Using Simulation Models to Assess the Impacts of Highway Work Zone Strategies;

Case Studies along Interstate Highways in Massachusetts and Rhode Island

Kevin D. Moriarty, John Collura, Michael Knodler, Daiheng Ni, and Kevin Heaslip

Kevin D. Moriarty (Corresponding Author)
Research Assistant
Department of Civil and Environmental Engineering
University of Massachusetts
Marston Hall
130 Natural Resources Road
Amherst, MA 01003
Phone: 717-350-6076
E-mail: kevindmoriarty@gmail.com

Dr. John Collura
Professor of Civil and Environmental Engineering
Department of Civil and Environmental Engineering
University of Massachusetts
214 Marston Hall
130 Natural Resources Way
Amherst, MA 01003
Phone: 413-545-5404
Email: collura@ecs.umass.edu

Dr. Michael Knodler
Assistant Professor of Civil and Environmental Engineering
Department of Civil and Environmental Engineering
University of Massachusetts
Marston Hall
130 Natural Resources Way
Amherst, MA 01003
Phone: 413-545-0228
Email: mknodler@ecs.umass.edu

Dr. Daiheng Ni
Assistant Professor of Civil and Environmental Engineering
Department of Civil and Environmental Engineering
University of Massachusetts
Marston Hall
130 Natural Resources Way
Amherst, MA 01003
Phone: 413-545-5408
Email: ni@ecs.umass.edu

Dr. Kevin Heaslip
Post Doctoral Associate
Transportation Research Center
University of Florida
512C Weil Hall
Gainesville, FL 32611
Phone: 352-392-3394
Email: kevin@ce.ufl.edu

Submitted: July 31, 2007

Word Count: 7,433 (includes abstract, tables, figures, and references)
Number of Tables: 2
Number of Figures: 4

ABSTRACT

As the National Highway System reaches the end of its serviceable life, it becomes necessary for transportation agencies to focus on the preservation, rehabilitation, and maintenance of these roads. With significant increases in the amount of work zone activity, transportation officials and contractors are challenged with finding ways to reduce the negative impacts on driver mobility. The key to addressing this challenge is to recognize these impacts well in advance. One major tool used for this purpose is computer simulation. There are many simulation models in existence, some of which are designed specifically for work zone analysis. Examples of these models include QUEWZ, QuickZone, and CA4PRS. QuickZone and QUEWZ are designed to estimate delays, queues, and delay-related costs associated with traffic impacts created by work zones. CA4PRS estimates the maximum distance of highway that can be rehabilitated or reconstructed with various project staging plans and resource constraints. This paper includes two case studies that illustrate and evaluate these models in terms of their ease of use, data requirements, and ability to simulate and assess work zone strategies along Interstate 91 in Greenfield, MA and Interstate 95 in West Greenwich, RI. The evaluation sheds light on the relative accuracy of these simulation models as well as their user-friendliness and data requirements. The results of this evaluation will be of interest to State and local transportation engineers responsible for planning and designing work zone strategies.

INTRODUCTION

Much of the Dwight D. Eisenhower National System of Interstate and Defense Highways is more than thirty years old [1]. As the National Highway System (NHS) continues to age and reach the end of its serviceable life, the focus of roadwork has shifted from new construction to rehabilitation and maintenance of existing roads. Between 1997 and 2001, federal funds earmarked for roadway projects have increased by $2.86 billion on average per year [2]. Additionally, between 1980 and 2000, capital spending on highways has increased 112 percent and maintenance spending has increased 14 percent [3].

The necessity for improvement coupled with increased levels of funding has resulted in an increase in the amount of work zone activity. During the peak summer roadwork season of 2001, approximately 13 percent of the NHS was under construction, resulting in the staging of 3,110 work zones [1, 4]. The presence of these work zones accounted for 20,876 miles of reduced roadway capacity, adding to the already existing problem of roadway congestion. The cause for such congestion problems is due to the fact that over the past twenty years, route-miles of highway have increased approximately 5 percent while vehicle-miles of travel have increased 79 percent [1].

With the staggering increase in vehicle-miles of travel, motorists are increasingly exposed to work zones. In 2001, more than 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 NHS, representing over 12 billion hours of exposure. Additionally, motorists experience a lane closure every 200 miles driven on the NHS, totaling approximately 6 billion vehicle-miles of travel through work zones nationally [5]. Fifty percent of all highway congestion is attributed to non-recurring delay, 24 percent of which is attributed directly to work zone activity [6].

The challenge faced by transportation officials and contractors is to reduce the negative impacts of work zones on driver mobility. Motorists throughout the United States have cited work zones as second only to poor overall traffic flow as being the major cause of traveler dissatisfaction [7]. A 1995 survey conducted by the Federal Highway Administration (FHWA) revealed that only 29 percent of respondents were satisfied with traffic flow through work zones. It has been estimated that daily road user costs on many urban freeway reconstruction projects total over $50,000 per day [8].

