Evaluation and Implementation of Traffic Simulation Models for Work Zones

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16. Abstract

As the National Highway System reaches the end of its serviceable life, transportation agencies increasingly need to focus on the preservation, rehabilitation, and maintenance of these roads. In light of 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 potential 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, CORSIM, and CA4PRS. This purpose of this paper is to present 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, shedding light on the relative reliability and accuracy of these simulation models as well as their user-friendliness and data requirements. This paper compares simulation results to actual work zones conditions in eight locations across New England. The results of this evaluation will be of interest to state and local transportation engineers responsible for planning and designing work zone strategies. This research has shown that some simulation models provide a low-risk, low-cost environment in which to test and analyze a variety of work zone alternatives. For example, QUEWZ and QuickZone were able to provide reasonable order of magnitude queue length estimates on interstate highways comparable to observations made in the field. In addition, such estimates required little data including hourly volume and roadway geometry information.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	Litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3

MASS

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

* SI is the symbol for the International System of Measurement

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2

VOLUME

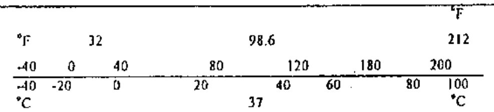
Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

MASS

Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celcius temperature	1.8C+32	Fahrenheit temperature	°F



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ABSTRACT

As the National Highway System reaches the end of its serviceable life, transportation agencies increasingly need to focus on the preservation, rehabilitation, and maintenance of these roads. In light of 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 potential 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, CORSIM, and CA4PRS. This purpose of this paper is to present 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, shedding light on the relative reliability and accuracy of these simulation models as well as their user-friendliness and data requirements. This paper compares simulation results to actual work zones conditions in eight locations across New England. The results of this evaluation will be of interest to state and local transportation engineers responsible for planning and designing work zone strategies. This research has shown that some simulation models provide a low-risk, low-cost environment in which to test and analyze a variety of work zone alternatives. For example, QUEWZ and QuickZone were able to provide reasonable order of magnitude queue length estimates on interstate highways comparable to observations made in the field. In addition, such estimates required little data including hourly volume and roadway geometry information.

INTRODUCTION

Much of the Dwight D. Eisenhower National System of Interstate and Defense Highways are 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 increased by $2.86 billion on average per year [2]. Additionally, between 1980 and 2000, capital spending on highways increased 112 percent and maintenance spending 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 from about 1985 to 2005, 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 can aid transportation officials and agencies 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), CORSIM, 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]. CORSIM is a user-friendly graphics post-processor that displays traffic networks, animates simulated traffic flow operations, animates and displays simulation output measures of effectiveness, and displays user-specified input parameters for simulated network objects [25]. 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 CORSIM, QuickZone and CA4PRS as well as their respective input requirements and output details.

QUEWZ Overview

QUEWZ (Queue and User Cost Evaluation of Work Zones) is a computerized version of commonly used manual techniques for estimating the queue lengths and additional road user costs resulting from work zone lane closures. It simulates traffic flows through freeway segments both with and without a work zone lane closure in place and estimates the changes in traffic flow characteristics and additional road user costs resulting from a lane closure whose time schedule and lane configuration are described by the model user. QUEWZ098 can also apply the same traffic flow simulations to identify time schedules for lane closures that will not produce excessive queue lengths and delays. QUEWZ requires MS-DOS [26]. QUEWZ can be purchased online through McTrans.

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. Annual Average Daily Traffic, 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].

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].

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.

CORSIM Overview

CORSIM is a widely used microscopic traffic simulation model that was developed under Federal Highway Administration sponsorship. It can be used to simulate traffic operations around a work zone on any classification of roadway by creating a block in lanes under construction. CORSIM is capable of simulating work zones through a prolonged incident blockage. It 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 [25].

CORSIM’s output provides the user with average travel time (in minutes) and average speed (in mph) for vehicles traversing the roadway simulated. By adding lane closure, CORSIM can model work zones experiencing lane closure or restricted usage. The free flow speed on the roadway may also be manipulated, which could be used to simulate reduced speed in some construction zones.

EVALUATION OF SIMULATION RESULTS

This section describes case studies that illustrate and evaluate the use of the simulation models. The simulation models were evaluated in terms of their ease of use, data requirements, and ability to simulate and assess work zone strategies, shedding light on their relative reliability and accuracy as well as their user-friendliness. The case studies include work zone projects along Interstate 91 in Greenfield, MA; Interstate 91 in Windsor, CT; Interstate 95 in West Greenwich, RI; Interstate 95 in Bangor, ME; Interstate 93 in Manchester, NH; State Route 9 in Hadley, MA; State Route 116 in Sunderland, MA; and State Route 125 in Andover, MA. Where possible, the evaluation portion of this research includes a comparison of the results simulated by CORSIM, QUEWZ, QuickZone, and CA4PRS to real-world work zone data. For example, field estimates on queue length were made by State DOT project engineers while the work zone was in place [25,26,27].

