone. However, CORSIM TRAFVU (TRAF Visualization Utility) is a user-friendly graphics post-processor that displays traffic networks, animates simulated traffic flow operations, exhibits simulation output in wide varied measures of effectiveness, and displays user-specified input parameters for simulated network objects. This has enhanced the ability of people both inside and outside the transportation profession to visualize the results of future actions. Simulation results can be displayed in public meetings, allowing decision-makers and the public a way to visualize traffic operations in ways that were not possible using conventional tools [3].

Simulation can be conducted at three levels: macroscopic, mesoscopic, and microscopic. Macroscopic models treat traffic as an aggregate fluid flow. These models are based on the use of continuum models, representing the relationship between speed, density, and flow. Macroscopic simulation considers platoons of vehicles flowing over small increments of time. Examples of macroscopic simulators include FREQ, CORFLO, and TRANSYT-7F. Mesoscopic models represent the middle ground between macro- and microscopic simulation.

Mesoscopic simulation assigns vehicle types and driver behaviors as well as relationships with roadway characteristics. Examples of mesoscopic simulators are CONTRAM and DYNASMART-P. Microscopic models analyze individual vehicle movements based on car-following and lane-changing theory. Microscopic simulation also takes into account the influence of vertical grade, horizontal curvature, and super elevation on traffic operational characteristics. Examples of microscopic simulators are CORSIM and VISSIM [3].

States have used computer simulation to predict traffic conditions in work zones as part of the decision-making process on large, highly visible projects. Simulation is not routinely used however in either the project planning or design phases of many of the nation's roadway reconstruction or rehabilitation activities. Simulation models are available to transportation officials and agencies that aid in the prediction of queue lengths, delay times, and travel speeds. FHWA's *Best Practices* reveals, however, that many simulation packages are not user-friendly and are not readily adaptable to local traffic conditions experienced during construction activities.

The *Best Practices* also identifies keys to state-of-the-art prediction modeling and analysis. One key is to update and enhance existing computer modeling software, creating a more user-friendly atmosphere that can realistically predict traffic impacts for various reconstruction alternatives on freeways as well as arterials. Another key is to develop user-friendly simulation software for analyzing specific changes to the traffic control plan at the project site. The last key is to develop user-friendly project-specific computer software than can predict capacity breakdowns on freeways before they actually occur.

According to the FHWA many agencies are making an effort to use more advanced tools, such as simulation, for work zone analysis. Different tools may be appropriate for different situations, depending on the size and scope of the project. Work zone specific simulation packages include QUEWZ, Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS), and Quick Zone. QUEWZ analyzes traffic conditions on freeway segments with and without lane closures, providing estimates of additional road user costs and of queuing as a result of work zone lane closures. CA4PRS estimates the maximum distance of highway that can be rehabilitated or reconstructed within various resource constraints and closure timeframes. Quick Zone compares traffic impacts for work zone mitigation strategies, estimating the costs, time delays, and potential backups associated with these impacts.

CORSIM and VISSIM are the two most widely used microscopic traffic simulation models. CORSIM was developed under Federal Highway Administration (FHWA) sponsorship. VISSIM is microscopic multi-modal traffic flow simulation software. It is developed by PTV— Planung Transport Verkehr AG in Karlsruhe, Germany. VISSIM was started in 1992 and is the global market leader today.

CORSIM and VISSIM can be adapted to simulate traffic operations around a work zone on the arterials in urban areas, suburbs and in towns. This is done by assuming that a lane closure for a work zone results in the same type of impact on traffic carrying capacity as a lane blockage caused by an incident. CORSIM is capable of simulating work zones through a prolonged incident blockage. This does not accurately depict traffic behavior in the approach to a work zone. When modeling a lane blockage in CORSIM, the program assumes that drivers have no knowledge of the approaching blockage and there is no taper. VISSIM, on the other hand, does

a better job of capturing an appropriate lane-changing behavior at work zones. It even allows introducing Variable Message Signs (VMS) [4].

Although traffic simulation models offer important advantages as analysis tools, they have some limitations and disadvantages compared to more traditional analysis tools. They are more costly and time consuming than traditional computational methods. Because of their complexity, it is also more difficult to maintain consistent standards for the use of simulation models as compared to other traffic engineering analyses. In this discussion, the reference to "traditional" analysis tools refers to methods utilizing equations to estimate capacity and delay, based on a given set of input parameters.

Because traffic simulation models have only come into widespread use in recent years, there are relatively few guidelines and standards to govern their use. While the transportation profession seems to be in agreement that traffic simulation models are highly useful tools, there are a variety of models available and a high potential for misuse and misinterpretation of results. In this, environment, it is highly desirable that traffic engineers and transportation planners work together to share knowledge and educate each other on the potential advantages and pitfalls in the use of traffic simulation models.

Work Zone Simulation Model

A work zone model design is usually based on the existing geometry of a typical interstate work zone with a lane closure, reducing two lanes to one. For example, a model was developed

specifically developed for a work zone on Interstate Highway 80, located in Scott County, Iowa, during the summer of 1998. It is, however, flexible enough to accommodate the potential modifications of work zone design and traffic characteristics. It also allows end-users to change parameters and conduct "what-if" analyses.

The work zone model is specifically designed to assess the pre-deployment results of introducing work zone strategy on roadways. The two most important components of the model are the inclusion of car-following and lane-changing algorithms. The car-following logic models a driver's behavior in response to speed changes of the lead vehicle. The lane-changing algorithm is more complex because the decision to change lanes depends on a number of factors. Prior to changing lanes, a driver determines whether it is possible, necessary, or desirable to do so. It is necessary, for example, for a vehicle to change lanes when it approaches a lane closure. It is, however, desirable to change lanes when a vehicle is behind a slow-moving vehicle.

Within the model each vehicle is generated according to an exponential distribution with an inter-arrival time of at least two seconds (i.e., two seconds headway). Upon its arrival, a number of attributes are assigned to the vehicle. These attributes include vehicle classification, speed, and lane assignment. The attributes are assigned following a discrete or continuous probability function. For example, if it is assumed that the traffic stream is composed of ten percent trucks, the model randomly assigns truck characteristics to ten percent of the vehicles.

Vehicles enter the model a few hundred feet upstream of the lane drop sign. It is therefore assumed that vehicles are well informed of the upcoming lane closure. A small percentage of vehicles, however, remain, on the terminating lane ever after the posted lane drop sign. These vehicles, called late mergers, will merge as soon as they find adequate gaps in the traveling lane. Those vehicles that are not able to merge before the lane is terminated (where the barrels are located) must eventually stop and wait for the next acceptable gap. The waiting time for these vehicles is sometimes long because the through-lane vehicles are not modeled to recognize the vehicles in the terminating lane and provide them a gap. Vehicles in the through lane, however, respond to late mergers who merge immediately in front of them by adjusting their speed. The capacity impacts of the late mergers and other errant merging behavior are examined using simulation in a "before and after" study.

Drivers who join the queue at its end and wait to reach the head of the queue view those drivers who travel to the head of the queue in the terminating lane as "cheaters." Two truck drivers have been commonly observed to block cheaters by collaborating. One truck will travel in the through lane while another truck will travel side-by-side in the closed lane. When the two trucks reach the lane closure taper, the truck in the terminating lane will merge ahead of the truck in the through lane. Usually the two drivers travel slowly through the queue creating a significant gap between their trucks and the vehicle immediately downstream. This errant behavior will be evaluated using the simulation.

Given the traffic volume and the population of trucks and slow-moving vehicles, the simulation model estimates the expected travel time and speed throughput of the modeled work zone. The

model enables a traffic engineer to visually present the impact of a scheduled road construction to public. A number of scenarios can be examined under various traffic conditions and designs to select the best plan before executing the actual construction activities.

Current State of the Art in Work Zone Simulation

Sterzin, Toledo, and Ben-Akiva summarized the state of micro simulation of work zone activities in this way, "None of the simulators surveyed explicitly models work zones. Ten simulators capture work zone effects by modeling it as a pre-defined incident. However, this approach does not necessarily capture all of the effects of work zones." This future identifies the need to improve micro simulation of work zones to evaluate various kinds of merging strategies like that of:

1. Static early merge

2. Static late merge

3. Dynamic early merge

4. Dynamic late merge

Many more difficult questions must be answered to have an accurate simulation of work zone traffic conditions. The calculation of demand and capacity are two calculations that are the most difficult in the evaluation of work zones. Demand calculations are difficult due to the diversions caused by drivers delaying, canceling, or diverting trips to other routes. One difficulty in finding a true capacity is that different researchers have different definitions of how work zone capacity is defined. Some researchers measured the mean queue discharge flow rate as work zone capacity when the upstream of work zones was in sustained congested traffic

flow, while some other researchers defined work zone capacity as the traffic flow rate on the onset of congested traffic conditions. One broadly employed method for evaluating the impacts of work zones is based on the FHWA developed software, Quick Zone. Quick Zone is a sketch level tool that supports assessment of work zone mitigation strategies and estimates the costs, traffic delays, and potential backups associated with these impacts. Quick Zone can be used to evaluate traffic delays associated with work zone schedules in relation to peak and off-peak traffic periods and/or with the employment of diversion routes. The program displays the amount of delay in vehicle hours and the maximum length of the projected traffic queue associated with the work activity. The shortcomings include the disability to depict the merging scenario, which is used nowadays to vary the capacity of the work zone. Furthermore links that are congested are not easily observed. In ordered to answer this questions micro-simulation have been evaluated.

CHAPTER III

RESEARCH OBJECTIVES

Transportation engineers are facing a major challenge in interpreting the effects of lane closure, while attempting to reduce delay to commuters traversing the work zones. It is important to assess the ability of each program to evaluate pre-deployment strategies, such as off/on peak and introducing detours; analysis could be used for planning work zone execution strategies to reduce inconvenience to commuters.

A major interest among professionals in transportation agencies is to have the ability to present reliable information regarding impacts that may occur with the implementation of a work zone strategy. This ability provides decision makers in these agencies the information needed to make informed decisions on the best work zone implementation for the local conditions in the area of the work zone. Effective tools to aid in the evaluations of these anticipated impacts include user friendly computer based simulation models that are adaptable to the many work zone configurations being considered in the planning, design, and implementation of the work zone strategy.

There are three major objectives of this research project.

The primary objective is to assess the capabilities of widely utilized simulation packages to interpret the effects work zone strategies. For example, by simulating for results changing the

variables like lane-closures (e.g., whether lanes may be closed, when they may be closed, how many lanes may be closed) we can get the approximate delay and queue thresholds, and changing work hour.

The assessment will include the following simulation packages: QUEWZ (Queue and User Cost Evaluation of Work Zones) and Quick Zone Criteria, constraints and parameters that will be used in this assessment are:

- Minimum length of work zone

- Maximization of work zone productivity

- Maximum tolerable traffic delay

- Optimal work zone season

- Nightmare work zones

- Quantify corridor delay resulting from capacity decreases in work zones

- Identify delay impacts of alternative project phasing plans

- Examine the impacts of construction staging by location along mainline, time-of-day (peak vs. off-peak), and season (summer vs. winter)

The second objective is to assess micro-simulation tools, such as CORSIM and VISSIM (where required), in terms of:

- Incorporating road monitoring systems in the assessment.

- How far these simulation packages can resemble the local traffic conditions on arterials.

- The better information of congested links in a particular stretch can be viewed to plan better.

- Interpret the abilities of these software's to assess the impacts of work zone strategies.

- To express the delay in Work zones in even in other terms of MOE.

The third objective is to make recommendations for the selection of simulations models on roadway reconstruction and rehabilitation projects in New England. The recommendations may include a software package or suite of packages and will consider the following factors and criteria:

- User Friendliness

- Convenient input with meaningful output

- Low software and hardware operating requirements

- Accurate for various work zone configurations

- Flexibility to replicate the site conditions

CHAPTER IV

RESEARCH APPROACH AND METHODOLOGY

The research approach includes an analysis of the effects of work zone strategies using

QUEWZ-98 Quick Zone and CORSIM on four urban and rural freeways and two arterials.

Table 1: List of the Evaluation Tools Used for Each Site

Site Location	Functional Classification	QUEWZ-98	QUICK ZONE	CORSIM
I-91 Greenfield/MA	rural freeway	*	*	
I-91 Windsor/CT	urban freeway	*	*	
I-95 Bangor/ME	rural freeway	*	*	
I-93 Manchester/NH	urban freeway		*	*
Rt-9 Hadley/MA	arterial			*
Rt-116 Sunderland/MA	arterial			*

The primary objective is to evaluate the capabilities of each software package to analyze the

effects of work zones on the traffic flow, how well each package can be utilized in simulating

the different time periods of a day, and analyzes the effects in order to plan the work zone

implementation effectively. Finally to suggest when and where, which software package should

be used to meet the accuracy and the goal to reduce traffic congestion due to work zones.

Selection of work zone sites for calibration was done as follows:

- Two-lane Interstate work zone, with maximum 40,000 AADT, reduced to one lane which contains both rural and urban freeways.

- Two-lane Interstate work zone, with maximum 40,000 AADT, reduced to one lane which contains both rural and urban freeways.

- Rural and Urban arterial projects.

Explanation of Selection of Software Packages

Initially the most popular and the software packages that are meant for and developed for evaluation of work zones find the queue length and user cost. Software packages have been evaluated in terms of:

- Accuracy,

- Flexibility of use and

- Accommodating the complex networks and the present technical installations, such as traffic signals, bus routes and pedestrians, in order to represent the actual prevailing conditions of the site.

QUEWZ and Quick Zone are a part of the evaluation of the rural and urban freeways. CORSIM has been adapted when rural and urban arterials have come into switch because:

- It accurately represents the network.

- It analyzes alternative routes to reduce the effect of congestion due to work zones.

- This tool is ideal in terms of work on arterials where the work lasts for less than month.

- Ideally the effect is analyzed by the peak hour traffic to identify the detour used in order to reduce travel time.

The simulation modeling described as above was undertaken to help quantify the benefits and impacts of different alternative route. Traffic operational analysis using the microscopic simulation modeling, was identified as the best approach for assessing the traffic performance impacts of various alternative detours. The capability of coding complex networks with traffic signals and bus schedules in CORSIM made it a potential package to choose for evaluation. This section describes how the simulation model was developed and run in support of this analysis

Five sites have been evaluated as shown in Table 1. The review and explanation procedure followed of the case studies is done in three stages, mainly due to the restrictions of the abilities of each individual software package to evaluate.

- **Analysis-1:** The first three sites I-91 Greenfield, MA; I-91 Windsor, CT; I-95 Bangor, ME are pretty straightforward sections, and the work zone was on one particular lane, where things were not complicated. Reducing lanes 2-1, 3-2, 3-1, or 4-2 implied that, these site conditions were easy enough to replicate in the software packages QUEWZ-98 and Quick Zone and were finally evaluated.

- **Analysis-2:** The site I-93 Manchester, NH consists of an on ramp and an off ramp and the work zone was not continuous as in the case of that site mentioned above. The Bridge portions are to be repaired; in order to replicate the intermittent work zones precisely, CORSIM was being used along with Quick Zone.