It is essential to recognize the impacts that proposed reconstruction or rehabilitation work can have on traffic well before construction begins. This allows for appropriate cost-effective mitigation strategies to be developed and implemented prior to delays occurring [8]. Work zone mobility assessments are necessary to understand the type, severity, and extent of impacts associated with different project alternatives. By aggressively anticipating and mitigating congestion caused by work zone activity, positive impacts of relieving such congestion can be realized [9]. Despite the increasing frequency of work zones, the effects of a project are not usually considered until the design phase. Moreover, user costs are rarely considered during the planning and development phases of many projects [10]. Being that agency and user costs are significantly affected by the timing and configuration of a work zone, it has become highly desirable to optimize work zone scheduling so as to minimize total cost [11]. It is in the interest of transportation engineers to be able to present reliable information regarding impacts that may occur with the implementation of a work zone strategy. One of the major tools used to realize these impacts is computer simulation.

SIMULATION

During the last 20 to 30 years, a large number of sophisticated traffic simulation models have been developed [12]. Simulation is a powerful tool that can be used in the analysis and assessment of transportation facilities. Simulation models have the capability to incorporate a number of analytical techniques into their framework for simulating complex components, providing users with a greater knowledge and understanding of the system being analyzed. The low-cost, low-risk environment allows users to test a number of assumptions and alternatives, analyzing the effects immediately.

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 [8].

According to the FHWA, many agencies are making an effort to use more advanced tools such as simulation for work zone analysis [13]. Different tools may be appropriate for different situations, with decisions being based on the size and scope of the project. Work zone specific simulation models include QUEWZ, Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS), and QuickZone. 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 [13]. CA4PRS estimates the maximum distance of highway that can be rehabilitated or reconstructed within various resource constraints and closure timeframes [14]. QuickZone compares traffic impacts for work zone mitigation strategies, estimating the costs, time delays, and potential backups associated with these impacts [15].

OVERVIEW OF WORK ZONE SIMULATION MODELS

The information in this section of the paper presents a broad perspective and review of the capabilities of QuickZone and CA4PRS as well as their respective input requirements and output details. Because QUEWZ is very similar to QuickZone and due to paper length constraints QUEWZ is not reviewed in detail.

QuickZone Overview

The QuickZone Delay Estimation Program was developed in response to the 1998 FHWA report Meeting the Customer's Needs for Mobility and Safety during Construction and Maintenance Operations (FHWA-PR-98-01-A) [16]. QuickZone is a traffic impact analysis tool used to estimate work zone delays in all four phases of the project development process (i.e. policy, planning, design, and operation). Target users include state and local planners, traffic operations and construction staff, and construction contractors [15].

QuickZone has been found to be a suitable tool to analyze both urban and non-urban corridors. Primary functions include [17]:

- Quantifying corridor delay resulting from capacity decreases in work zones
- Identifying delay impacts of alternative project phasing plans
- Examining impacts of construction staging by location, time of day (peak vs. off-peak), and season (summer vs. winter)
- Assessing travel demand measures and other delay mitigation strategies
- Supporting tradeoff analyses between construction and delay costs
- Establishing work completion incentives

QuickZone has also been applied to evaluate proposed changes to lane closure schedules during construction, identify work that could be scheduled during nighttime hours, explore the feasibility of completely closing a road during construction, and schedule work around seasonal traffic demands.

QuickZone analysis requires four critical user-defined components. Network Data describes the mainline facility under construction as well as alternatives present within the corridor (i.e. detours). Project Data describes the plan for the work zone strategy and phasing, including capacity reductions resulting from the work zone. Travel Demand Data describes the patterns of pre-construction corridor utilization. Corridor Management Data describes various mitigation strategies to be implemented in each phase, including estimates of additional capacity changes resulting from these strategies [15]. Specific inputs for analysis include node coordinates, link characteristics, demand characteristics (e.g. AADT, hourly demand, and seasonality), project and phasing information, work zone information (e.g. affected links, capacity decreases, mitigation strategies, and changes in travel behavior), and delay cost parameters [18].

QuickZone provides users with four forms of output. The Project Delay Summary profiles the expected delay by time of day in each phase, as well as total delay and length of the mainline queue. The Travel Behavior Summary displays the expected changes in volume on both the mainline and adjacent facilities. The Amortized Delay and Construction Costs Graph shows the amortized project costs over the total expected life of the reconstruction operations. The Summary Worksheet provides an overview of queue, delay, travel behavior, cost, and input parameters [15].

Output is displayed in both tabular and graphical forms. Tabular performance measures include the total average daily delay per phase in vehicle-hours, the maximum length of mainline queue in miles, and the total travel time in minutes. A road user cost report presents the average road user cost per day as well as detour delay costs and incentive/disincentive equivalence costs. Graphical performance measures include a delay graph, which displays the average delay by time of day for project phases in vehicle-hours. The output also indicates changes in travel behavior due to the presence of work zones, both in volume and in percentage [19].

QuickZone output is helpful in identifying project phases likely to be generators of delay throughout the duration of the project. It also helps to determine if the amount of delay is reasonable and acceptable. If the delay is acceptable, then the project proceeds as planned. If the delay is unacceptable, then QuickZone helps to identify the most cost-effective construction strategy for both the motorist and the contractor [20].

CA4PRS Overview

CA4PRS was developed to aid California's Department of Transportation (Caltrans) in their 1998 Long-Life Pavement Rehabilitation Strategies (LLPRS) program. CA4PRS is a systematic construction engineering and management tool for the rehabilitation and reconstruction of highways. The software is used to estimate the maximum probable length of highway pavement that can be rehabilitated or reconstructed given various project constraints [14]. Target users include state highway agencies, design and construction engineers, consultants, and paving contractors [21].