Table 1A summarizes a comparative review of the queue lengths estimated with QuickZone and QUEWZ simulation packages and queue lengths observed in the field along the interstate projects. It can be seen from these results that QUEWZ and QuickZone produced queue length estimates close to the queue length estimates observed in the field. N/A indicates that no analysis was performed. It should also be noted that the QUEWZ estimates of percent error in this research are comparable with those produced by research done at The University of Iowa. The percent error in this research for QUEWZ queue lengths was 0-6.25% and percent error in the University of Iowa study [29] QUEWZ volume estimates were 1-19.2%. Figures 1 and 2 present the results graphically.

Table 1A: Comparison of Queue Lengths Derived from Field Observations and QUEWZ and QuickZone Simulation Analyses (in Miles)

Work Zone	**QuickZone**			**QUEWZ**			**Field Observations**
	Moriarty	*Wu*	*Khanta*	*Moriarty*	*Wu*	*Khanta*	
I-91 Greenfield, MA[1]							
1 lane closed	3.57-4.86	3.57	5.2	2.5-3.75	3.75	4.2	4-6 Miles
I-95 West Greenwich, RI[1,2]	5.47-12.73	5.47	N/A	N/A	N/A	N/A	10 Miles
I-91 Windsor, CT[1]							
1 lane closed	N/A	0.3	0	N/A	0.3-0.4	0-0.19	0-0.5 Miles
2 lane closed	N/A	0.5	N/A	N/A	0.7-0.8	N/A	N/A
I-95 Bangor, ME[1]							
1 lane closed	N/A	4.5-4.7	4.5-4.7	N/A	4.1-4.7 mi	4.1-4.7	4-5 Miles
I-93 Manchester, NH[3]	N/A	N/A	4.1	N/A	N/A	3.9	N/A

Notes: Ranges denote estimates for two different days.
N/A indicates Not Available