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- **Analysis-3:** In the case of the Route-9 (arterial) and Route-116 (arterial), replication of site characteristics more precisely motivated the use of CORSIM.

Analysis 1

QUEWZ Analysis for I-91 in Greenfield, MA

Q98MENU is the main program of the simulation package of QUEWZ-98. Q98MENU is called by typing Q98MENU at the DOS prompt and by pressing the Enter key. A menu driven procedure leads the user through the process of entering data and running QUEWZ-98. This section explains the use of each screen as applied to the work zone strategy along Interstate 91 in Greenfield, MA

After Q98MENU is called, an introductory screen is automatically displayed as shown in Figure 1. When the user presses any key, the screen automatically moves to the main menu. QUEWZ-98 has two output options. The first task in creating a new file for this specific work zone strategy is to select among the primary model options: (1) road user cost estimates for a specified lane closure configuration and schedule of work activities, and (2) acceptable lane closure schedules for all possible lane closure configurations.
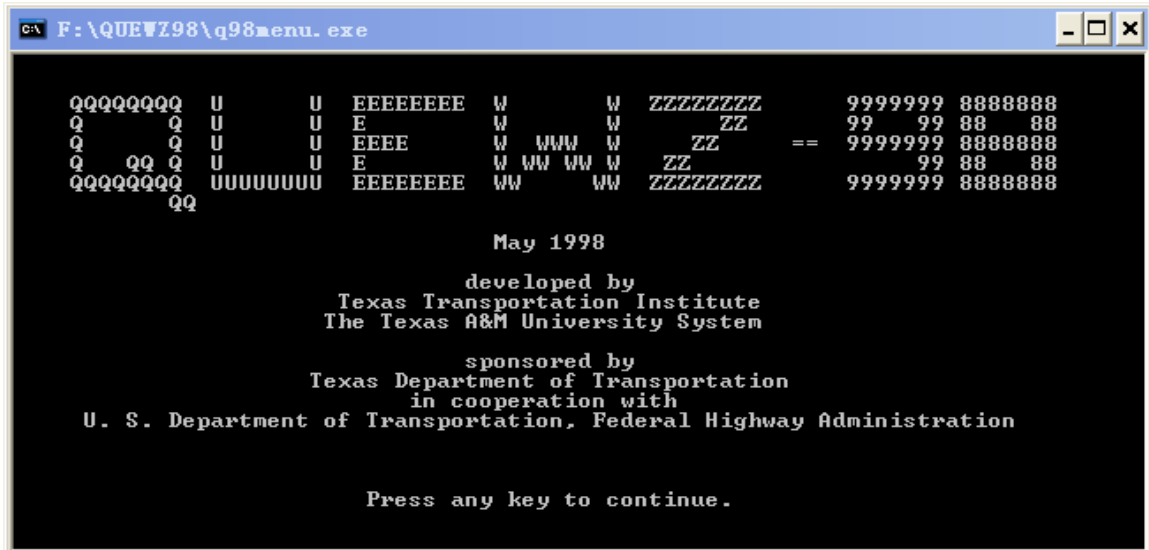
Figure 1: QUEWZ-98 Introductory Screen

Input Section Illustration

For this research, the first output option, 'Road user cost estimates,' is selected. Since the user

is provided with the directional hourly volume, he or she will choose the first option in

'Volume Data Input Options.' The model options screen is shown in Figure 2.
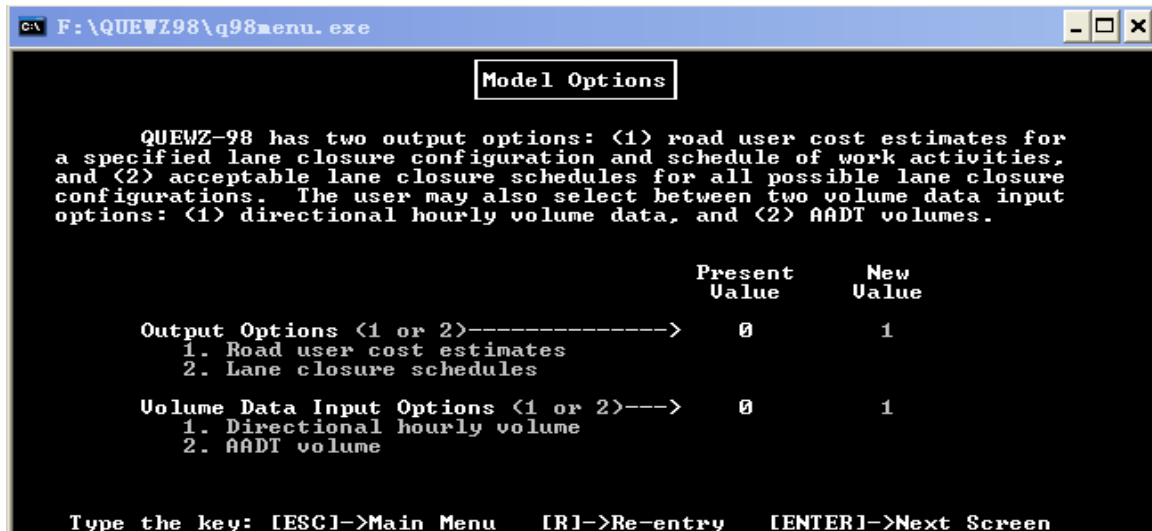
Figure 2: Model Options Screen for I-91 in Greenfield, MA

The second screen image is called Model Constants Screen, shown in Figure 3. This screen allows the user to either accept the model default values or specify new values for several model constants. In this case, a few assumptions were made. Cost Update Factor is 1.0, while the Percentage of Heavy Vehicles is written on the documents as 8%. The Free Flow Speed is 60mph and LOS D/E Breakpoint Speed is 46mph. Due to the specific traffic demand, the Speed at Capacity can only by 30mph, while the LOS Breakpoint Volume is 1850vphpl. Finally, in this screen, the user will enter the Volume at Capacity 2000vphvl, which is provided in the documents.
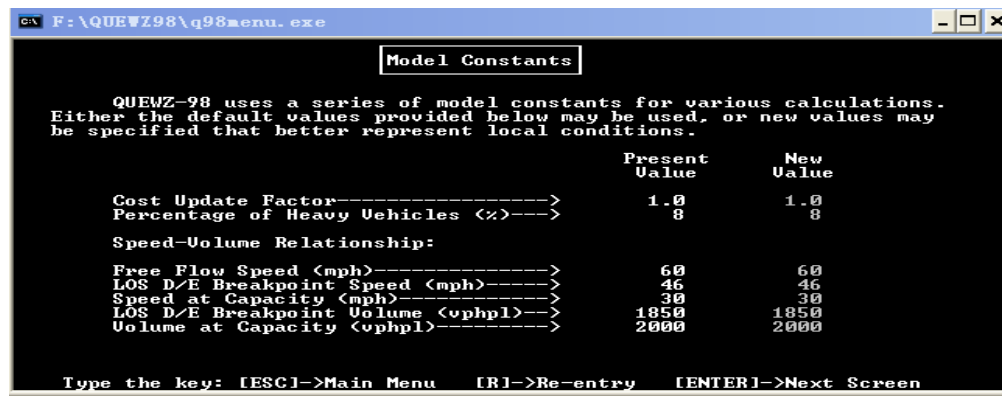
Figure 3: Model Constants Screen for I-91 in Greenfield, MA

When the road user cost output option is selected, the first section that appears after the two preliminary screens is the Diversion Algorithm screen in Figure 4. This screen allows us to choose whether or not to engage the diversion algorithm. The diversion algorithm computes how much traffic should be diverted from the freeway to avoid excessive queuing. There are two alternatives for defining excessive queuing: (1) a critical length of queue in miles, or (2) a maximum acceptable delay to motorists in minutes. Assumptions are made about the queue

length and delay. The assumption is a queue length of 2 miles for selection 1 and a delay of 20 minutes for selection 2.
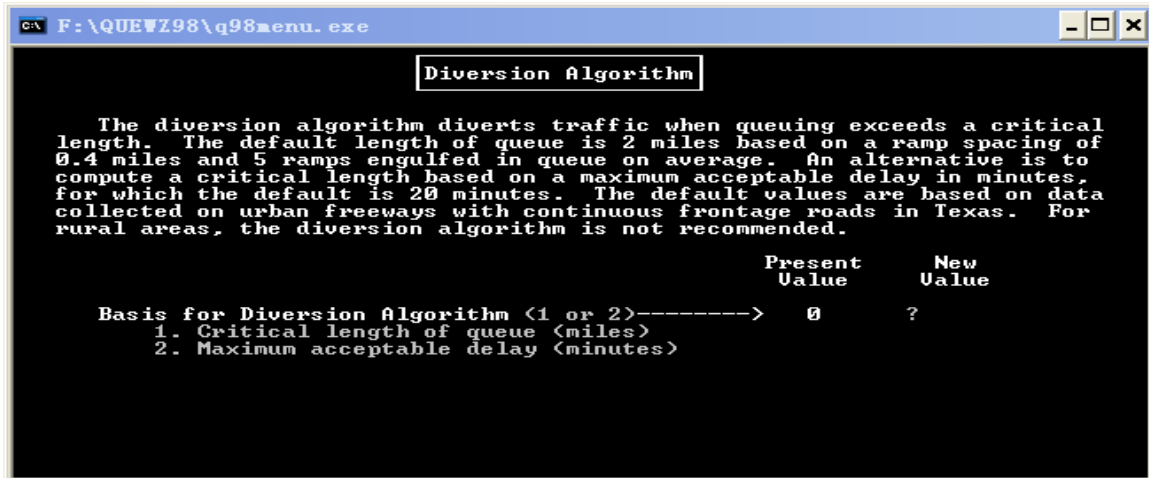
Figure 4: Diversion Algorithm Screen for I-91 in Greenfield, MA

The next screen is the description of Lane Closure Configuration. Figure 5 is the Lane Closure Configuration Screen for the Road User Cost Output Option. According to the information provided in Heaslip's dissertation [14], the number of directions is given; the total number of lanes, the number of lanes open to traffic and length of the lane closure are entered.
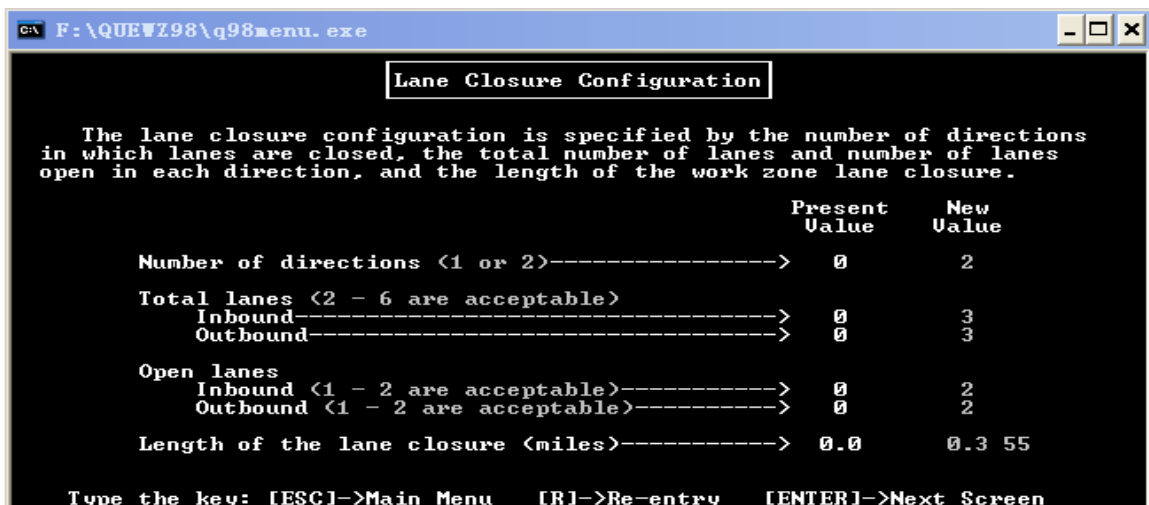
Figure 5: Lane Closure Configuration Screen for I-91 in Greenfield, MA

Figure 6 asks when the lane closure should be included in the schedule, which illustrates the screen displayed to obtain the necessary data on the schedule of work activity for the road user cost option. Data is requested for both the hours when the lane closure begins and ends and the hours when the work activity begins and ends. According to the information provided by the field engineers and the documents, we know when the closures begin and end, and when the work activities begin and end. This information is then entered.
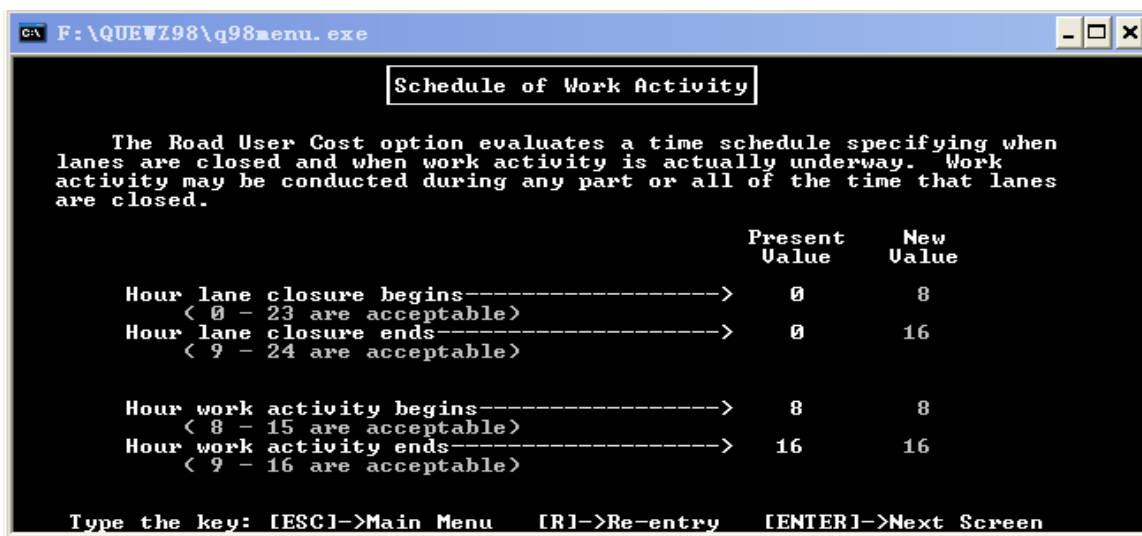
Figure 6: Schedule of Work Activity Screen for I-91 in Greenfield, MA