CA4PRS has been found to be a beneficial tool for highway agencies, especially during the design stages when resulting analysis can be used to optimize pavement, construction, and operations. It is also useful to optimize rehabilitation strategies that balance the construction schedule with driver inconvenience and costs [22]. One of the major benefits of CA4PRS is its ability to be integrated with micro- and macroscopic traffic simulation models to quantify road user costs during construction.

CA4PRS requires four user-defined inputs. *Project Details* includes project descriptions, route names, station miles, location, and the total lane-miles to be rehabilitated. *Scheduling* includes mobilization and demobilization times, lead-lag relationships, and alternative closure timeframes. The *Resource Profile* specifies contractor logistics and resource constraints such as the location and size of batch plants and the number and capacity of hauling trucks. *Analysis* allows for the selection of a number of construction windows, rehabilitation sequences, mix designs, and cross-sectional changes [23]. Specific analysis input variables include pavement strategy (i.e. PCC, CSOL, FDAC), construction window, lane closure tactics, material constraints, pavement cross section, concrete pavement base types, contractor logistical resource constraints, and scheduling interfaces [14].

CA4PRS is capable of performing both deterministic and probabilistic analysis. Deterministic analysis treats input parameters as constants. This analysis mode seeks a single maximum distance of pavement that can be rehabilitated within the construction window under the given project constraints. On the other hand, probabilistic analysis treats input parameters as random variables. Each variable is described using one of several statistical distributions, permitting the review of the likelihood of achieving different production rates using Monte Carlo simulation [14].

Output is displayed in graphical and tabular form for both deterministic and probabilistic analysis. *Production Details* includes a user input summary, the maximum production of each rehabilitation scenario in terms of lane-miles, and the total number of lane closures required to finish the entire rehabilitation project scope based on the maximum production of each scenario. The *Production Chart* shows the optimally balanced maximum duration of demolition and paving activities within the given closure time limit. It illustrates the linear progress of the main rehabilitation operations over time. The difference is that probabilistic output plots the distribution of maximum production, showing the most likely maximum production as the mean and productions at ± 0.5 standard deviations as the lower and upper bounds [14].

CA4PRS output allows various traffic lane closure strategies and pavement design alternatives to be evaluated. The goal is to maximize new pavement life expectancy and construction production while minimizing traffic delay and costs. Additionally, CA4PRS is used to check construction staging plans, identify critical resources constraining production, and quantify the probability of meeting work incentives/disincentives as well as cost plus schedule (i.e. A + B) contracts [23].

It should be noted that CA4PRS can be used as a companion simulation model with delay estimation tools such as QuickZone or QUEWZ. Based on the required input, CA4PRS can establish an estimate of the number of lane

closure windows required to complete the rehabilitation project. These lane closure windows can then be entered into QuickZone or QUEWZ and analyzed to estimate the associated delay and queue length.

MODELING INTERSTATE 91, GREENFIELD, MA

QuickZone Delay Estimation Program Version 1.01 and CA4PRS Version 1.5a were used to analyze the effects of the proposed work zone on driver mobility and the maximum possible rehabilitation production, respectively. The following sections explain the use of these simulation models with respect to this specific location.

QuickZone Analysis of I-91

The work zone along I-91 was established under the direction of the Massachusetts Highway Department. It is approximately one-quarter mile in length and is located just to the south of the Route 2/2A interchange. For this location, two lanes of travel are normally available in each direction. Freeflow speed was determined to be 70 miles per hour as recommended by the Highway Performance Monitoring System Field Manual [24]. Using the freeway capacity estimation procedure described by the same resource, capacity was calculated as 2395 vehicles per hour per lane. The resulting jam density was calculated as 135 vehicles per mile per lane. The travel demand data for this analysis was in the form of hourly counts and was entered for each link over a seven day, 24-hour period. 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. It should be noted that, while other input data was alluded to in the QuickZone overview, only the most significant data has been mentioned here.

QuickZone is capable of producing several output parameters that may be of interest to the analysts. For the purposes of this research, the evaluation parameter chosen was queue length measured in miles. The results of the analysis show Sunday to be the only day in which delay is expected to occur due to the presence of the work zone. The capacity reductions as calculated by the HCM 2000 method cause this section of Interstate 91 to have a greater demand that it can accommodate without producing motorist delay during this time period. Figure 1 shows the weekly delay graph (above) and the daily delay graph for Sunday (below).