Sources: [1] Wu, 2008
[2] Moriarty, 2007
[3] Khanta, 2008

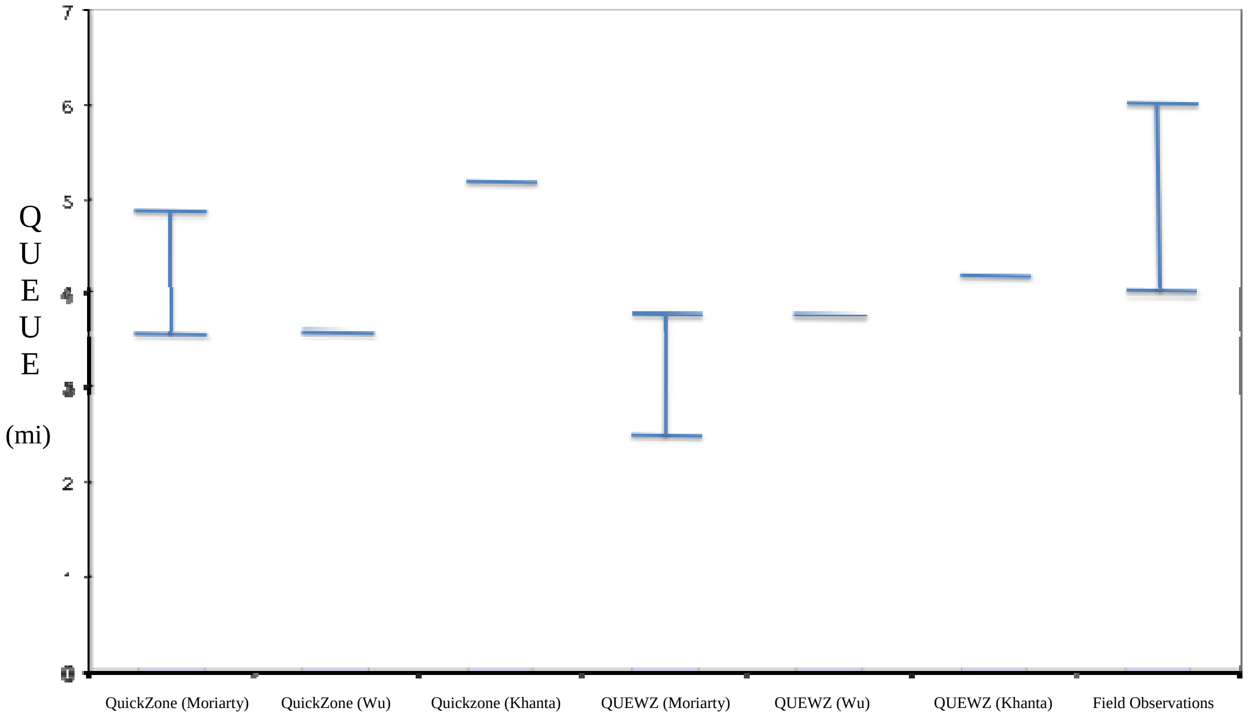

Figure 1: Comparison of Queue Lengths Derived from Field Observations and QUEWZ and QuickZone Simulation Analysis on I-91 in Greenfield, MA

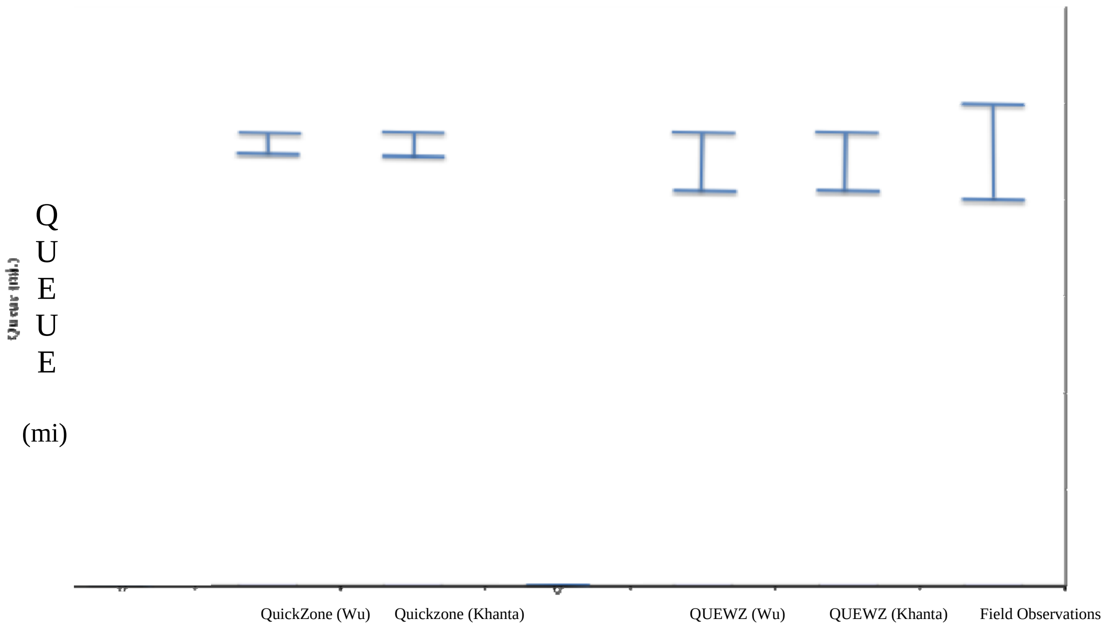

Figure 2: Comparison of Queue Lengths Derived from Field Observations and QUEWZ and QuickZone Simulation Analysis on I-95 in Bangor, ME

It is interesting to note that along Interstate 91 in Greenfield, MA, QuickZone estimated a maximum queue of 3.85 miles to occur on a Sunday due to the recreational ski traffic returning home. The queue begins to generate around 11:00 am, reaching 3.85 its maximum at approximately 4:00 pm. The queue was estimated to be totally dissipated by 7:00 pm. 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 local 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 may be due to other factors such as different work zone staging strategies, driver unfamiliarity, work zone intensity, and poor mitigation strategies.

The QuickZone analysis of Interstate 95 in West Greenwich, RI suggests that no queue should have been 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, researchers 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 would 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. It should be noted that a RIDOT official 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. 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 be consistent with the RIDOT official's estimate.

The QuickZone analysis of Interstate 91 in Windsor, CT (1 lane closed) suggests no queue on Monday and a maximum queue of 0.3 miles 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 field observations provided by the resident engineer working for Connecticut Department of Transportation, Quick Zone provided a fairly accurate estimate of the actual queue length. QuickZone also yielded a queue length in Bangor, ME that was similar to that estimated based on field observations. For further details regarding work zones, QUEWZ and QuickZone inputs, and sample input screens, see the Appendices.