After we choose the option of directional hourly volume data, for this situation, the Directional Hourly Volume Data screen appears. If the closures are in both directions, then two screens (one for each direction) are displayed subsequently. Figure 7 and Figure 8 display northbound and southbound hourly volume data, respectively.

```
F:\QUEWZ98\q98menu.exe                                          - □ ×

           ┌─────────────────────────────────────────────────────┐
           │ Directional Hourly Volume Data - [Inbound]          │
           └─────────────────────────────────────────────────────┘

        Volume data are required at least for the time period during which
     lanes are closed.  Up and Down arrow keys may be used to move about the
     screen.

                          Present  New                        Present  New
             Hour         Value    Value          Hour         Value    Value

 12.00 a.m. -  1.00 a.m. 0        933    12.00 p.m. -  1.00 p.m. 0        3819
  1.00 a.m. -  2.00 a.m. 0        555     1.00 p.m. -  2.00 p.m. 0        3873
  2.00 a.m. -  3.00 a.m. 0        372     2.00 p.m. -  3.00 p.m. 0        3868
  3.00 a.m. -  4.00 a.m. 0        275     3.00 p.m. -  4.00 p.m. 0        4327
  4.00 a.m. -  5.00 a.m. 0        340     4.00 p.m. -  5.00 p.m. 0        5277
  5.00 a.m. -  6.00 a.m. 0        903     5.00 p.m. -  6.00 p.m. 0        5033
  6.00 a.m. -  7.00 a.m. 0        3312    6.00 p.m. -  7.00 p.m. 0        4903
  7.00 a.m. -  8.00 a.m. 0        4674    7.00 p.m. -  8.00 p.m. 0        3894
  8.00 a.m. -  9.00 a.m. 0        4517    8.00 p.m. -  9.00 p.m. 0        3274
  9.00 a.m. - 10.00 a.m. 0        3537    9.00 p.m. - 10.00 p.m. 0        2725
 10.00 a.m. - 11.00 a.m. 0        3288   10.00 p.m. - 11.00 p.m. 0        2451
 11.00 a.m. - 12.00 p.m. 0        3863   11.00 p.m. - 12.00 a.m. 0        2198

       Type the key: [ESC]->Main Menu    [R]->Re-entry    [ENTER]->Next Screen
```

Figure 7: Directional Hourly Volume Data Screen (NB) for in I-91 Greenfield, MA

```
F:\QUEWZ98\q98menu.exe                                          - □ ×

           ┌─────────────────────────────────────────────────────┐
           │ Directional Hourly Volume Data - [Outbound]         │
           └─────────────────────────────────────────────────────┘

        Volume data are required at least for the time period during which
     lanes are closed.  Up and Down arrow keys may be used to move about the
     screen.

                          Present  New                        Present  New
             Hour         Value    Value          Hour         Value    Value

 12.00 a.m. -  1.00 a.m. 0        933    12.00 p.m. -  1.00 p.m. 0        3819
  1.00 a.m. -  2.00 a.m. 0        555     1.00 p.m. -  2.00 p.m. 0        3873
  2.00 a.m. -  3.00 a.m. 0        372     2.00 p.m. -  3.00 p.m. 0        3868
  3.00 a.m. -  4.00 a.m. 0        275     3.00 p.m. -  4.00 p.m. 0        4327
  4.00 a.m. -  5.00 a.m. 0        340     4.00 p.m. -  5.00 p.m. 0        5277
  5.00 a.m. -  6.00 a.m. 0        703     5.00 p.m. -  6.00 p.m. 0        5033
  6.00 a.m. -  7.00 a.m. 0        3312    6.00 p.m. -  7.00 p.m. 0        4903
  7.00 a.m. -  8.00 a.m. 0        4674    7.00 p.m. -  8.00 p.m. 0        3894
  8.00 a.m. -  9.00 a.m. 0        4517    8.00 p.m. -  9.00 p.m. 0        3274
  9.00 a.m. - 10.00 a.m. 0        3537    9.00 p.m. - 10.00 p.m. 0        2725
 10.00 a.m. - 11.00 a.m. 0        3288   10.00 p.m. - 11.00 p.m. 0        2451
 11.00 a.m. - 12.00 p.m. 0        3863   11.00 p.m. - 12.00 a.m. 0        2198

       Type the key: [ESC]->Main Menu    [R]->Re-entry    [ENTER]->Next Screen
```

Figure 8: Directional Hourly Volume Data Screen (SB) for I-91 in Greenfield, MA

Output Section

This section describes output format for the project of Interstate 91 in Greenfield, MA. It is a word format where the output is in terms of queue (in miles), as shown in the table below.

Table 2: Work Zone Output Parameters for I-91 in Greenfield, MA

Hour (24hr)	Approach Speed (mph)	Work Zone Speed (mph)	Queue Length (mi)
10 --11	57	48	0.0
11 -- 12	57	20	0.0
12 -- 13	56	20	0.2
13 -- 14	56	20	0.6
14 -- 15	56	20	1.2
15 -- 16	56	20	2.0
16 -- 17	55	20	3.1
17 -- 18	56	20	4.0
18 -- 19	57	20	4.2
19 -- 20	58	20	3.4
20 -- 21	58	20	1.7
21-- 23	59	46	0.4
22 -- 23	59	58	0.0
23 -- 24	60	58	0.0

The procedure for entering data in this screen is similar to previous screens. Preliminary Screens are the first group. In this group, the first screen that appears when main menu item 1 is selected is the Model Options Screen. For this second specific work zone location, a series of screens are captured and illustrated. Figure 9 and Figure 10 are the screens for the project of work zone segment in Interstate 91 Windsor, CT. The directional hourly volume data is provided by the Connecticut Department of Transportation. In this research, the output is queue length (in miles).

Figure 9: Model Options Screen for I-91 in Windsor, CT

```
                    ┌─────────────────┐
                    │ Model Constants │
                    └─────────────────┘

        QUEWZ-98 uses a series of model constants for various calculations.
     Either the default values provided below may be used, or new values may
     be specified that better represent local conditions.

                                                      Present      New
                                                      Value        Value

        Cost Update Factor----------------->          1.0          1.0
        Percentage of Heavy Vehicles (%)--->          8            8

        Speed-Volume Relationship:

        Free Flow Speed (mph)--------------->         60           70
        LOS D/E Breakpoint Speed (mph)------>         46           56
        Speed at Capacity (mph)------------->         30           40
        LOS D/E Breakpoint Volume (vphpl)-->          1850         2100 0
        Volume at Capacity (vphpl)---------->         2000         2395 5


     Type the key: [ESC]->Main Menu    [R]->Re-entry    [ENTER]->Next Screen
```

Figure 10: Model Constants Screen for I-91 in Windsor, CT

The free-flow speed was determined to be 70 miles per hour (mph), based on the recommendations of the Highway Performance Monitoring System Field Manual. The freeway capacity was estimated as 2395 vehicles per hour per lane (vphpl) with a resulting jam density of 135 vehicles per mile per lane (vpmpl). LOS D/E Breakpoint Volume was determined to be 2100 vehicles per hour per lane (vphpl). The work zone lane closure procedure, the number of lanes to be closed and the time to be closed is shown in the Figure 11 and Figure 12.


```
                    ┌────────────────────────────┐
                    │ Lane Closure Configuration │
                    └────────────────────────────┘

        The lane closure configuration is specified by the number of directions
     in which lanes are closed, the total number of lanes and number of lanes
     open in each direction, and the length of the work zone lane closure.

                                                      Present      New
                                                      Value        Value

        Number of directions (1 or 2)--------------->   0            1

        Total lanes (2 - 6 are acceptable)
             Inbound--------------------------------->   0            2
             Outbound-------------------------------->   0            2

        Open lanes
             Inbound (1 - 2 are acceptable)---------->   0            1
             Outbound-------------------------------->   0            2

        Length of the lane closure (miles)----------> 0.0          1.0

     Type the key: [ESC]->Main Menu    [R]->Re-entry    [ENTER]->Next Screen
```

Figure 11: Lane Closure Configuration Screen for I- 91 in Windsor, CT

```
┌─────────────────────┐
│ Schedule of Work Activity │
└─────────────────────┘

    The Road User Cost option evaluates a time schedule specifying when
lanes are closed and when work activity is actually underway.  Work
activity may be conducted during any part or all of the time that lanes
are closed.

                                              Present    New
                                               Value    Value

     Hour lane closure begins----------------->   0        8
         ( 0 - 23 are acceptable)
     Hour lane closure ends------------------->    0       16
         ( 9 - 24 are acceptable)


     Hour work activity begins--------------->     8        8
         ( 8 - 15 are acceptable)
     Hour work activity ends----------------->    16       16
         ( 9 - 16 are acceptable)


 Type the key: [ESC]->Main Menu    [R]->Re-entry    [ENTER]->Next Screen
```
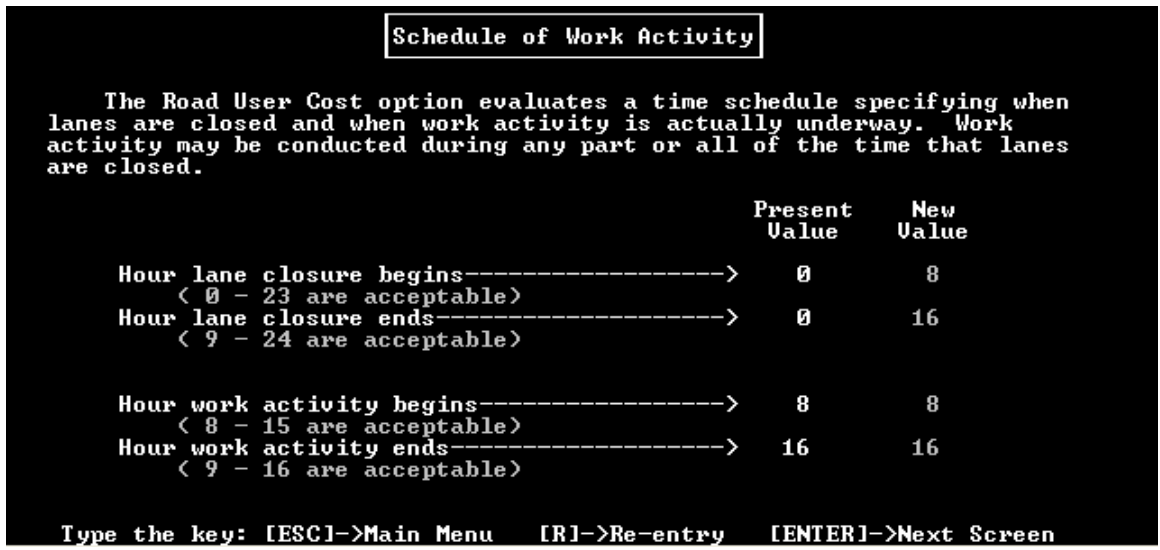
Figure 12: Schedule of Work Activity Screen for I-91 in Windsor, CT

QUEWZ Analysis for I-95 in Bangor, ME

The Maine Department of Transportation provided us with the directional hourly volume. For this research, the output is queue length (in miles). The free-flow speed was determined to be 70 miles per hour (mph), based on the recommendations of the Highway Performance Monitoring System Field Manual. The freeway capacity was calculated as 2400 vehicles per hour per lane with a resulting jam density of 140 vehicles per miles per lane. LOS D/E Breakpoint Volume was determined to be 2100 vehicles per hour per lane. Timings for both the days, when lane closure begins and ends the hours, when the work activity begins and ends. The engineers told us it lasted from 8 am till 4 pm every day of the week. The values were then entered into the simulation model. The output for the Interstate 95 Bangor, Maine project is presented in the simulation evaluation results.

QuickZone Analysis for I-91 in Greenfield, MA

Project BR# G-12-058, Bridge Rehabilitation Route I-91 Northbound and Southbound over the B&M Railroad was established under the direction of the Massachusetts Highway Department. The work zone is approximately one-quarter mile in length and is located as shown in Figure 13 [10].
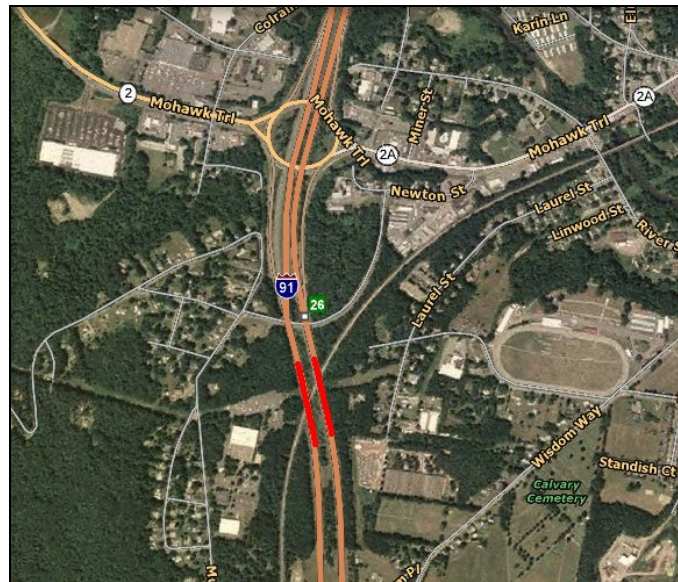

Figure 13: Work Zone Location for I-91 in Greenfield, MA

As described in the previous chapter, QuickZone has four critical user-defined input components for analysis. For this research, only the southbound direction was selected for analysis. Starting with *Network Data*, node information was entered to define the beginning and end of each link in the roadway section. Node information is based upon an X-Y coordinate system defined by the user and is used to graphically generate the analysis network, as shown in Figure 14.
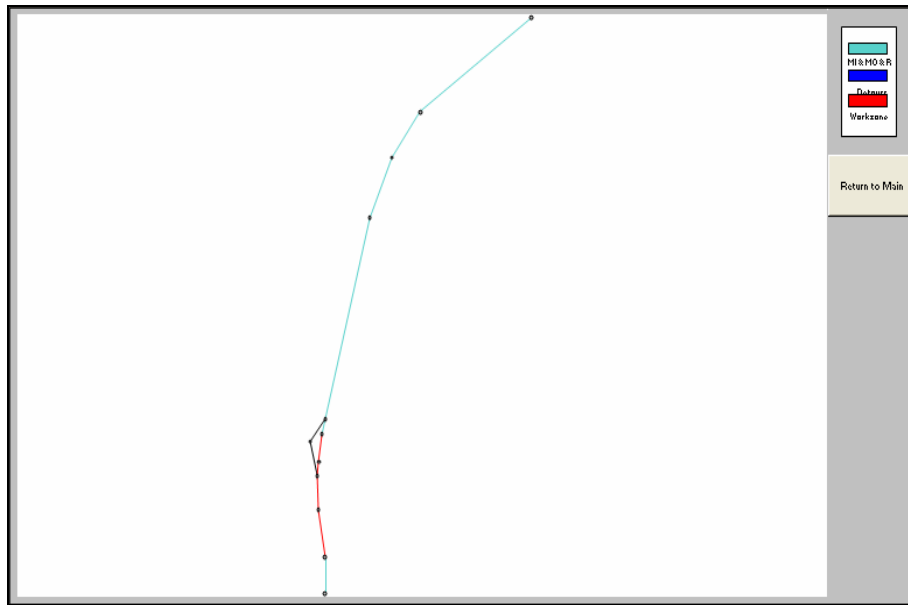
Figure 14: Analysis Network for I-91 in Greenfield, MA

Links are identified by the nodes defined previously and posses several attributes. These include the number of lanes, length, freeflow speed, capacity, jam density, and type (e.g. mainline, work zone, or detour). For this location, two lanes are normally available for travel in the southbound direction. Link lengths were adopted from work previously done by the author, but could also have been scaled from construction documents. Free-flow speed was determined to be 70 miles per hour (mph) as recommended by the Highway Performance Monitoring System Field Manual. Using the freeway capacity estimation procedure described by the same resource, capacity was calculated as 2395 vehicles per hour per lane (vphpl). The resulting jam density was calculated as 135 vehicles per mile per lane (vpmpl). Figure 15 provides an image of this link characteristic input as seen in QuickZone.