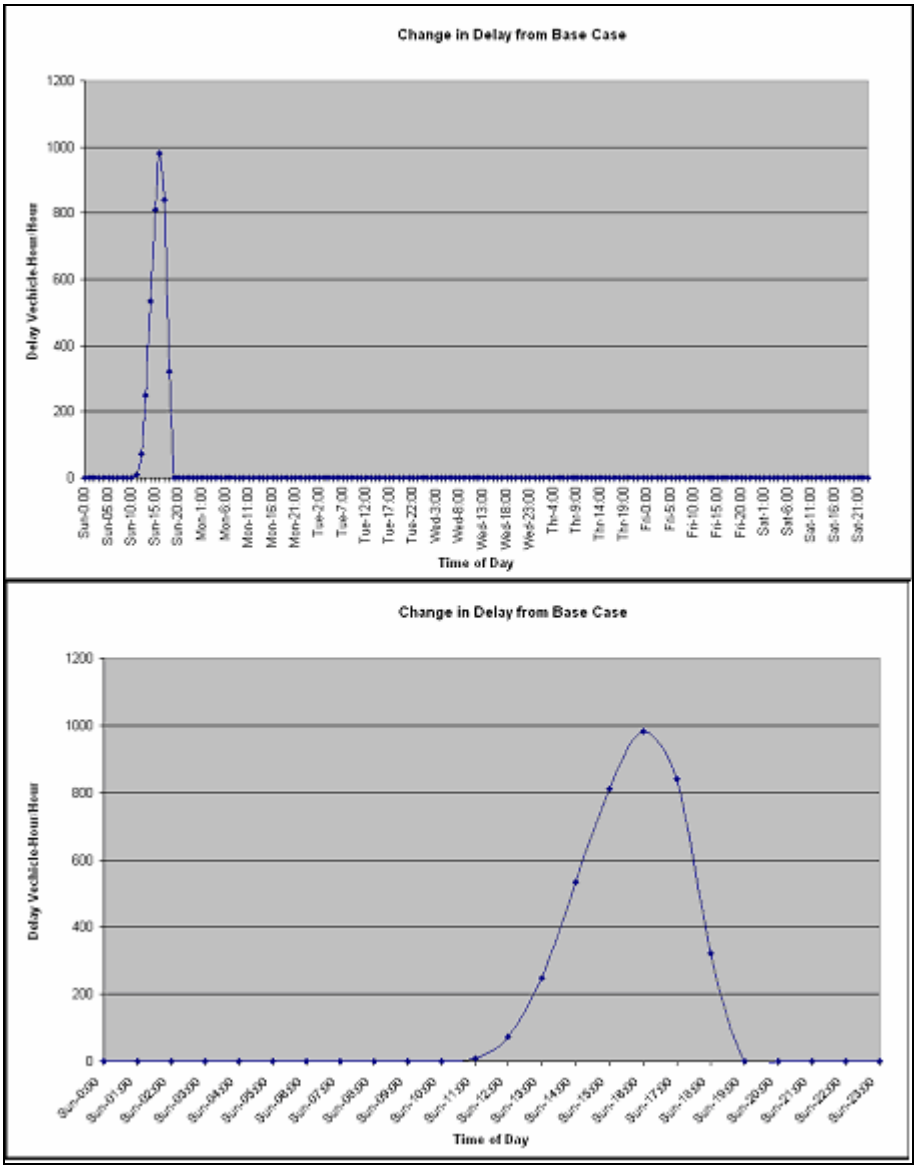

Figure 1: I-91 Delay Graphs

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 7:00 pm. This period of delay is estimated to result in a maximum queue length of 3.85 miles. The associated time delay to motorists caused by this maximum queue is expected to be 13 minutes.

CA4PRS Analysis of I-91

This portion of the research required a number of assumptions to be made. Assumed values included mobilization and demobilization times, construction window timeframes, truck capacities and efficiencies, and batch plant capacities. The reason for so many assumptions is due to the fact that these values are related more directly to the knowledge of a pavement rehabilitation contractor than a transportation professional. The pavement cross section consisted of three lifts: binder course, surface course, and friction course. The binder and friction courses are each 1.75 inches thick and assumed to have a cooling time of 3.00 hours each. The friction course is 1.25 inches thick and assumed to have a cooling time of 6.00 hours.

A deterministic Full-Depth Asphalt Concrete analysis was used to estimate the maximum rehabilitation production possible based on the logistical and resource inputs provided. For this work zone location, CA4PRS estimated this value to be 0.80 lane-miles. Figure 2 shows the production detail results (above) and the production chart (below) that illustrates the progress and interrelationship of the proposed rehabilitation activities over time.

Figure 2: I-91 CA4PRS Output

MODELING INTERSTATE 95, WEST GREENWICH, RI

In the same fashion as Interstate 91, QuickZone Delay Estimation Program Version 1.01 and CA4PRS Version 1.5a were used to analyze the effects of the proposed work zone on driver mobility and the maximum possible rehabilitation production, respectively, for Interstate 95.

QuickZone Analysis of I-95

The work zone along I-95 was established under the direction of the Rhode Island Department of Transportation. It is approximately one-quarter mile in length and is an overpass over Robin Hollow Road, a smaller local road. For this location, two lanes of travel are normally available in each direction. Freeflow speed was determined to be 70

miles per hour based on the recommendations of the Highway Performance Monitoring System Field Manual [24]. The freeway capacity was estimated as 2395 vehicles per hour per lane with a resulting jam density of 135 vehicles per mile per lane. The travel demand data for this analysis was in the form of hourly counts and was entered for each link over a seven day, 24-hour period. The location utilized the existing 12-foot shoulder to maintain two lanes of flow through the work zone. Capacity decreases were estimated using the 2000 Highway Capacity Manual function within the program. Due to the presence of the work zone, the capacity of the defined work zone links was reduced by a total of 1590 vehicles per hour. This resulted in a two-lane capacity of 3200 vehicle per hour for the work zone area. Again, only the most significant input data has been mentioned here.