Table 1B summarizes the results of the use of CA4PRS. For both Interstate 91 in Greenfield, MA, and Interstate 95 in West Greenwich, RI, CA4PRS estimated the maximum rehabilitation production to be 0.80 lane-miles. CA4PRS also yielded a 2.46 lane-mile maximum rehabilitation production for Interstate 91 in Windsor, CT, and a 0.33 lane-mile maximum rehabilitation production for Interstate 95 in Bangor, ME. Worthy of note is the challenge that is created by the necessity that many of the input parameters for the analyses using CA4PRS were assumed values which increases the uncertainty of the comparison. The reason for so many assumptions is that these values are more directly related to the construction contractor rather than the transportation analyst. 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 in West Greenwich, RI, zone is approximately 15 feet wide and 100 feet long per phase. The same small-scale conditions exist along Interstate 91 in the Greenfield, MA work zone. The field observation data would be best captured by visiting the site on a day when rehabilitation activity is taking place. CA4PRS provides the user with an estimate of how many lane miles can be paved at once while maintaining a specified level of service (LOS) for a given road segment. From the Table 1(b), we can see the estimated maximum possible rehabilitation production measured in lane miles for the given work zones based on one lane of closure and LOS D/E.

Table 1C summarizes the results using CORSIM and shows the average vehicle speed (in mph) and travel time (in minutes) for a vehicle traversing a work zone along 3 different roadways in Massachusetts (SR 9 in Hadley, SR 116 in Sunderland, and SR 125 in Andover). Where there are sufficient data, these numbers are compared to values measured in the field. N/A indicates that no analysis was performed. These results show that CORSIM produced travel time and speed estimates comparable to those observed in the field. However, it should be noted that the University of Iowa study reported that CORSIM showed a trend of inaccuracies when used in work zone analyses [29].

Table 1B: CA4PRS Results

Work Zone	CA4PRS[3]	
	Moriarty	*Wu*
I-91 Greenfield, MA[1] - *1 lane closed*	0.80 lane-miles	0.80 lane-miles
I-95 West Greenwich, RI[1,2]	0.80 lane-miles	0.80 lane-miles
I-91 Windsor, CT[1] - *1 lane closed*	N/A	2.46 lane-miles
I-95 Bangor, ME[1] - *1 lane closed*	N/A	0.33 lane-miles

Note: CA4PRS calculates max possible rehabilitation production measured in lane miles (parameters used LOS D/E)

Sources: [1] Wu, 2008, [2] Moriarty, 2007

Table 1C: Comparison of Travel Times and Speeds Derived from Field Observations and CORSIM Simulation Analyses

		No Work zone		**with Work zone (1 lane closed)**		**with Work zone (detour selected)**	
		WB	*EB*	*WB*	*EB*	*WB*	*EB*
SR 9 Hadley, MA [1]	*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

		No Work zone (Berthaume)		**No Work zone (Khanta)**		**Field Observations (no workzone)**		**with Work zone (Berthaume)**		**with Work zone (Khanta)**		**Field Observations (w/ workzone)**	
		EB	*WB*	*EB*	*WB*	*EB*	*WB*	*EB*	*WB*	*EB*	*WB*	*EB*	*WB*
SR 116 Sunderland, MA	*Travel Time*$_{(min)}$	1.23	1.25	1.15	1.10	1.50	1.45	3.13	3.02	3.00	2.98	4.40	4.33
(1.00 mi)	*Average Speed*$_{(mph)}$	48.78	48.00	52.17	54.55	40.00	41.38	19.17	19.87	20.00	20.13	13.64	13.86
		SB	*NB*	*SB*	*NB*	*SB*	*NB*	*SB*	*NB*	*SB*	*NB*	*SB*	*NB*
SR 125 Andover, MA	*Travel Time*$_{(min)}$	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.42	2.41	2.60	2.47
(1.70 mi)	*Average Speed*$_{(mph)}$	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	42.15	42.32	39.23	41.30