Link #	A Node	B Node	Lanes	Capacity (VPL)	Length (Miles)	Freeflow Speed (mph)	Jam Density (V/mi/L)	I or O	Type
1	1	2	2	2395	0.76	70	135	I	M
2	2	3	2	2395	0.26	70	135	I	M
3	3	4	2	2395	0.31	70	135	I	M
4	4	5	2	2395	0.95	70	135	I	M
5	5	6	2	2395	0.07	70	135	I	M
6	6	7	2	2395	0.13	70	135	I	WZ
7	7	8	2	2395	0.06	70	135	I	WZ
8	8	9	2	2395	0.16	70	135	I	WZ
9	9	10	2	2395	0.22	70	135	I	WZ
10	10	11	2	2395	0.17	70	135	I	M
11	5	12	1	1100	0.14	50	88	I	
12	12	8	1	1100	0.16	50	88	I	

Figure 15: Link Characteristics for I-91 in Greenfield, MA

Travel Demand Data is essential to produce reliable analysis results. Depending on the availability or quantity of such data, this portion of input may be the most extensive and time consuming. The user specifies either the average annual daily traffic (AADT) or hourly counts in terms of vehicles. The travel demand data for this analysis was adopted from work previously completed by Heaslip. This data was in the form of hourly counts and was entered for each link over a seven day, 24-hour period. Additionally, truck percentages of 1.67 percent were applied to each link. A snapshot of the traffic demand entered in QuickZone is shown in Figure 16.

Sunday

Link	I or O	AADT	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00
1	I		117	68	45	22	48	108	196	312	496	812	1095	1266	1362
2	I		117	68	45	22	48	108	196	312	496	812	1095	1266	1362
3	I		117	68	45	22	48	108	196	312	496	812	1095	1266	1362
4	I		117	68	45	22	48	108	196	312	496	812	1095	1266	1362
5	I		64	44	28	17	37	73	131	224	365	596	846	1008	1099
6	I		64	44	28	17	37	73	131	224	365	596	846	1008	1099
7	I		64	44	28	17	37	73	131	224	365	596	846	1008	1099
8	I		153	108	57	29	63	132	247	363	579	947	1321	1557	1611
9	I		153	108	57	29	63	132	247	363	579	947	1321	1557	1611
10	I		153	108	57	29	63	132	247	363	579	947	1321	1557	1611
11	I		53	24	17	5	10	35	65	88	131	216	249	258	263
12	I		89	64	29	12	26	59	116	139	213	350	476	549	513

Figure 16: Network Demand for I-91 in Greenfield, MA

Project Data includes both global parameters as well as specific construction phase data. The global parameters provide basic project information that will later be used in the analysis of

defined construction phases. For this research, a number of assumptions were made in regard to the global parameters. A project start date of May 1, 2005 was selected with a construction phase duration of 42 weeks. The yearly demand increase was assumed to be the default value of two percent and the yearly capacity decrease was assumed to be zero percent. The project infrastructure cost of $1.85 million was obtained from project information provided by the Massachusetts Highway Department.

The construction phase data describes the major capacity reducing activities throughout the project's duration. For analysis purposes, the left lane in the southbound direction was considered closed, mirroring the actual staged lane drop. Work zones were established 24 hours per day, seven days per week for the duration of this project phase. Details for Construction Phase 1 (as entered in Quick Zone) are shown in Figure 17. Within this window, the work zone plan editor allows the user to describe individual work tasks during the defined construction phase. The work zone plan defines the capacity impact of a specific construction activity and how the traffic on individual links will react to the construction. Modifications can be made to the start and end time of each day's activity, to the affected link's associated capacity decreases, to mitigation strategies, and to changes in travel behavior. For this analysis, capacity decreases were estimated using the 2000 Highway Capacity Manual function within the QuickZone program. Due to the presence of the work zone and the lane drop, the capacity of each of the defined work zone links was reduced by a total of 3190 vehicles per hour. This resulted in a work zone capacity of 1600 vehicles per hour for the one available lane. An example work zone plan for Construction Phase 1 is shown in Figure 17 and Figure 18.

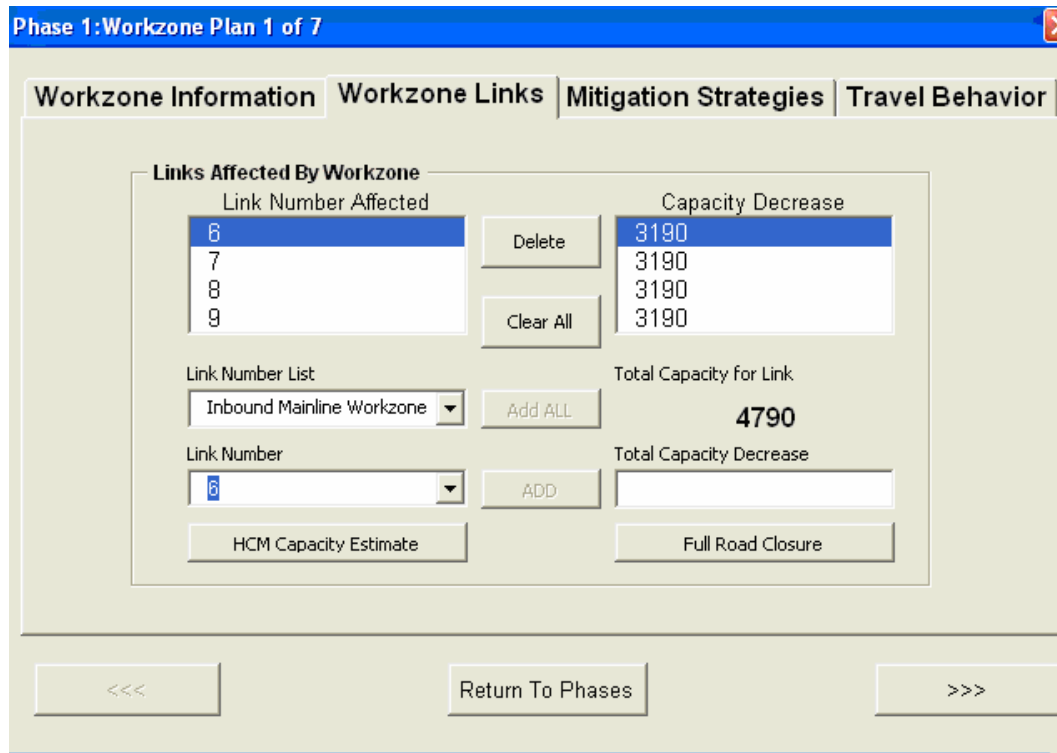**Figure 17: Construction Phase Information for I-91 in Greenfield, MA**

Figure 18: Work Zone Link Editor for I-91 in Greenfield, MA

Quick Zone's goal in terms of ease-of-use is less than three hours to prepare and input a network, and less than three minutes to analyze the data and produce delay profiles over the project duration. For this analysis, data entry took approximately two and half hours, the analysis took under one minute.

The analysis results show that on Sunday at 4:00 pm to have the highest delay in vehicle hours per hour for this particular phase of the Interstate 91 project. The delay graph in Figure 19 shows the delay value to be 982.2 vehicle-hours per hour. The same figure shows how delay varies over a seven day, 24-hour period. The QuickZone output reveals that motorists traveling through this work zone will experience delay caused by its existence on Sunday only. The

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capacity reductions as calculated by the HCM 2000 method cause this section of I- 91 to have a greater demand than it can support only during the afternoon hours of Sunday. Users have the ability to analyze a particular construction phase if more than one are defined and may select the exact days which they wish to review. The daily delay graph shown in Figure 19 illustrates the propagation of delay for Sunday. It can be seen that the delay starts to generate around 11:00 am, reaching a maximum at 4:00 pm. QuickZone estimates the delay to be totally dissipated by 7:00pm.
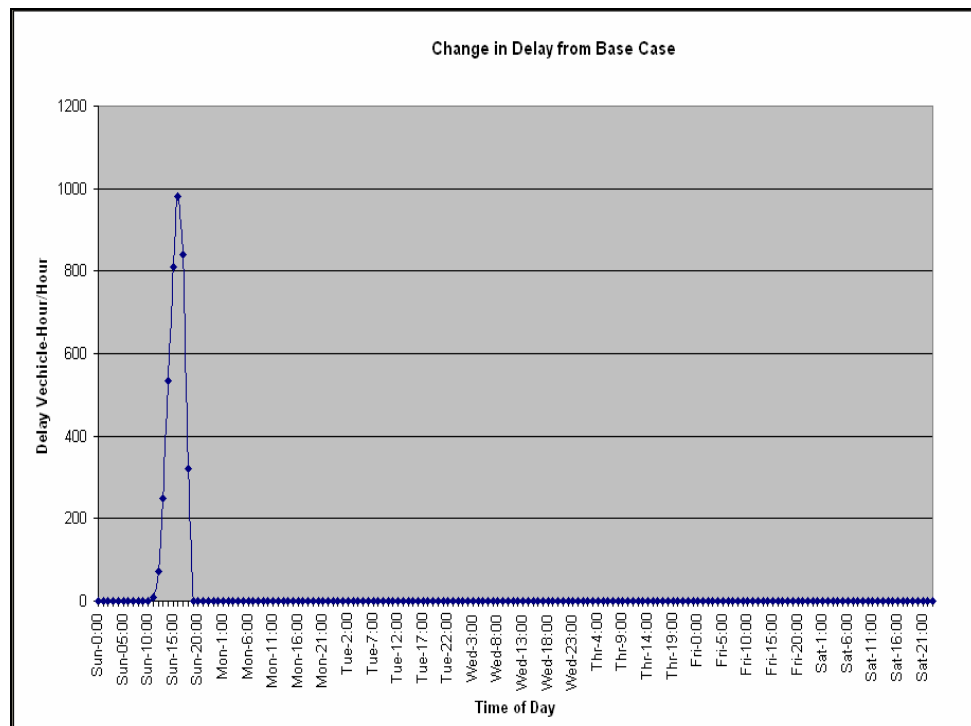

Figure 19: Weekly Delay Estimation Graph for I-91 in Greenfield, MA

The summary table provides data on key elements relative to the project: queue in terms of miles and delay in veh-hr per hr. For this analysis, the summary table reveals that the weekly maximum queue occurs on Sunday with a value of 3.85 miles. The resulting weekly maximum

delay is estimated as 13 minutes. Additionally, the table reveals that the expected weekly queue will total 14.1 miles. A snapshot of the queue, delay, travel behavior, and cost for this project as estimated by QuickZone is shown in Figure 20.

Queue-Both		Delay-Both			Phase Travel Behavior (Weekly Inbound + Outbound)				Cost (millions $)-Both			
Weekly Max (mi)	Weekly Total (mi)	Weekly User Max (min)	Weekly Total (VH)	Phase Total 1000 (VH)	Take Detour (V)	1HR Shifting	Cancel Trip (V)	Mode Shift (V)	Infrastructure	Delay Car	Delay Trucks	Delay Total
3.85	14.1	13	3817.7	160	0	933	116	116	1.85	1.28	0.07	1.35
3.85	14.1	13	3817.7									
0	0	0	0									
0	0	0	0									
0	0	0	0									
0	0	0	0									
0	0	0	0									
0	0	0	0									
0	0	0	0	0	0	0	0	0	0	0	0	0
									1.85	1.28	0.07	1.35

Figure 20: Analysis Summary Table for I-91 in Greenfield, MA

It should be noted that QuickZone is capable of analyzing full lane closures. In order to conduct such an analysis, however, detour routes must be defined as part of the analysis network. The definition of these routes includes starting and ending points, link lengths and characteristics, daily demands, etc. Analyzing a full lane closure for this portion of Interstate 91 is possible, but is not included within this research.

QuickZone Analysis for I-91 in Windsor, CT

Project No. 63-577 is the project of Interstates I-91 Resurfacing and Safety Improvements. The work zone located on the pedestrian bridge in Hartford to north of Capen Street in Windsor, which is approximately one quarter to one third mile in length and is located as shown in Figure 21.

As with the Interstate 91, Windsor, CT, QuickZone Delay Estimate Program Version 1.01 is used to analyze the effects and productivity of this site. The following sections explain the use of the simulation models regarding to this specific section.
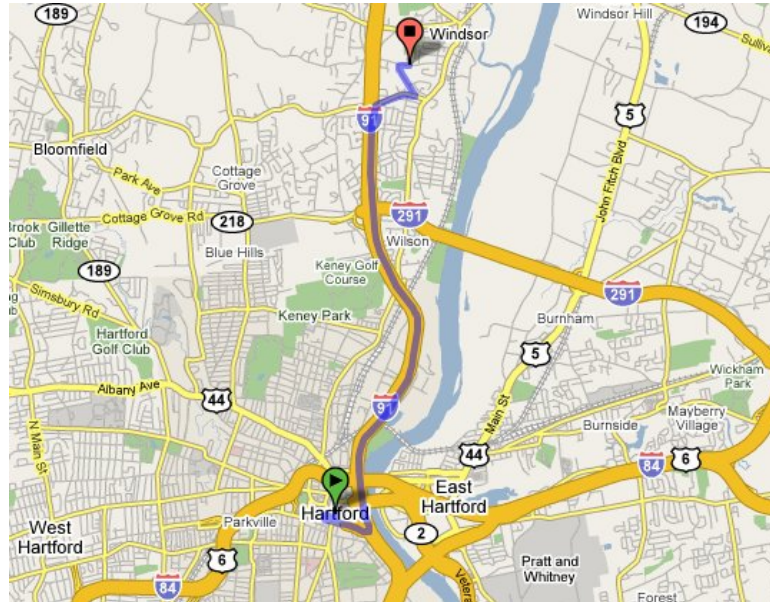

Figure 21: Work Zone Location for I-91 in Windsor, CT

The QuickZone analysis procedure for this work zone was carried out in the same way as for Interstate 91 in Greenfield, MA. For this portion of the research, only the southbound direction of travel was selected for analysis. Node information was entered to define the beginning and end of the roadway section, as shown in Figure 22.
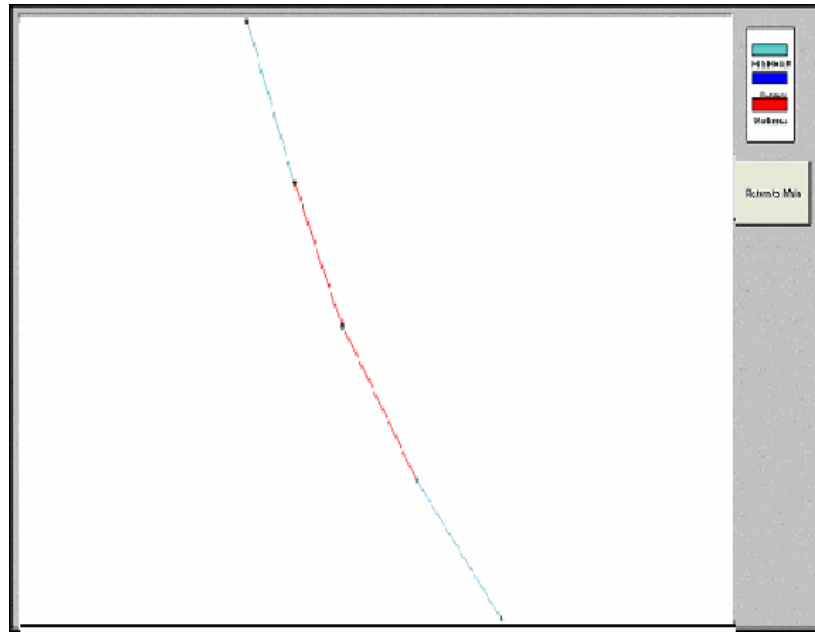
Figure 22: Analysis network for I-91 in Windsor, CT

Link lengths were scaled from construction documents provided by the Connecticut Department of Transportation as shown in the Figure 23.