As with Interstate 91, the evaluation parameter chosen was queue length measured in miles. The analysis results show this particular work zone strategy to create no delay. For this reason, two additional QuickZone analyses for Interstate 95 reviewed the impact on driver mobility given different lane closure windows. This scenario was presented to simulate the effect of the necessity to close a lane for construction activity or a vehicle crash in the work zone area. The motivation behind these additional analyses stemmed from a conversation with a site worker who claimed that the only time a traffic backup occurs is when conditions force the closure of a lane. The claim was that queues may extend all the way back to I-295, approximately 10 miles from the work zone location.

For these analyses, all of the original input parameters remained the same. The capacities of the defined work zone links were reduced using the HCM 2000 method function within the QuickZone program. It was estimated that a lane closure would result in a total capacity decrease of 3190 vehicles per hour for each link, leaving a capacity of 1600 vehicles per hour.

The first alternative analysis considered a 24-hour lane closure. This closure window in conjunction with the estimated capacity reduction showed significant queueing and delay compared to the original analysis scenario. QuickZone revealed a maximum queue length of 12.73 miles with an associated 43.1 minute delay to occur on a Friday. The next highest queue length occurred on a Saturday with a queue length of 10.99 miles and an associated delay of 37.2 minutes. Sunday experiences a 10.85-mile queue, resulting in a 36.7 minute delay. If the lane closure were to occur Monday through Thursday, queueing and delays would still be experienced but on a much smaller scale. Figure 5 shows the weekly delay graph for this 24-hour lane closure scenario.

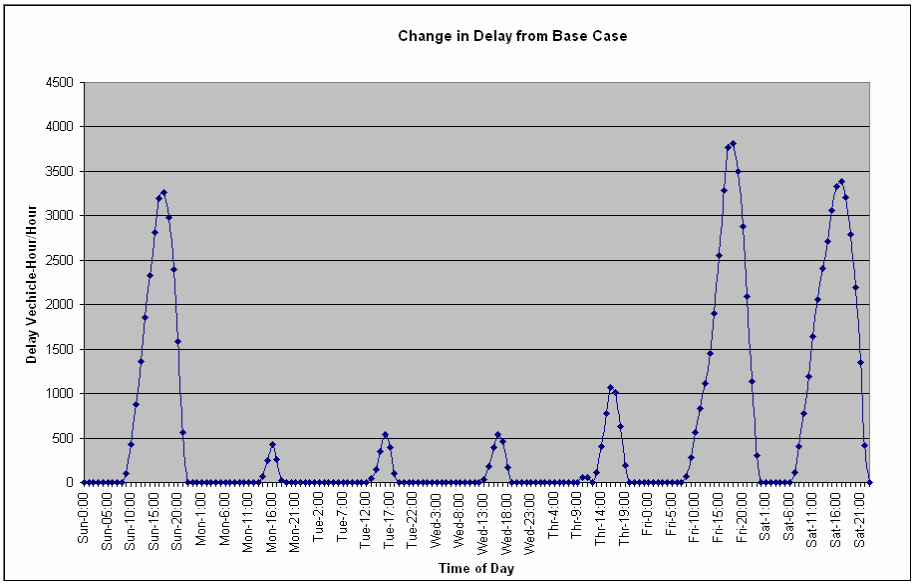

Figure 3: I-95 24-hour Lane Closure Weekly Delay Graph

The second alternative analysis considered a 1-hour lane closure between 4:00 pm and 5:00 pm. This period of time was selected for analysis as the highest traffic demand is experienced during this timeframe. Again, the results of the QuickZone analysis showed the formation of queueing and delays compared to the original analysis scenario. The maximum queue was 5.47 miles on a Friday, resulting in 18.5 minutes of delay. The second largest delay under these conditions occurred on a Sunday, showing a 3.39-mile queue and an associated 11.5-minute delay. The

remaining days of the week, Monday through Thursday and Saturday, also produced delay but on a smaller scale. Figure 6 shows the weekly delay graph for the 1-hour lane closure scenario.