Note: N/A indicates Not Available

Source: [1] Khanta, 2008

Table 2: Work Zone Software Comparison

Characters and Parameters	CA4PRS	QuickZone	QUEWZ	CORSIM
Data Assembly Time (hrs.); does not include field collection	1 to 2	2 to 6	1 to 2	2 to 6
Data Input Time (hrs.)	1	1.5 to 2.5	1	2 to 3
Data Analysis Time (min.); does not include review of output	<1	<1	<1	5
Major Inputs		-Lane Geometry -Hourly Volume	-Lane Geometry -Hourly Volume	-Lane Geometry -Hourly Volume
Major Outputs	-Max Possible Rehab. Length (mi.)	-Queue Length (mi.)	-Queue Length (mi.)	-Travel Time (min) -Avg, Speed (mph)
Minimum Length work zone	X			
Maximization of work zone productivity	X	X		
Optimal construction staging	X	X	X	
Maximum tolerable traffic delay		X	X	
Optimal work zone season		X		
Nighttime work zones	X	X	X	X
Crash frequency				
Minimal user cost rehabilitation strategy	X	X	X	
Construction window lane closure tactic	X		X	X
Material selection: curing time for concrete or cooling time for asphalt	X			
Pavement cross section: thickness of new concrete or asphalt	X			
Contractor's logistical resource: location, capacity, and numbers of rehabilitation equipment available	X			
Scheduling interface: mobilization/demobilization, traffic control time, and activity lead-lag time relationships and buffer sizes	X			X
Quantify corridor delay results from capacity decreasing work zones		X	X	X
Identify delay impacts of alternative project phasing plans		X	X	
Support tradeoff analysis between construction costs and delay costs	X	X		
Examine the impacts of construction staging by location along mainline, time-of-day (peak vs. off-peak), and seasonal (summer vs. winter)		X		
Assess travel demand and measures and other delay mitigation strategies		X	X	X
Help establish work completion incentives	X	X		

Sources: Wu, 2008 and Moriarty, 2007

Table 2 presents a comparison of the general characteristics, parameters, and constraints of three software packages and also provides a summary of the time required to assemble, input, and analyze the data for the QuickZone and CA4PRS simulation models as reported by Moriarty (27). It is hoped that the information presented will lend insight to the general functional purposes and user-friendliness of each package. It should be noted that time requirements may 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 package and fundamental traffic flow concepts.

From the Table 2, it can be seen that CA4PRS takes significantly less time to assemble and model data than QuickZone. CA4PRS and QuickZone have many different purposes and capabilities and QUEWZ has fewer.

SUMMARY AND CONCLUSIONS

This paper has focused on the application and of QUEWZ, CORSIM, 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 model. The research has illustrated the use of both the data input and output procedures for QuickZone, QUEWZ, CORSIM, and CA4PRS. Where possible, the simulated results have been compared directly to observed field data collected in this study and by others (29) , allowing for a judgment to be made as to the reliability and 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 may be more difficult to gather, 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:

- Applying and evaluating 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 some simulation models provide a low-risk, low-cost environment in which to test and analyze a variety of work zone alternatives. For example, QUEWZ and QuickZone were able to provide reasonable order of magnitude queue length estimates on interstate highways comparable to observations made in the field. In addition, such estimates required little data including hourly volume and roadway geometry information. Care must be taken, however, in using simulation results to make concrete decisions. It is strongly recommended 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.

In the evaluation of alternative work zone strategies along arterials, it was clear that the analysis in this study was considerably strengthened by CORSIM due to its abilities to analyze complicated arterial networks, provide visual depiction of congested areas, and build complex networks that are adaptable to the latest traffic control devices [25].

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Appendices:

Figure A1: Work Zone Segments**:** Selected Software Program Inputs and Related Information