Link #	A Node	B Node	Lanes	Capacity (VPL)	Length (Miles)	Freeflow Speed (mph)	Jam Density (V/mi/L)	I or O	Type
1	1	2	2	2395	0.28	70	135	I	M
2	2	3	2	2395	0.08	70	135	I	WZ
3	3	4	2	2395	0.21	70	135	I	WZ
4	4	5	2	2395	0.28	70	135	I	WZ
5	5	6	2	2395	0.28	70	135	I	M

Figure 23: Link Characteristics for I-91 in Windsor, CT

The travel demand data for this analysis was also provided by the Connecticut Department of Transportation. This data was in the form of hourly counts and was entered for each link over a seven day, 24-hour period. Truck percentages of two percent were assumed for this location and applied to each link over the same time period. A snapshot of the traffic demand as entered in QuickZone is shown in Figure 24.

Sunday																
Link	I or O	AADT	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00
1	I		283	256	233	168	166	327	652	870	1132	1429	1733	2016	2070
2	I		283	256	233	168	166	327	652	870	1132	1429	1733	2016	2070
3	I		283	256	233	168	166	327	652	870	1132	1429	1733	2016	2070
4	I		283	256	233	168	166	327	652	870	1132	1429	1733	2016	2070
5	I		283	256	233	168	166	327	652	870	1132	1429	1733	2016	2070

Figure 24: Network Demand for I-91 in Windsor, CT

As with Interstate 91 Windsor, CT, several assumptions were made with regard to global parameters. The phase duration was estimated by the Connecticut Department of Transportation to be 36 weeks. The yearly demand increase was assumed to be the default value of two percent and the yearly capacity decrease was assumed to be zero percent. The project infrastructure cost of $1.05 million was obtained from an estimate provided by the Connecticut Department of Transportation. Finally the output is in terms of queue in miles and delay in veh-hr per hr.

QuickZone Analysis for I-95 in Bangor, ME

This work zone located on the two lane interstate highway in Bangor, Maine, which is approximately one quarter to one third mile in length and is located as shown in Figure 25.

QuickZone Delay Estimate Program Version 1.01 and QUEWZ-98 were used to analyze the effects and productivity of this site. The following sections explain the use of QuickZone regarding to this specific section.
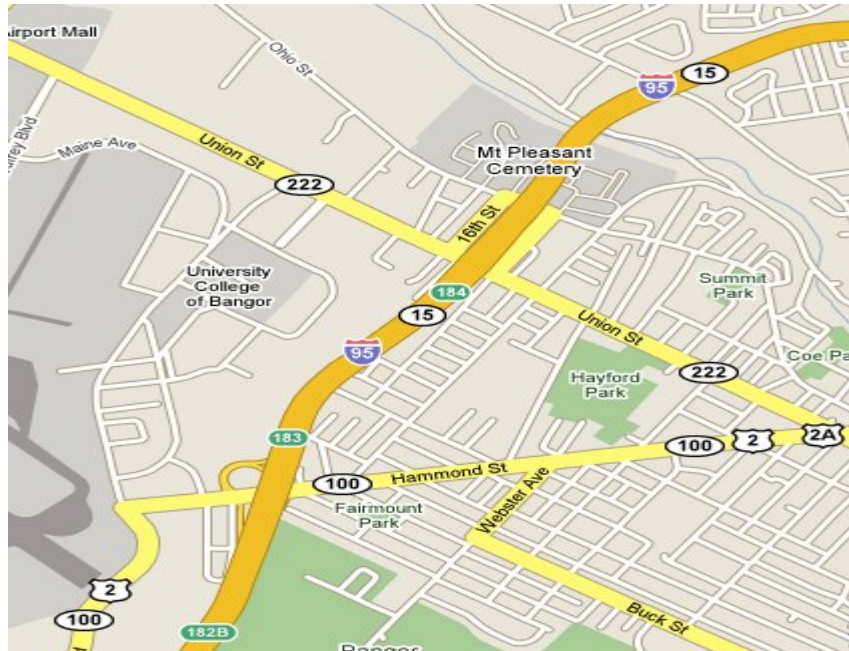
Figure 25: Work Zone Location for I-95 in Bangor, ME

The QuickZone analysis procedure for this work zone was carried out in the same way as for Interstate 91 in Greenfield, MA, and Interstate 91 in Windsor, CT. For this portion of the research, only the southbound direction was selected for analysis. Node information was entered to define the beginning and end of the roadway section. Link lengths were scaled from construction documents provided by the Maine Department of Transportation.

The travel demand data for this analysis was also provided by the Maine Department of Transportation. This data was in the form of hourly counts and was entered for each link over a seven day, 24-hour period. Truck percentages of two percent were assumed for this location and applied to each link over the same time period.

As with Interstate 95 in Bangor, ME, several assumptions were made. The phase duration was estimated by the Maine Department of Transportation to be twelve weeks. The project infrastructure cost of $1.15 million was obtained from an estimate provided by the Maine Department of Transportation.

The analysis results show Monday at 6:00 pm has the highest delay in vehicle-hours per hour. The QuickZone output reveals that motorists traveling through this work zone will experience delay on Monday evening and Friday evening. The capacity reductions as calculated by the HCM 2000 method cause this section of Interstate 91 to have a greater demand than it can support only during the afternoon hours of Sunday.

Simulation Results 1

Table 3 and Table 4 provide an evaluation of the results of this research for the QuickZone and QUEWZ simulation models.

For QuickZone, the parameter used for comparison is queue length. Beginning with Interstate 91 in Windsor, CT, QuickZone estimated a no queue on Monday and a maximum of 0.3 miles queue on Friday. The queue begins to build at around 9:00 pm. The queue is estimated to dissipate by early morning of the following day. Comparing these estimates to real-world data provided by the resident engineer working for Connecticut Department of Transportation, Quick Zone provides a fairly accurate estimate of the actual queue length.

Table 3: Queue Length Estimates Comparison of I-91 CT, MA and I-95 ME: Field Observation and QUEWZ-98 Simulation Results (in miles)

		I-91 Windsor, CT (3 lanes)			I-91 Greenfield, MA (2 lanes)				I-91 Bangor, ME (2 lanes)		
		Simulated Results		Field Observation	Simulated Results			Field Observation	Simulated Results		Field Obeseravtion
		Wu	Khanta		Moriarity	Wu	Khanta		Wu	Khanta	
MON	1 lane closed	0.3 (8pm)	0.3 (8pm)	0 ~ 0.5[1]	3.75	3.75 (6 - 7pm)	4.2(6 - 7)pm)	4 ~ 6[2]	4.1 (6-7pm)	4.1(6-7pm)	4-5 (6-7pm)[3]
FRI	1 lane closed	0.4 (9pm)	0	0 ~ 0.5[1]	2.5	2.5(7 - 8pm)	2.5(7 - 8pm)	4 ~ 6[2]	4.7 (4-5pm)	4.7(4-5pm)	4-5 (4-5pm)[3]
Notes	[1]Provided by Leon Alford, the Resident Engineer in Connecticut DOT										
	[2]Provided by Kevin Heaslip's dissertation "Modeling Driver Behavior in work zones "Presented at TRB annual meeting Jan 2008										
	[3]Provided by Redignton R.Robbins, the engineer at Maine DOT										

Table 4: Queue Length Estimates Comparison of I-91 CT, MA and I-95 ME: Field Observation and QuickZone Simulation Results (in miles)

		I-91 Windsor, CT (3 lanes)			I-91 Greenfield, MA (2 lanes)				I-91 Bangor, ME (2 lanes)		
		Simulated Results		Field Observation	Simulated Results			Field Observation	Simulated Results		Field Obeseravtion
		Wu	Khanta		Moriarity	Wu	Khanta		Wu	Khanta	
MON	1 lane closed	0.3 (9pm)	0	0 ~ 0.5[1]	3.75	3.75 (4 - 5pm)	5.2(4-5pm)	4 ~ 6[2]	4.5 (5pm)	4.5(5pm)	4-5 (6-7pm)[3]
FRI	1 lane closed	0.3 (9pm)	0.2 (9pm)	0 ~ 0.5[1]	N/A	4.86(5pm)	5.6(5pm)	4 ~ 6[2]	4.7 (4-5pm)	4.7(4-5pm)	4-5 (4-5pm)[3]
Notes	[1]Provided by Leon Alford, the Resident Engineer in Connecticut DOT										
	[2]Provided by Kevin Heaslip's dissertation "Modeling Driver Behavior in work zones "Presented at TRB annual meeting Jan 2008										
	[3]Provided by Redignton R.Robbins, the engineer at Maine DOT										

QUEWZ's estimates are very similar to Quick Zone's. QUEWZ provides fairly accurate estimation of the queue length as well. QUEWZ estimated a maximum queue of 0.3 miles to occur on Monday. The queue begins to build at around 8:00pm on the Monday that was modeled. These results are consistent with the real-world date.

QuickZone estimated that Interstate 91 in Greenfield, MA had a 5.2-mile queue that occurs on a Monday. The queue begins to generate around 11:00 am, reaching its maximum at approximately 4:00 pm. The queue is estimated to dissipate by 7:00 pm. Comparing these estimates to real-world data; QuickZone provides a fairly accurate estimate of the actual queue length. Heaslip reports that on most Sundays, the queue would be 4 to 6 miles with propagation beginning at about 11:30 am. The queues would dissipate between 4 to 6 pm, depending on demand for that afternoon. QUEWZ's results are also fairly comparable to the real-world data. The simulated results are in the same order of magnitude with the field observed results. Therefore, QUEWZ provides fairly accurate estimation of queue length.

Analysis 2

QuickZone Analysis for I-93 in Manchester, NH

This work zone is located on the three lane interstate highway in Manchester, New Hampshire, which consists of intermittent bridge rehabilitation works along the 1.7 mile length and the locations were cited as red shown in Figure 26.

QuickZone Delay Estimate Program Version 1.01 and QUEWZ-98 were used to analyze the effects and productivity of this site. The following sections explain the use of QuickZone regarding this specific section.
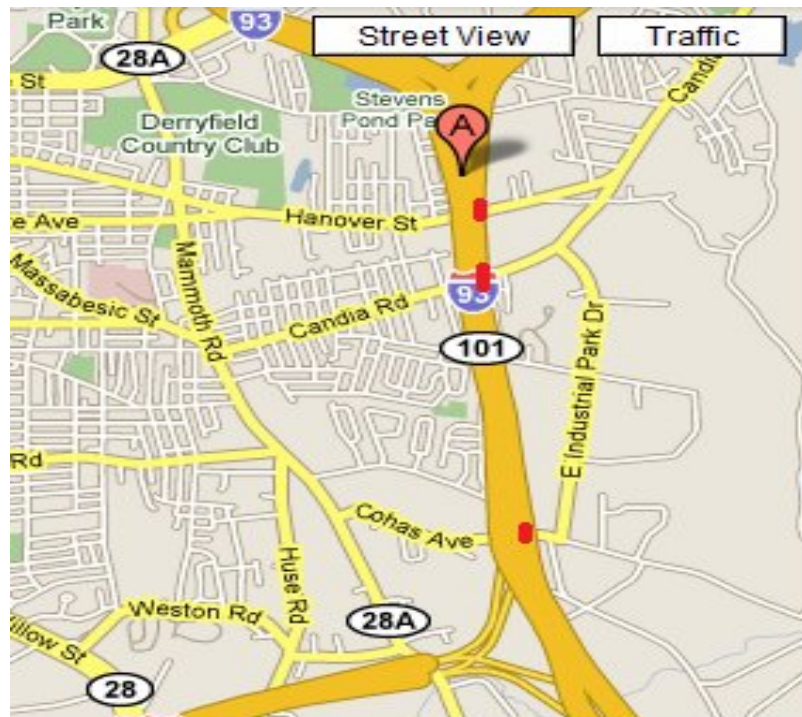

Figure 26: Work Zone Location for I-93 in Manchester, NH

The QuickZone analysis procedure for this work zone was carried out in the same way as for Interstate 91 in Greenfield, MA. For this portion of the research, only the northbound direction of travel was selected for analysis. Node information was entered to define the beginning and end of the roadway section. Link lengths were scaled from construction documents provided by the New Hampshire Department of Transportation.

The travel demand data for this analysis was also provided by the New Hampshire Department of Transportation. This data was in the form of hourly counts and was entered for each link over a seven day, 24-hour period. Truck percentages of four percent were assumed for this location and applied to each link over the same time period. The analysis results show that Monday at 6:00 pm has the highest delay in vehicle-hours per hour for this particular phase of the Interstate 93 Manchester, NH project.

CORSIM Analysis for I- 93 in Manchester, NH

CORSIM is a comprehensive microscopic traffic simulation tool used to analyze work zone for I-93 in Manchester, New Hampshire. The reason behind the selection of CORSIM is the entire route is not being rehabilitated, only the part of the road where bridges are being repaired. Therefore, CORSIM has the capability of creating long term events only on that particular area of Bridge Rehabilitation. The project involves bridge rehabilitation and bridgework along I-93/I-293/NH101 in city of Manchester. The work zone is approximately two miles on the I-93 NB and 1.7 miles on I-93SB. The construction activity requires closure of one lane in each direction along I-293/I-93/NH 101.

In this research, North bound was analyzed. The bitmap that is obtained from Google Maps is uploaded to scale and used to create a network. Scaling the bitmap is crucial to obtain accurate results.