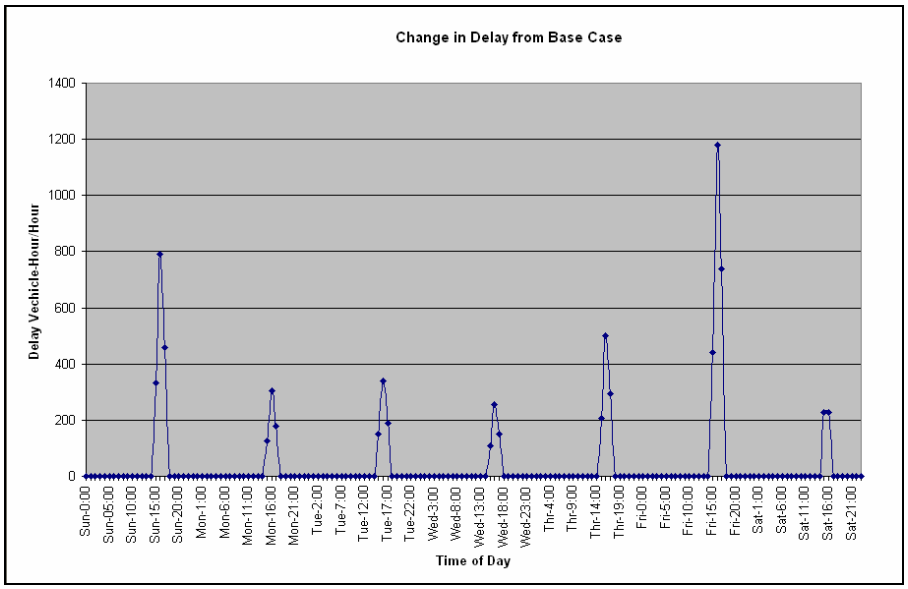

Figure 4: I-95 1-hour Lane Closure Weekly Delay Graph

<u>CA4PRS Analysis of I-95</u>

As with Interstate 91, a number of assumptions were required to be made for the analysis of Interstate 95. That being said, all of the assumed values remained unchanged for this analysis. For this reason, a deterministic Full-Depth Asphalt Concrete analysis produced identical results. CA4PRS estimated the maximum possible rehabilitation production to be 0.80 lane-miles based on the logistical and resource inputs provided. Please refer back to Figures 3 and 4 to see the visual representation of these results as provided by CA4PRS.

EVALUATION OF SIMULATION RESULTS

The evaluation portion of this research is a comparison of the results simulated by QuickZone and CA4PRS to real-world work zone data. For QuickZone, the parameter used for comparison is queue length. Beginning with Interstate 91 in Greenfield, MA, QuickZone estimated a maximum queue of 3.85 miles to occur on a Sunday. The queue begins to generate around 11:00 am, reaching its maximum at approximately 4:00 pm. The queue is estimated to be totally dissipated by 7:00 pm. This is the only queue estimated by QuickZone as it is the only period of time in which the travel demand exceeds the work zone capacity. Comparing these estimates to real-world data provided by past research, QuickZone provides a fairly accurate estimate of the actual queue length. The research 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." It was also reported by the media and the Massachusetts State Police that queues of approximately 12 miles had formed in the early stages of the project [25]. The estimation provided by QuickZone does not confirm this portion of the reported real-world data. It is believed that this is due to other factors such as different work zone staging strategies, driver unfamiliarity, work zone intensity, poor mitigation strategies, etc.

The QuickZone analysis of Interstate 95 in West Greenwich, RI suggests that no queue is ever experienced. These results confirm the observations made on a site visit by the research project team as well as information gathered from a construction worker during the same visit. On Tuesday, June 19, 2007, the author visited the work zone site from 2:30 pm to 4:30 pm. During this time period, no queue formation was observed nor did there appear to be any sign of a queue developing. The increase in travel demand was noticeable during this time, but traffic continued to flow steadily through the work zone area at an estimated 65 mph. A RIDOT official stated that a queue will not form as two lanes of travel are available and maintained through the work zone area. Additionally, the area is in a rural setting in which travel demands are not very high.

As mentioned previously, a site worker did reveal that the only time a queue forms for this particular work site is when a crash occurs or when the workers must shut down one or more travel lanes for construction activity. The worker stated that in the occurrence of a traffic incident or lane closure, traffic may back up as far as I-295, approximately 10 miles from the work zone site. The worker did, however, make it perfectly clear that the Rhode Island Department of Transportation is very strict with construction activity causing problems with traffic. In an analysis of alternative lane closure conditions, QuickZone estimated that a 24-hour lane closure would produce a maximum queue of 12.73 miles on a Friday. Additionally, the maximum estimated queue length for a 1-hour lane closure was 5.47 miles on a Friday. The simulation results appear to support the worker's claim, as substantial queue lengths are both estimated and have been observed. How well the simulated results reflect the actual data, however, is uncertain as such data is not available.

As for CA4PRS, it is much more difficult to make a comparative evaluation of the maximum rehabilitation results provided. For both Interstate 91 and Interstate 95, CA4PRS estimated the maximum rehabilitation production to be 0.80 lane-miles. Recall, however, that many of the input parameters for the analyses using CA4PRS were assumed values. The reason for so many assumptions is that these values are more directly related to the construction contractor rather than the transportation professional. For this research, the accuracy of a direct comparison would have to be questioned due to the large number of assumptions made. The maximum rehabilitation production and the construction activity timeframe appear to be reasonable estimates, but the physical size of the paving activity does not provide a good comparative representation. A RIDOT official revealed that the paving area along the Interstate 95 work zone is approximately 15 feet wide and 100 feet long per phase. The same small-scale conditions exist along the Interstate 91 work zone. The real-world data would be best captured by visiting the site on a day when rehabilitation activity is taking place.

For a clearer side-by-side comparison of estimated to actual results presented above in text, Table 1 has been included below. It should be noted that research using the QUEWZ simulation model has produced similar queue length results for the Interstate 91 and Interstate 95 work zone locations [25]. (Note: N/A implies not available)

Table 1: Research Evaluation Comparison

Simulation Model	Work Zone Site and Location	Estimated Results	Actual Results
QuickZone (queue length)	Interstate 91, Greenfield, MA	3.57 miles	4 to 6 miles
	Interstate 95, West Greenwich, RI	0 miles	0 miles
		12.73 miles	~10 miles
		5.47 miles	
CA4PRS (max. production)	Interstate 91, Greenfield, MA	0.80 lane-miles	N/A
	Interstate 95, West Greenwich, RI	0.80 lane-miles	N/A

Table 2 below provides a summary of the time required to assemble, input, and analyze the data for the QuickZone and CA4PRS simulation models. It is hoped that the information presented will lend insight to the user-friendliness of each simulation model. It should be noted that these times will vary from project to project due to the availability of the necessary data. The times will also vary relative to the user's familiarity with a given simulation model.