Figure A2: Sample Input Screenshot of QUEWZ, Entry Data

Figure A3: Sample Input Screenshot of QUEWZ, Hourly Volume

Figure A4: Sample Input Screenshot of QuickZone, Node Data

Figure A5: Sample Input Screenshot of QuickZone, Links

Figure A6: Sample Input Screenshot of QuickZone, Demands

Figure A7: Sample Input Screenshot of QuickZone, AADT Patterns

Figure A8: Sample Input Screenshot of QuickZone, Project Information

Figure A9: Sample Input Screenshot of QuickZone, Construction Phase Info

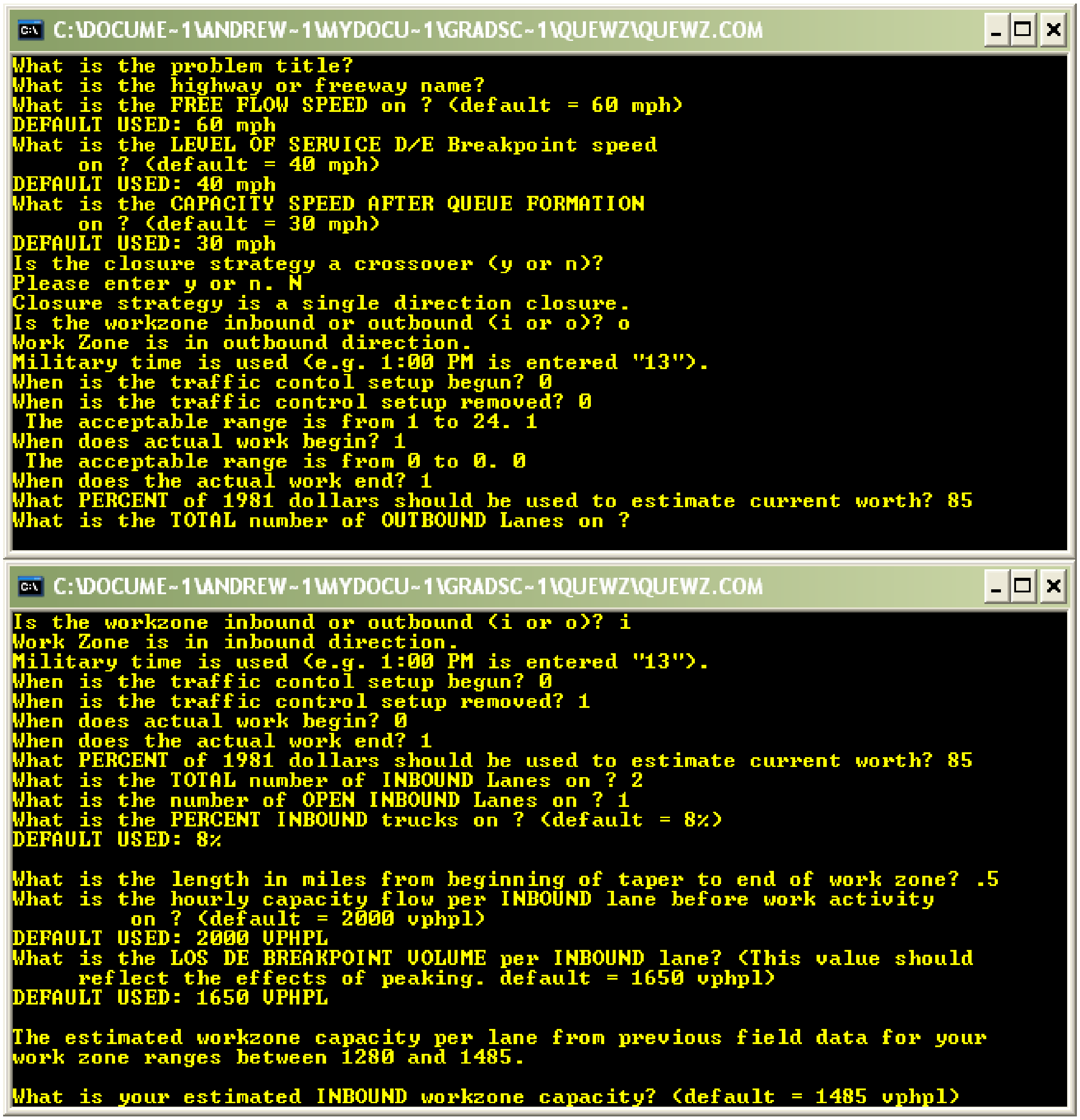
Figure A10: Sample Input Screenshot of QuickZone, User Cost Parameters

Work Zone	INPUTS						
	Shoulder Width (ft)	*Length of WZ (mi)*	*% Heavy Vehicles*	*Free Flow Speed (mph)*	*Number of Lanes per Direction*	*ADT*	*Hours of Lane Closure*
I-91 Greenfield, MA[1,2] *1 lane closed*	12	0.57	1.67	70	2	72000	8am - 4pm
I-95 West Greenwich, RI[1,2]	12	~0.25	2	70	2	34000	24 hour
I-91 Windsor, CT[1] *1 lane closed* *2 lane closed*	12	0.57	8	60	2	N/A	8am - 4pm
I-95 Bangor, ME[3] *1 lane closed*	12	~0.3	2	45	2	30,320	8am – 4pm
I-93 Manchester, NH[3]	12	1.7	12	65	4	114,000	24 hours
Route 9 in Amherst, MA[3] *1 lane closed*	~0-2	N/A	<7%	30	1	33,600	8am – 4pm
Route 116 Sunderland, MA[3] *1 lane closed*	~4	N/A	<5%	55	1	17,500	8am – 4pm
SR. 114/125 Andover, MA[3] *1 lane closed*	~4	0.32	<5%	55	2	~1550 veh/hour	24 hour