Travel demand data entry at the origins of the network is entered either in the vehicle counts or volumes (vph). The data is obtained from the tables of the material provided by the state of New Hampshire Department of Transportation (NHDOT). A snapshot of the entry properties of the origins is shown in Figure 27.
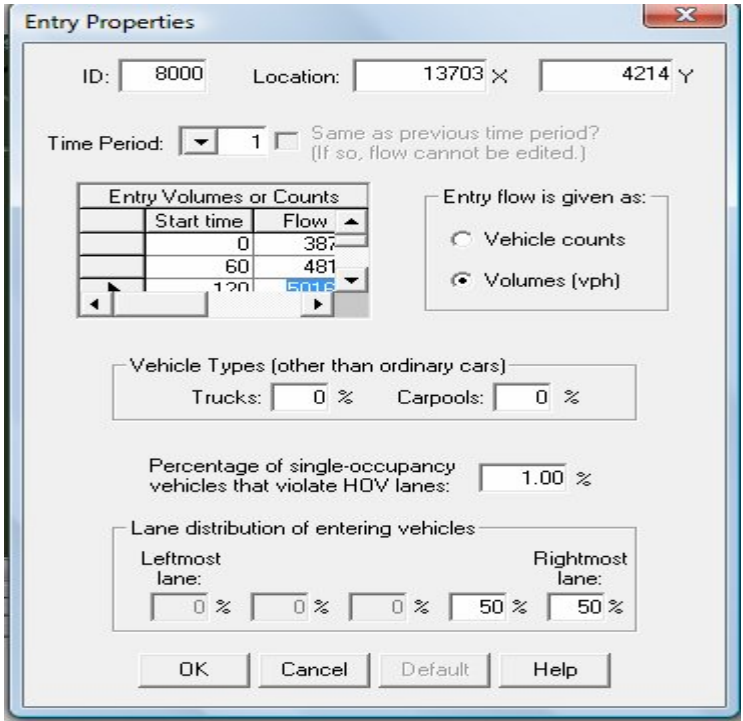
Figure 27: Network volume input data for I-93 in Manchester, NH

The second step in editing the surface link properties over the entire network is entering data such as the number of lanes data (acquired from Google Maps), and lane channelization (as

observed from Google Maps). This part of the editing takes time depending upon the networks

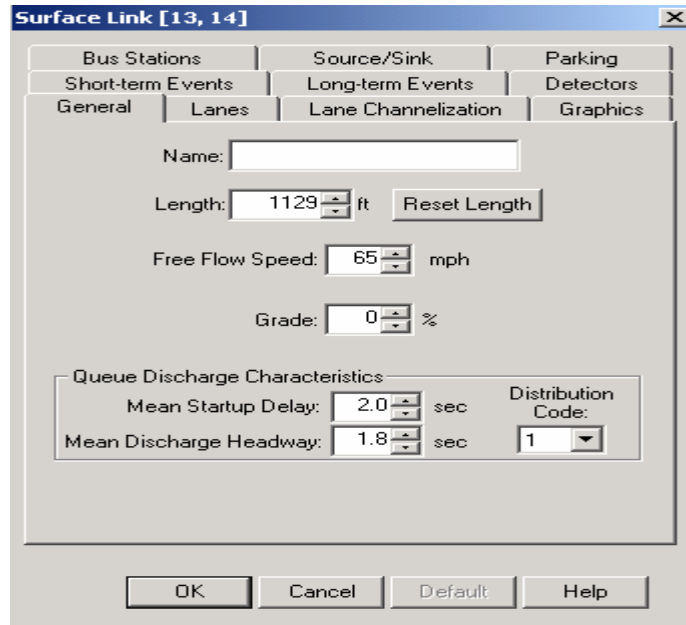complexity and size. The surface link editable window is shown in Figure 28.

Figure 28: Road Geometric properties for I-93 in Manchester, NH

The next step is editing properties of intersections, such as nodes, turn moments (according to

Google Maps), relative turn volume percentages data from the material of NHDOT, and finally

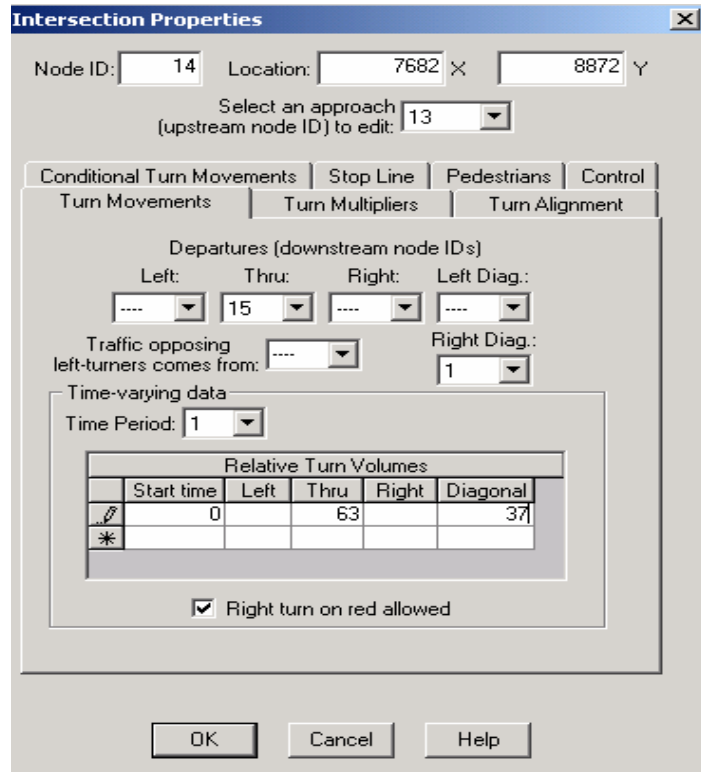adjustment of turn alignment of the all links near the intersection as shown in the Figure 29.

Figure 29: Intersection properties for I-93 in Manchester, NH

Run the simulation using CORSIM

Figure 30 (TRAFVU) has an overview of which links are the more congested in the network so that special attention can be taken while planning the pavement rehabilitation strategy in these links to reduce inconvenience to the commuters.
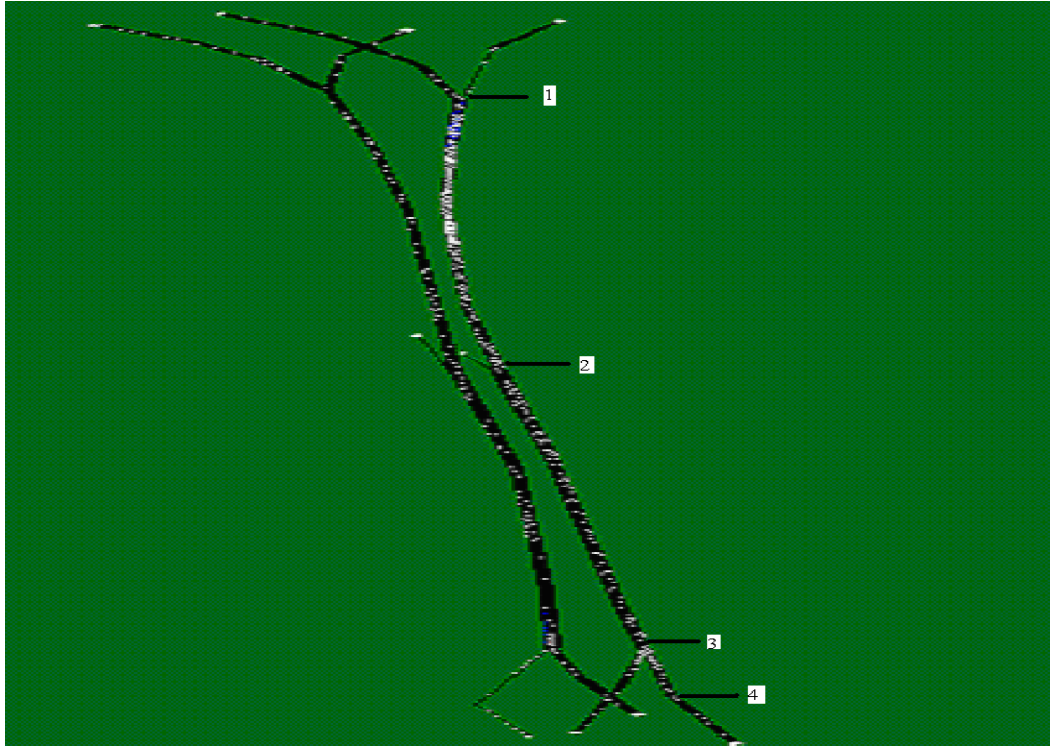
47

Figure 30: TRAFVU snapshot of I-93 Manchester, NH.

From the observations of the above figure on I-93 NB:

Between the points 1 to 2 the delay is high, the same as between 3 to 4

Queue is even also accumulated on the I-293; the left link of the link (3,4)

The MOE considered from the results of the CORSIM are the changes in average speed of vehicles in certain congested links of the network and delay time to traverse the network due to the lane closure.

Simulation Results 2

The evaluation portion of this research is to explain how well the software packages like QUEWZ, QuickZone and CORSIM were able to interpret the variations and forthcoming congestion problems due to the work zones in terms of delay in travel time, and speed variations due to the work zone on freeways. The summary of results is listed below in Table 5.

Beginning with Interstate 93 in Manchester, NH, QUEWZ estimated a 3.9-mile queue on Saturday. The queue begins to generate at 3pm, reaching a maximum at approximately 5pm and dissipating at around 8 pm. In case of Quick zone the value is 4.1-mile on Saturday. The queue begins to generate at 2pm, reaching a maximum at approximately 5pm and dissipating at around 10 pm. Difference in the results of the software packages is due to the individual capabilities of precise input data requirement. QuickZone requires data for preparing network which plays a key role in affecting in queue length due to addition of on and off ramps at intervals in the complex network.

CORSIM is a comprehensive microscopic traffic simulation tool which will help us to view the moving traffic so that we can come to conclusions about which links of the network congestion effects are greater in peak hour, so prior steps can be taken to reduce the effects, special attributes of the CORSIM are that it allows to load bitmap of real world scale and the network can be replicated as almost similar to the real world. The congestion is calculated in terms vehicles per lane per hour and difference in the travel time with and with work zone and can be observed with variation in the speed in each links due to work zone. Graphic views from the TRAFVU results will show which links of the network are more crowded with vehicles (Figure 30). Table 5 has been included below showing the results of various simulation tools.

Table 5: Simulation Results of I-93(SB) in Manchester, NH: Queue length and Travel Time Estimates

Simulation Package	Work zone Site and Location	Input DATA		Estimated Results in Terms
QUEWZ	Interstate 93, Manchester, NH	24hr volume		Max Queue length (mi)
				3.9 (6pm)
QuickZone	Interstate 93, Manchester, NH	24hr volume	Network data	Max Queue length (mi)
				4.1 (6pm)
CORSIM	Interstate 93, Manchester, NH	Peak hour volume	Network[1]	Increase in travel time (t_1-t_2)
				30 mins
[1] scaled to real world and nearly exact configuration t_1 = travel time without work zone in (min) t_2= travel time with work zone in (min)				

Analysis 3

CORSIM Analysis for Route-9 in Hadley, MA

Rehabilitation on both the eastbound and westbound of Route 9 Hadley, MA was established under the direction of Massachusetts Highway Department. The work zone is approximately 1.5 miles in length, located in Figure 31. The study site is the rural arterial (Route 9) near the Hadley area. The arterial Route 9 has pre-timed signals at each main junction and yield signs where required. In addition, Route 9 experiences heavy congestion that has been observed during the peak hour. Heavy inbound traffic was observed during morning peak and outbound traffic in afternoon peak. The reason for selecting the site is its recurring congestion, which worsens during road work.
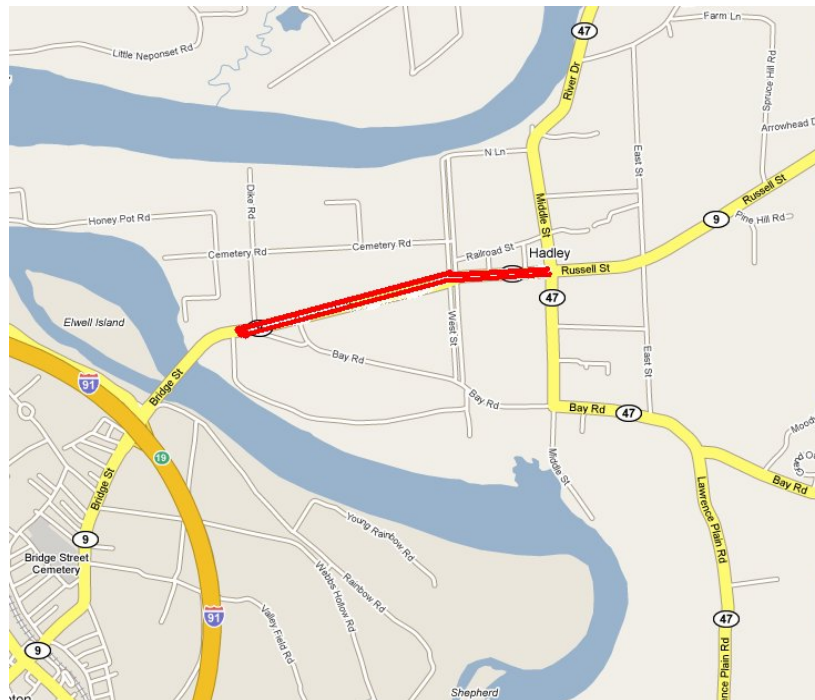

Figure 31: Work Zone location for Route-9 in Hadley, MA

Procedure to Run CORSIM Model:

Data Collection

Though the CORSIM simulation package is a very powerful tool, its accuracy is determined by the data used to create the simulation network. The required data was obtained to determine the following data fields would be necessary to run the simulation using the CORSIM software package:

1. Surface link properties (lengths, lanes, curvature, bus stations, long-term events, lane channelization); Figure 32

2. Traffic controls (signal timing, signs); Figure 33

3. Demands (entry volumes, turn volumes); and Figure 34

4. Calibration (traffic counts, & performance data such as speed and travel time); Figure 35

Furthermore, complete data collection for all the entry points was deemed infeasible. This is because access to automated data collection equipment was unavailable and it was then believed that the freeway and off-ramp data collected represented an unacceptable safety risk. As a result, it was decided to use the available count data from MassHighway, and, likewise, engineering judgment when data was not available.
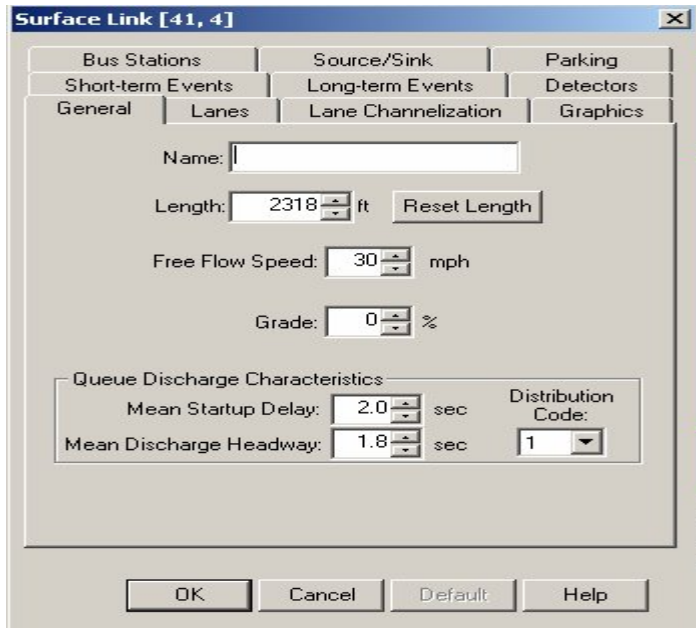
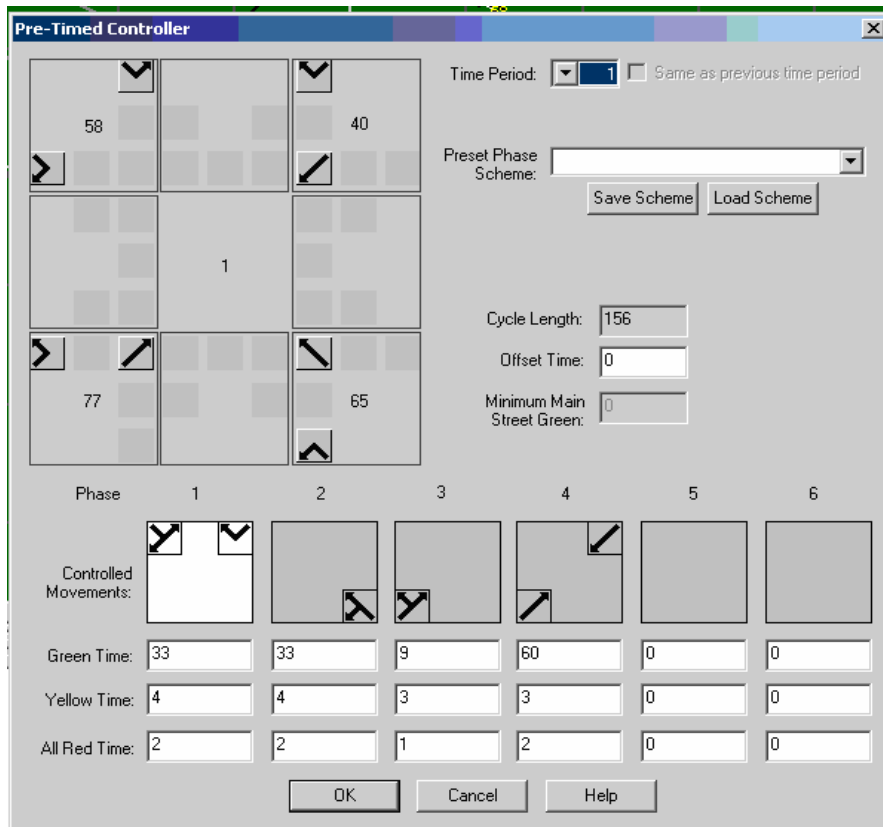**Figure 32: Surface link properties for Rt-9 in Hadley, MA**

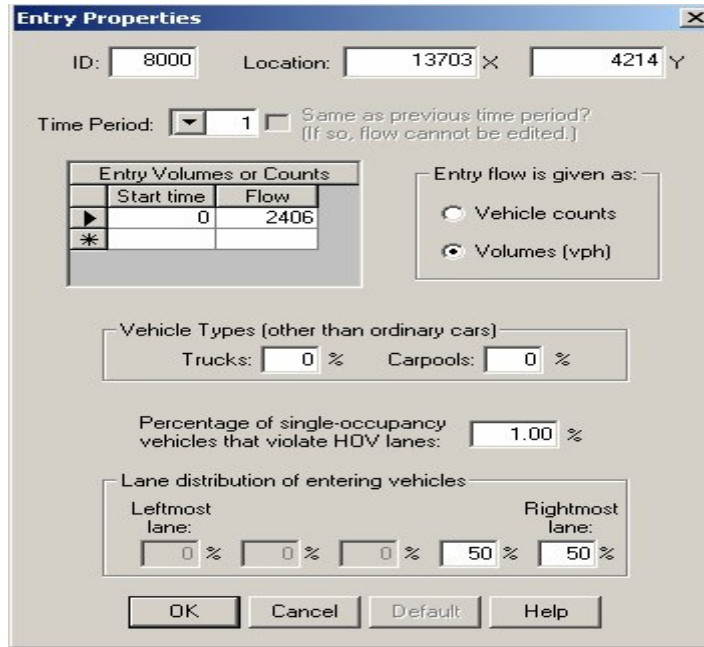**Figure 33: Signal Phase Timing for Route-9 in Hadley, MA**

Figure 34: Entry Properties for Route-9 in Hadley, MA
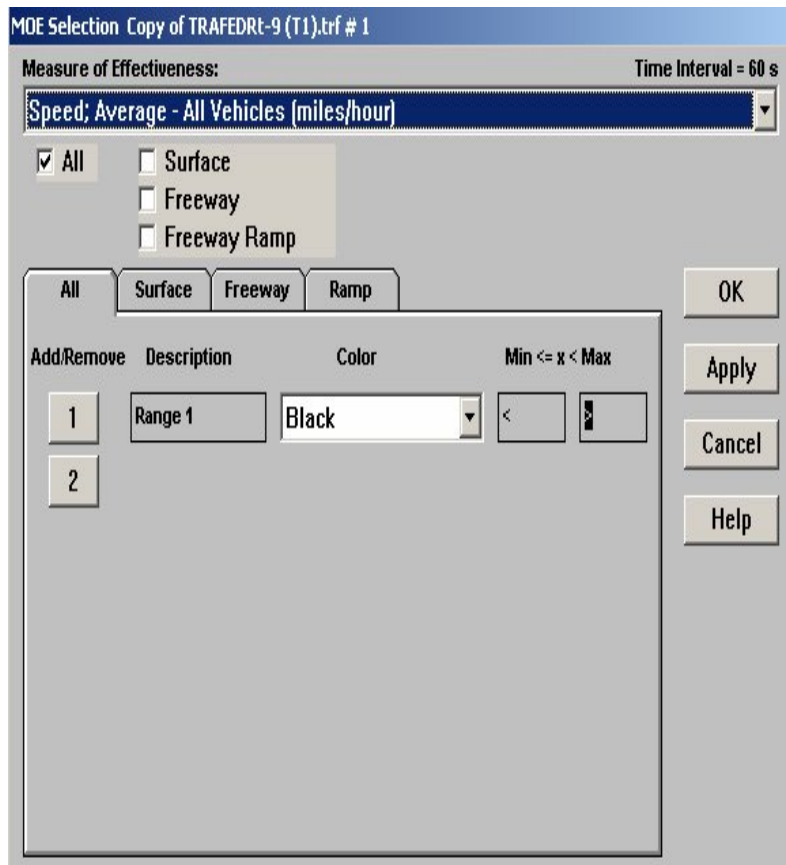

Figure 35: TRAFVU Dialog Box (MOE) for Route-9 in Hadley, MA

Road Geometry

Google Maps and field inspections were used to obtain the lengths and number of lanes for each route. Turn lanes and pocket lengths were determined for each intersection.

Traffic Controls

Existing signal timing of all the signalized intersections of Route 9 was obtained from field inspections using the Jamar Board for the evening peak.

Demands

Field measurements of traffic volumes on the freeway mainline, ramps, and turning movement counts at each intersection were conducted for a 15 min period using Jamar Board during the pm peak period (4:00 to 6:00 pm) in all the junctions of the network, ie

1. Route 9 ∕ Route 116

2. Route 9 ∕ Route 47

3. Route 9∕ Damon Road

Calibration Data

Volume counts for the origins and destinations are obtained from the masstraveler.com website, and the speed limits along each road of the network are obtained by field observation of the entire network.

CORSIM Methodology

Base Model Development

Building a model is analogous to building a house, as one begins with a blueprint, and then builds each element in sequence: the foundation, the framing, the roof, the utilities and drywall, and finally the interior details. The development of a successful simulation model is similar to that of the start with a blueprint (the link-node diagram), and then proceeding to build the model in sequence: coding links and nodes, filling in the link geometries, adding traffic control data at appropriate nodes, coding travel demand data, and finally selecting the model run control parameters.

The first step is to code the link-node diagram.

The next steps are to input:

1. The link geometry data,

2. The intersection traffic control data,

3. Traffic operations and data management data,

4. The traffic count data and

5. The run control parameters

The network is copied from the Google maps, and then uploaded into CORSIM using appropriate ratios (so that the model is to scale). This is demonstrated in Figure 36
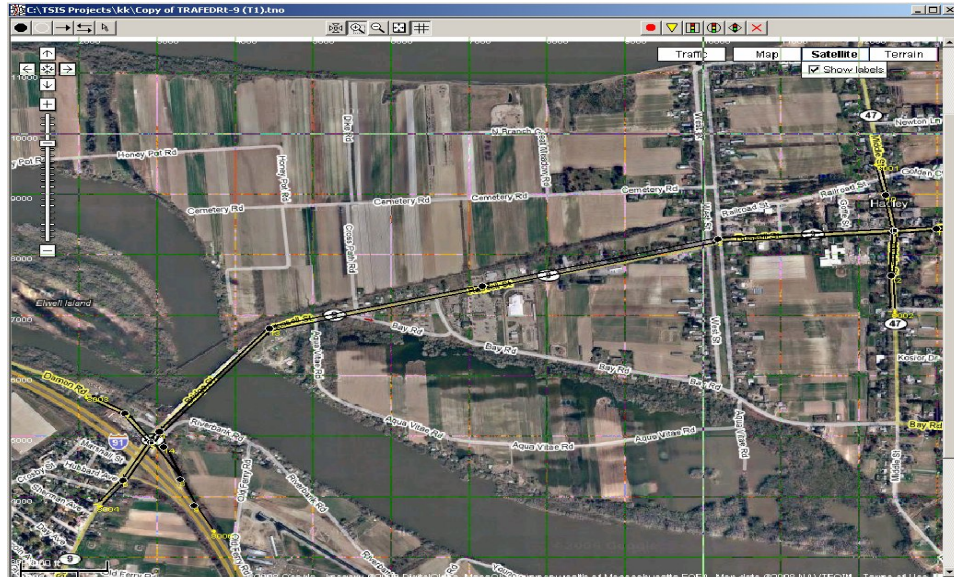
Figure 36: CORSIM Link-node diagram for Route-9 in Hadley, MA

Nodes are the intersection of two or more links. Nodes are usually placed in the model using X-Y coordinates and they represent an intersection or a location where there is a change in the link geometry. The node locations are obtained from aerial photographs, maps or physical survey. Finally the origin and destinations are created at exits of the network.

Links are one-directional segments of surface streets or freeways. Links represent the length of the segment, and usually contain data on the geometric characteristics of the road or highway between nodes. Ideally, a link represents a roadway segment with uniform geometry and traffic operations conditions.

Link Geometry Data

Once the coding of link-node diagram is completed, then we input the physical and operational characteristics of the links into the model. In this phase the following should be inputted in the software:

- Number of lanes

- Lane width

- Link length

- Others

Traffic Control Data at Intersections and Junctions

Vehicles are moved according to car-following logic, in response to traffic control devices and in response to other demands. Traffic control devices used for CORSIM simulation model are

- Yield signs

- Stop signs

- Signals (pre-timed)

Traffic Operations and Management data on links

Traffic operations and management data for links consist of regulatory data (speed limit, variable speed limit).

Volume Estimation

Count data from the MassHighway website is summarized in Table 5. However this data required further manipulation. Due to the fact that CORSIM allows volumes to be input separately for separate directions, directional design hourly volumes (DDHV) were required. To calculate DDHV the following equation was used:

$$DDHV = K * D_i \quad (1)$$

Where

K = of daily traffic occurring during the peak hour

D_i = proportion of peak hour traffic traveling direction i

For the purposes of the analysis it was assumed MassHighway data was a good approximation the actual average annual daily traffic (AADT), therefore AADT ≈ ADT * (seasonal adjustment factor). The on-site data counts were also only available for the peak 15 minutes of the afternoon rush; therefore it was necessary to adjust these numbers to hourly volumes as one hour is the intended simulation duration. Simply applying four in this situation would yield an overestimate as the volume data was taken for the peak 15 minutes and therefore a peak hour factor (PHF) must be applied using the following equation:

$$PHF = \frac{hourly\_volume}{max.\_rate\_of\_flow} = \frac{PHV}{4*V_{m15}} \rightarrow PHV = PHF*4*V_{m15} \tag{2}$$

Where

V_{m15} = peak 15 minute hourly volume

Next K was calculated using the following equation:

$$K = \frac{PHV}{AADT} = \frac{PHF*4*V_{m15}}{AADT} \tag{3}$$

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Finally, D could be calculated by dividing the observed volume in the peak direction by

(V_{Dm15}) by the total observed peak volume (V_{m15}) yielding the following equation:

$$D_i = \frac{V_{Dm15}}{V_{m15}} \quad (4)$$

Table 6: Traffic Volume Calculations

Input	DHV (entering)	ADT	K	D (entering)	V_m15	V_Dm15	PHF~	PHV	PDHV
Rt. 9 West	1621.8	11000	0.31	0.48	996	477	0.85	3386.4	1621.8
Route 9, EB	1149.2	10400	0.38	0.29	1170	338	0.85	3978	1149.2
47 @ 9 SB	183.6	4700	0.05	0.72	75	54	0.85	255	183.6

Once the volume data had was properly calculated and properly formatted vehicle network was built using the TRAFED tool within TSIS CORSIM interface. The network consists of surface links (black), with nodes connecting links at strategic points including intersections. The manual count data was used determine turn volumes at the intersection of Damon Road and Route 9. It was then necessary to make sure each link represented the system geography as accurately as possible. The final step before running the simulations was entering signal timing for the signal controlled intersections.

Network Calibration

Using data from MassHighway and manual counts obtained using the Jamar Board manual counting device; a network was created that roughly approximated field observation. However, due to the fact that volume data was not formatted ideally and several assumptions were needed

to be made achieve the fidelity of data required for the CORSIM model, further calibration of the model was necessary. Using notes taken in the field and engineering judgment, technicians visually inspected the TRAFVU network animation for discrepancies in volumes, vehicle speeds, performance of intersections, queue lengths, turning movement intentions and actual turning movements. This technique was especially useful when estimating traffic volumes which are highly sensitive to the values of K and D, as values for K and D could only be roughly approximated many cases. Using this method also ensured minimal errors in signal timing inputs.