Table 2: Time Requirements for Simulation Model Data

Simulation Model	Work Zone Site and Location	Data Assembly Time	Data Input Time	Data Analysis Time
QuickZone	Interstate 91, Greenfield, MA	2 - 3 hrs	2.5 hrs	< 1 min
	Interstate 95, West Greenwich, RI	5 - 6 hrs	1.5 hrs	< 1 min
CA4PRS	Interstate 91, Greenfield, MA	1 - 2 hrs	1 hr	< 1 min
	Interstate 95, West Greenwich, RI	1 - 2 hrs	1 hr	< 1 min

SUMMARY AND CONCLUSIONS

This paper has focused on the application and evaluation of QuickZone and CA4PRS to simulate and assess work zone strategies implemented in New England. An overview of these simulation models has provided a means for potential users to gain a broad perspective of the requirements and capabilities of each. A more detailed perspective could be gained through the presentation of two case studies: Interstate 91 in Greenfield, MA and Interstate 95 in

West Greenwich, RI. The research has explained and illustrated both the data input and output procedures for both QuickZone and CA4PRS. The simulated results have been compared directly to observed field data, allowing for a judgment to be made as to the accuracy of the estimation ability of these models. Additionally, the use of these models to conduct this research has shed light on a number of other factors of interest to potential users including software/hardware requirements, user-friendliness, convenience, and flexibility.

QuickZone can be obtained from McTrans at the University of Florida. The model runs as a Microsoft EXCEL macro and can be accessed directly from the computer's desktop. QuickZone requires a minimum of Microsoft Windows 95 with Microsoft EXCEL 97 or newer. Along with being a generally accurate simulation model, QuickZone also appears to be rather user-friendly. Although initial data entry may be a time consuming process, alternative work zone strategies can be analyzed with relative ease. This allows the user to compare several viable options and select the most optimal. The required base input is also relatively easy to obtain. More detailed input such as seasonal traffic demands and pre-construction travel behaviors, however, may be more difficult to gather. It should be noted that this more detailed information is not absolutely necessary to run an analysis, but may provide the user with more accurate results. The results produced by QuickZone do provide the user with meaningful information, from queue length to time delay to user costs. The benefit of QuickZone is that these results are provided in both tabular and graphical form, allowing users to have multiple means of interpretation. Future research involving QuickZone could include:

- Application and evaluation of QuickZone to various roadway classifications (i.e. higher volume interstates, rural or urban arterials, two- or three-lane interstates, local roads, etc)
- Analyzing the effect of work zone intensity as adjusted within the HCM capacity reduction function
- Analyzing the effect of full road closures with the use of detour routes
- Analyzing the effects of altering pre-construction travel behaviors and work zone mitigation strategies
- Developing a way to account for speed differentials upon approach, passage, and exit of the work zone and analyzing the associated effects related to speed

CA4PRS can be obtained from the Office of Technology Licensing at the University of California Berkeley. The model is a stand-alone software package that runs with Microsoft Windows 95 or higher directly from the computer's desktop. The physical data entry process for this model is quite simple. Gathering the necessary data, however, is not quite so simple. Most of the data required for an accurate CA4PRS analysis is directly related to the paving contractor rather than to the transportation professional. Contractors have a much better knowledge about input such as truck hauling capacities, work efficiencies, pavement properties, and the like. The outputs of maximum rehabilitation production and project progress seem to be useful for pavement rehabilitation strategy analysis. Future research involving CA4PRS could include:

- Analyzing maximum rehabilitation production with more accurate information with the aid of a paving contractor
- Analyzing maximum rehabilitation production using the "probabilistic" functions rather than the "deterministic" mode
- Analyzing large-scale rehabilitation projects
- Establishing pavement rehabilitation activity windows with CA4PRS and analyzing the associated delay and queue lengths with QuickZone

This research has shown that simulation provides a low-risk, low-cost environment in which to test and analyze a variety of work zone alternatives. Care must be taken, however, in using simulation results to make concrete decisions. It is stressed that users of these simulation models have a fundamental understanding of highway capacity analyses and traffic flow fundamentals. Users must trust their intuition and use their knowledge when results appear to be out of the ordinary. Simulation does, however, give the transportation world a better understanding of the impacts of highway work zone strategies.

For a more detailed description of the research presented here, please contact Kevin D. Moriarty at kevindmoriarty@gmail.com. This paper is an abridged version of the author's M.S. Thesis presented at the University of Massachusetts in July 2007 under the direction of Dr. John Collura.