Notes: N/A indicates Not Applicable

Sources:
[1] Wu, 2008
[2] Moriarty, 2007
[3] Khanta, 2008

Figure A1: Work Zone Segments**:** Selected Software Program Inputs and Related Information



```
What is the problem title?
What is the highway or freeway name?
What is the FREE FLOW SPEED on ? (default = 60 mph)
DEFAULT USED: 60 mph
What is the LEVEL OF SERVICE D/E Breakpoint speed
     on ? (default = 40 mph)
DEFAULT USED: 40 mph
What is the CAPACITY SPEED AFTER QUEUE FORMATION
     on ? (default = 30 mph)
DEFAULT USED: 30 mph
Is the closure strategy a crossover (y or n)?
Please enter y or n. N
Closure strategy is a single direction closure.
Is the workzone inbound or outbound (i or o)? o
Work Zone is in outbound direction.
Military time is used (e.g. 1:00 PM is entered "13").
When is the traffic contol setup begun? 0
When is the traffic control setup removed? 0
 The acceptable range is from 1 to 24. 1
When does actual work begin? 1
 The acceptable range is from 0 to 0. 0
When does the actual work end? 1
What PERCENT of 1981 dollars should be used to estimate current worth? 85
What is the TOTAL number of OUTBOUND Lanes on ?
```

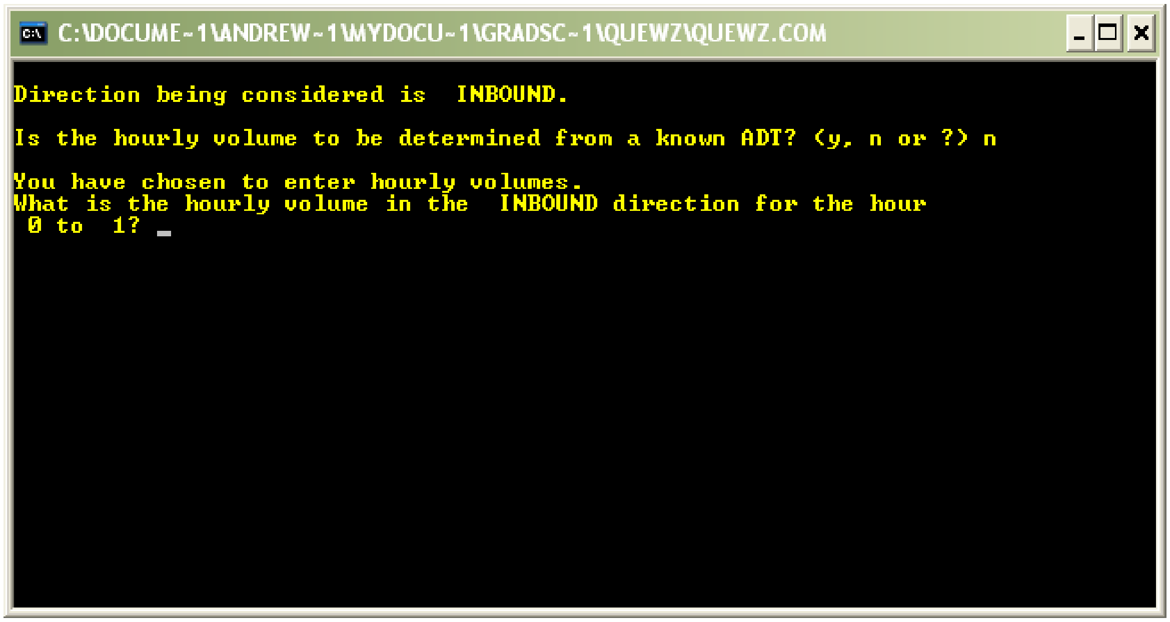
```
Is the workzone inbound or outbound (i or o)? i
Work Zone is in inbound direction.
Military time is used (e.g. 1:00 PM is entered "13").
When is the traffic contol setup begun? 0
When is the traffic control setup removed? 1
When does actual work begin? 0
When does the actual work end? 1
What PERCENT of 1981 dollars should be used to estimate current worth? 85
What is the TOTAL number of INBOUND Lanes on ? 2
What is the number of OPEN INBOUND Lanes on ? 1
What is the PERCENT INBOUND trucks on ? (default = 8%)
DEFAULT USED: 8%

What is the length in miles from beginning of taper to end of work zone? .5
What is the hourly capacity flow per INBOUND lane before work activity
         on ? (default = 2000 vphpl)
DEFAULT USED: 2000 VPHPL
What is the LOS DE BREAKPOINT VOLUME per INBOUND lane? (This value should
     reflect the effects of peaking. default = 1650 vphpl)
DEFAULT USED: 1650 VPHPL

The estimated workzone capacity per lane from previous field data for your
work zone ranges between 1280 and 1485.

What is your estimated INBOUND workzone capacity? (default = 1485 vphpl)
```