Simulation Run Control Data

 CORSIM simulation software contains run control parameters to enable the modeler to customize the software operation for their specific modeling needs. These parameters include:

•Length of simulation time;

•Selected MOE(delay person-time) or outputs (e.g., reports, animation files, or both);
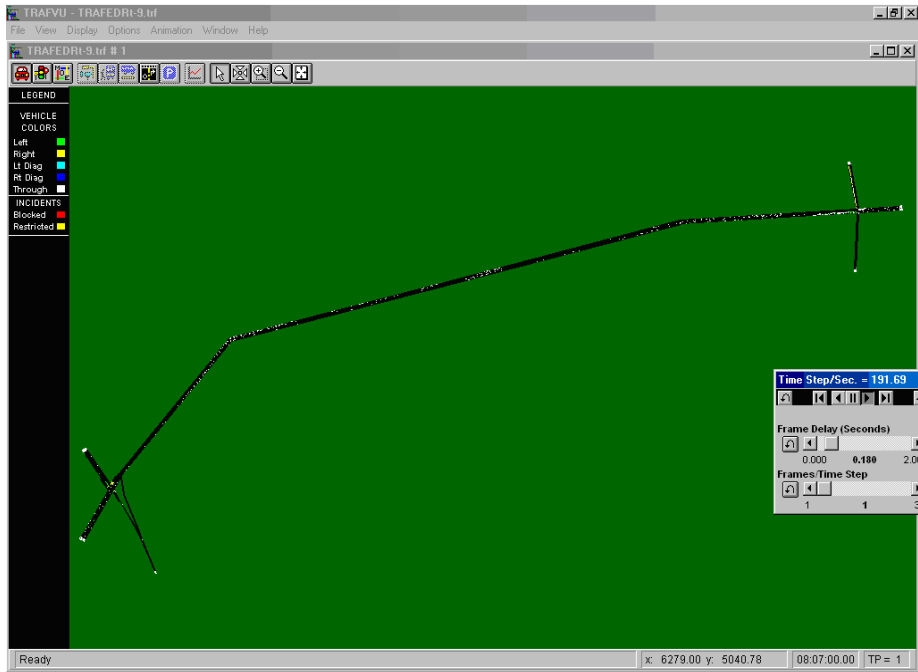
Figure 37 and Figure 38 are the Simulation Output results

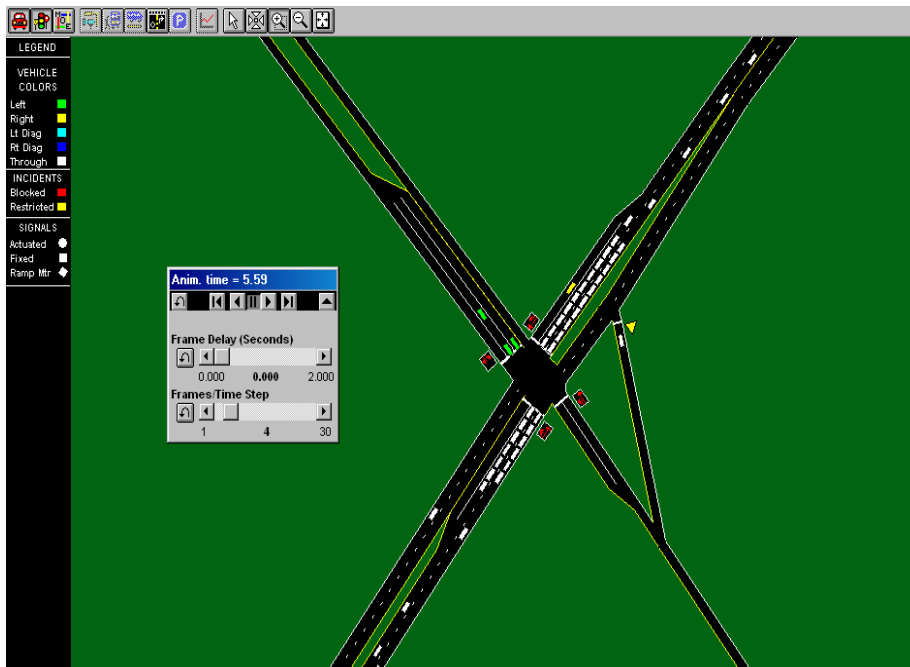**Figure 37: TRAFVU snapshot of Route-9 in Hadley, MA**

Figure 38: TRAFVU snapshot showing the I-91 off-ramp onto Route-9 (Exit 19)

Methodology

The procedure followed in evaluating Route-9 is as follows:

Step 1: Route 9 is evaluated for no Work zone.

Step 2: Evaluated for 1 lane closure for both the eastbound and westbound (Scenario-1)

Step 3: Choosing a detour (Figure below) for the westbound traffic with change in signal phase

timing at the intersection of Route-9/Route-47 (Scenario-2) as shown in the Figure 39.

Finally the results are comapred so as to fianlize the best Work Zone strategy to be followed.
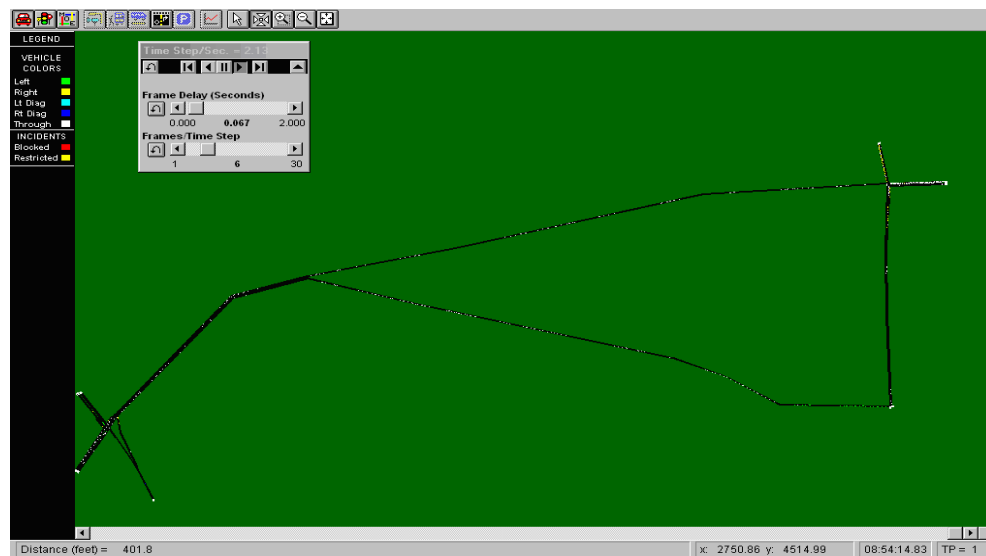

Figure 39: TRAFVU snapshot displaying the detour analyzed for Route-9(EB) lane closure

<u>CORSIM Analysis for Route-116 in Sunderland, MA</u>

Route 116 was resurfaced on August 12th & 13th, 2008, between the Sunderland Bridge and the T intersection, where Route-116 meets Route-5 as show in the figure 40. We used the resurfacing work as an opportunity to test the CORSIM simulation package.
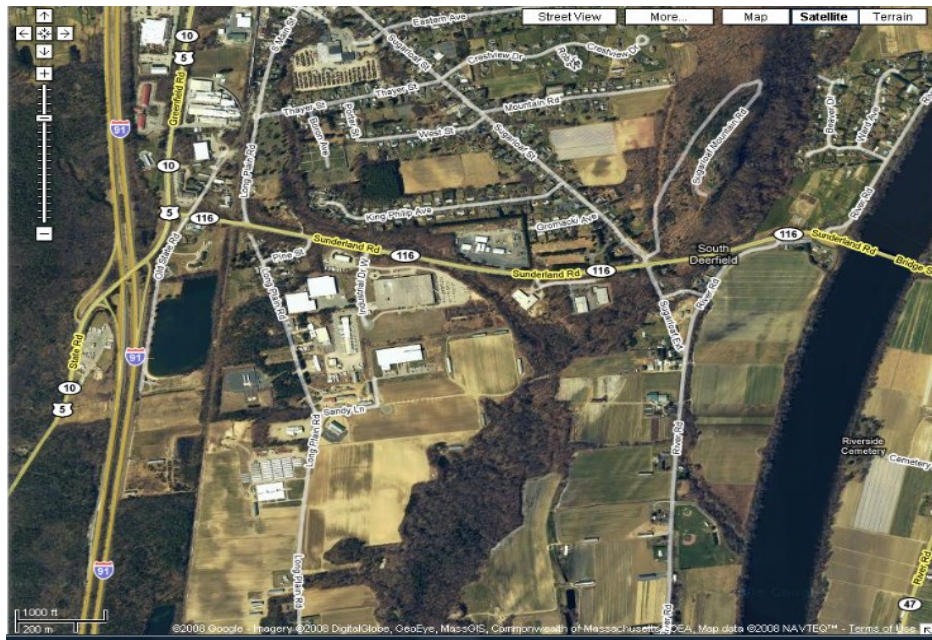

Figure 40 CORSIM link-node diagram for Route-116 in Sunderland, MA

This particular section of 116 has wide lanes with a huge breakdown lane; therefore, it was possible to move the traffic of both sides into one lane during resurfacing. A police officer directed traffic around the paver, allowing one lane to go at a time near the merging of the two lane traffic on to one lane along with the shoulder.

We (Khanta and Andrew) visited this site numerous times, collecting Traffic flows, average speeds, and travel times (for both the EB and WB directions) before and during construction using the floating car technique. This data was used to simulate Route 116 for the stretch, both before and during construction. The incident created by the police officer was simulated by

creating 60 second event which blocks the traffic along that stretch of road for both directions alternatively.

Simulation Results 3

The MOE for the vehicles traversing Route-9 are Travel Time in minutes and Average Speed in mph.

Table 7: Travel Time & Average Speed Estimates Comparison of Route-9 Hadley, MA: Field Observations and CORSIM Simulation Results (in min)

Route-9 Hadley, MA	No Work zone		with Work zone (scenario-1)		with Work zone (scenario-2)	
	WB	EB	WB	EB	WB	EB
Travel Time$_{(min)}$	6.59	21.33	9.09	40.45	7.2	27.56
Average Speed$_{(mph)}$	20.41	15.11	10.9	3.44	13.76	14.85

Travel time in the WB direction increased from 6.59 min to 9.09 min in case of scenario-1 and 7.2 in case of scenario-2.In EB direction the travel time increased from 21.33 min to 40.45min in scenario-1 and 27.56 min in scenario-2 due to lane closure. The travel time in case of EB traffic increased almost 1.92 times due to the Work Zone, the scenario to indicate as better option to move the vehicles on as the travel time is reduced to 27.56 min.

By evaluating alternative routes the minimum travel time route can chosen as there will not be more delay in the case of arterials, and delay or Queue back ups occur more over in rush hour periods only to a certain extent not as in the case of freeways.

From the results and observations of TRAFVU, MOE of the alternative scenarios, traffic signals cycle can be changed to relieve congestion according to the morning and evening peak hour, if not by choosing alternative routes.

The second part of the Analysis-3 description is of Route-116 in Sunderland, MA. Results of the CORSIM simulation tool and Field Observations are compared in Table 8 below.

Table 8: Travel Time Estimates Comparison of Route-116 in Sunderland, MA: Field Observation and CORSIM Simulation Results (in min)

Route 116, Sunderland, MA		No Work Zone		Work Zone	
		EB	WB	EB	WB
Travel Time (min)	Field observations	1:30[1]	1:27[1]	4:24[1]	4:20[1]
	CORSIM Run 1[2]	1:14	1:15	3:08	3:01
	CORSIM Run 2[2]	1:09	1:06	3:00	2:59

Note: [1] Travel time estimates in field observations were obtained by Floating Car Technique.

[2] Differences in travel time estimates in CORSIM Runs are a result of differences in network coding.

Projected travel time values were consistent with those attained from the field. Field times could have been greater for a number of reasons, including the number of interchanges, the raised structures in the road (such as sewer caps) due to preparation for resurfacing, and the fact

that the roads simulated were "straighter" and therefore shorter than the actual roadway and there were pretty number of turns.

Simulated travel times during construction, however, were significantly less than those attained on site. Using the average speed during construction for the free flow speed and volumes counted during construction, the network was constructed to model the construction zone. It was observed that the lane width values played no role in changing travel time, which is a practical error. From our experience on site, the narrow lanes created during construction caused traffic to move slowly and carefully.

Also, the values entered into the simulator were collected during construction, and speeds were slower than those collected prior to construction. The slower travel speeds (25mph compared to 50mph) entered increased travel time. Even with this increased travel time, the simulated values were off by over a minute in both directions for both simulations. Replicating the work zone conditions in simulation is incomplete due to the limited capabilities.

CHAPTER V

SUMARRY, CONCLUSIONS AND RECOMMENDATIONS

The selection and use of a proper simulation package can be very important steps in the evaluation of alternative work zone strategies. For rural and urban freeways QuickZone yielded good results and is capable of analyzing 24 hr volumes to estimate the expected queues. Such results may help transportation engineers evaluate alternative strategies including detours and night and weekend work schedules to reduce congestion. QUEWZ also does a good job in determining the queue length for alternative work strategies on freeways but unlike QuickZone is not as effective in considering the network structure.

In the evaluation of alternative work zone strategies along arterials software packages such as CORSIM and VISSIM should be considered because they can better analyze complicated arterial networks and can better depict the congested areas visually. It was clear that the analysis in this study was considerably strengthened by using CORSIM due to its capability of allowing to building complex networks with adaptability of latest traffic devices. When presented with results from a simulation model, many often have a degree of skepticism. This natural reaction can be addressed, at least in part, with the two-model approach as employed in this study. Of course, resources, which include time, money and experience, do not always permit the use of multiple models. It is hoped that similar studies will be conducted that highlight where specific simulation models might perform well, such as in the case of arterials. This will allow those using just one particular model to have more confidence in their results.

It goes without saying that analysts should have a strong technical knowledge of the simulation models being used. For the work described here, this was particularly important. Since the system was severely congested, minor changes to a package (such as in the use of CORSIM input files) often had a significant impact on the results. In particular, detailed knowledge of the following was found to be critical with CORSIM. For example, factors affecting lane selection including congested conditions are exacerbated by vehicles that bypass the back of a queue in their desired lane and then stop in another lane and wait to join the queue. In CORSIM it is possible to minimize this behavior with appropriate model coding techniques. Lane channelization, turning bay, lane alignment, and lane-change parameters may also impact lane selection.

This study also illustrated the value in using a range of performance measures. More generally, it proved the value in providing as much comparative information as possible before selecting a work zone strategy. In this case, data were available from two models for multiple performance measures, and for a range of demand scenarios. The results were generally consistent and the end product was a set of clear, defensible, and well-supported conclusions about the performance of the design alternative chosen. For the arterial analysis, multiple performance measures were used. System measures were supplemented by user-specific measures (e.g., travel time on average speed). Evaluation using multiple measures was found to be superior for three reasons:

Different models may have different ways of producing results. For example, control delay (at a signal) is measured differently, depending on the model.

Multiple measures provide more confidence when comparing alternatives (i.e., demonstrating that more than one performance comparison suggested a superior alternative).

It was clear that the sensitivity analysis would be a valuable part of this analysis. Again, it provided confidence to everyone that the results are consistent and reasonable. The sensitivity analysis will add another facet to the comparison process, more than one model developed, more than one performance measure applied, and more than one set of demand assumptions considered.

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