REFERENCES

1. Keenan, C. (2004). Work Zones That Work. Public Roads Magazine 68 (3), November/December 2004. <http://www.thfrc.gov/pubrds/04nov/04.htm>. Date accessed: October 2006.
2. U.S. Department of Transportation, Federal Highway Administration (2001). Highway Statistics 2001, Publication No. FHWA-PL-02-020. Washington, D.C., 2001. <http://www.ops.fhwa.dot.gov/wz/resources/facts_stats.htm>. Date accessed: March 2007.
3. Consdorf, A. (2003). The Decade Mobility Died: America's Congestion Crisis, Parts I – III. Better Roads, February 2003. <http://www.ops.fhwa.dot.gov/wz/resources/facts_stats.htm>. Date accessed: March 2007.
4. U.S. Department of Transportation, Federal Highway Administration (2002). A Snapshot of Peak Summer Work Zone Activity Reported on State Road Closure and Construction Websites. Washington, D.C., August 2002. <http://www.ops.fhwa.dot.gov/wz/resources/facts_stats.htm>. Date accessed: March 2007.
5. U.S. Department of Transportation, Federal Highway Administration (2004). Characteristics of Today's Work Zones. Presented at the 2004 TRB Annual Meeting by Gerald Ullman. Washington, D.C., January 2004. <http://www.ops.fhwa.dot.gov/wz/resources/facts_stats.htm>. Date accessed: March 2007.
6. U.S. Department of Energy (2002). Temporary Losses of Highway Capacity of Impacts on Performance. Oak Ridge National Laboratory (ORNL/TM-2002/3), May 2002. <http://www.ops.fhwa.dot.gov/wz/resources/facts_stats.htm>. Date accessed: March 2007.
7. U.S. Department of Transportation, Federal Highway Administration (2001). Moving Ahead: The American Public Speaks on Roadways and Transportation Communities, Publication No. FHWA-OP-01-017. Washington, D.C., 2001. <http://www.ops.fhwa.dot.gov/wz/resources/facts_stats.htm>. Date accessed: March 2007.
8. U.S. Department of Transportation, Federal Highway Administration (1998). Meeting the Customer's Needs for Mobility and Safety during Construction and Maintenance Operations, Publication No. HPQ-98-1. Washington, D.C., September 1998. <http://www.fhwa.dot.gov/reports/bestprac.pdf>. Date accessed: March 2007.
9. U.S. Department of Transportation, Federal Highway Administration. Making Work Zones Work Better. <http://ops.fhwa.dot.gov/wz/about/wz_story.htm>. Date accessed: March 2007.
10. Harding, J. (2000). Strategic Work-Zone Analysis Tools. Public Roads Magazine 64 (3), November/December 2000. <http://www.tfhrc.gov/pubrds/nov00/strategic.htm>. Date accessed: October 2006.
11. Chien, S. and Y. Tang (2002). Optimizing Work Zones for Two-Lane Highway Maintenance Projects. Journal of Transportation Engineering 128 (2) March/April 2002.
12. Chowdury, M. A. and A. Sadek (2003). Fundamentals of Intelligent Transportation Systems Planning. Artech House, Boston, MA, 2003.
13. Krammes, R. A., G. L. Ullman, J. L. Memmott, and C. L. Dudek (1993). User's Manual for QUEWZ-92. Texas Transportation Institute, January 1993. <http://ttiresearch.tamu.edu/g-ullman/quewz-92/1108-7.fin.pdf>. Date accessed: March 2007.
14. Lee, E. B. and C. W. Ibbs (2005). A Computer Simulation Model: Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS). Journal of Construction Engineering Management 131 (4). <http://scitation.aip.org/getpdf/servlet/GetPDFServlet?filetype=pdf&id=JCEMD400013100000400044 9000001&idtype=cvips&prog=normal>. Date accessed: August 2006.
15. QuickZone Delay Estimation Program Version 1.01 User Guide (2002). Mitrerek Systems. February 2002.

16. U.S. Department of Transportation, Federal Highway Administration. Corporate Research and Technology: QuickZone. <http://www.fhwa.dot.gov/crt/lifecycle/quickzone.cfm>. Date accessed: August 2006.

17. Turner-Fairbanks Highway Research Center. QuickZone: A New Work Zone Delay Estimation Tool. <http://www.tfhrc.gov/its/quickzone.htm>. Date accessed: August 2006.

18. McTrans. QuickZone. <http://mcrtrans.ce.ufl.edu/featured/QZone/>. Date accessed: August 2006.

19. U.S. Department of Transportation, Federal Highway Administration (2005). QuickZone 2.0 Offers Improved Work Zone Planning. Focus, April 2005. <http://www.tfhrc.gov/focus/apr05/01.htm>. Date accessed: August 2006.

20. Curtis, D. (2001). QuickZone. Public Roads Magazine 65 (1), July/August 2001. <http://www.tfhrc.gov/pubrds/julaug01/quickzone.htm>. Date accessed: August 2006.

21. Washington State Department of Transportation. Construction Analysis for Pavement Rehabilitation Strategies. <http://www.wsdot.wa.gov/biz/mats/Folios/ConstructionAnalysisforPavementRehabilitationStrategies.pdf>. Date accessed: August 2006.

22. U.S. Department of Transportation, Federal Highway Administration (2006). Accelerating Urban Highway Rehabilitation with Construction Analysis Software. Focus, June 2006. <http://www.tfhrc.gov/focus/june06/01.htm>. Date accessed: August 2006.

23. U.S. Department of Transportation, Federal Highway Administration. Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS). Collaboration of FHWA and CA, FL, MN, TX, and WA DOTs. <http://puffin.its.berkeley.edu/pavementresearch/PDF/CA4PRSweb.pdf>. Date accessed: August 2006.

24. U.S. Department of Transportation, Federal Highway Administration. Highway Performance Monitoring System Field Manual. Appendix N: Procedures for Estimating Highway Capacity. <http://www.fhwa.dot.gov/ohim/hpmsmanl/appn1.htm>. Date accessed: June 2007.

25. Ongoing research being conducted at the University of Massachusetts Amherst.