Figure A2: Sample Input Screenshot of QUEWZ, Entry Data

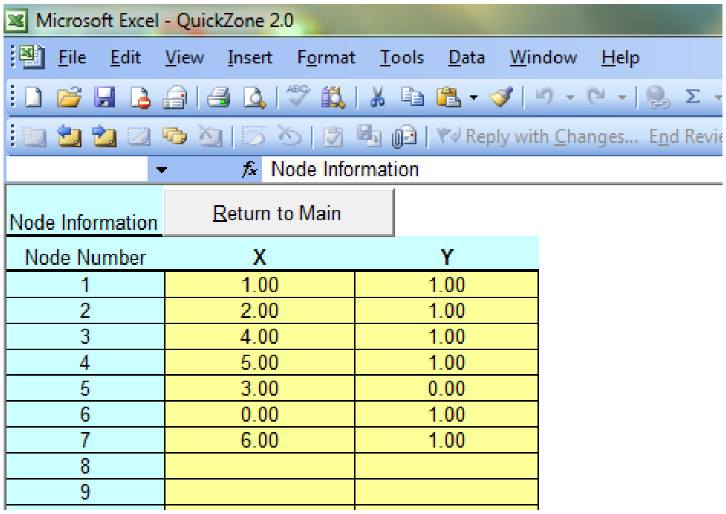


```
Direction being considered is  INBOUND.

Is the hourly volume to be determined from a known ADT? (y, n or ?) n

You have chosen to enter hourly volumes.
What is the hourly volume in the  INBOUND direction for the hour
 0 to  1? _
```

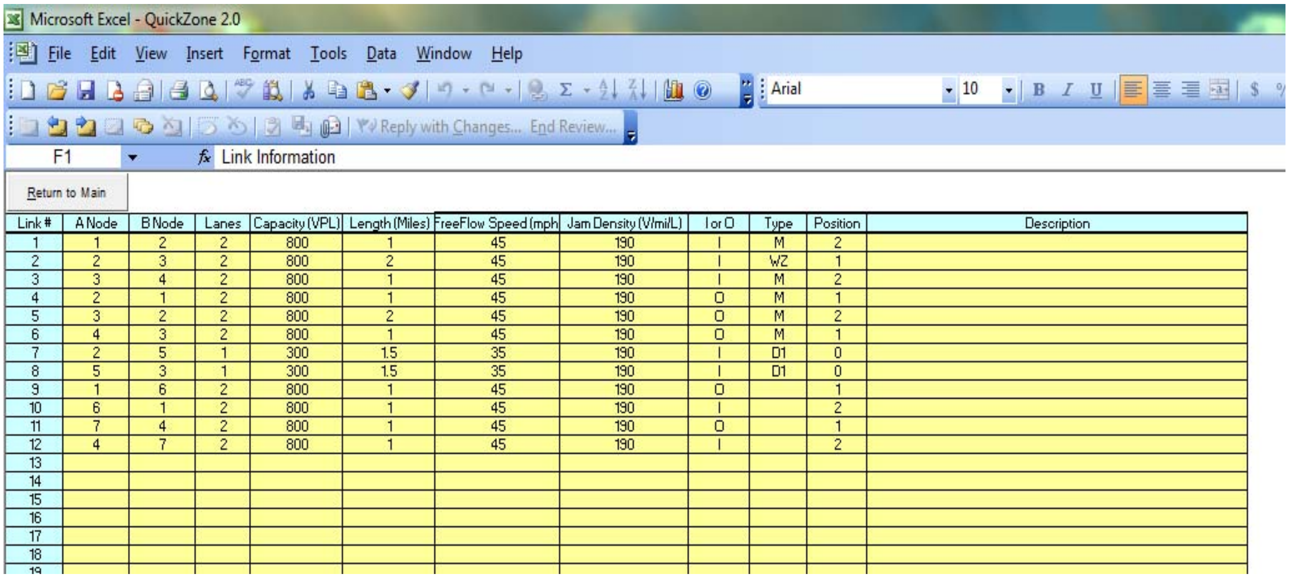
Figure A3: Sample Input Screenshot of QUEWZ, Hourly Volume



Node Information

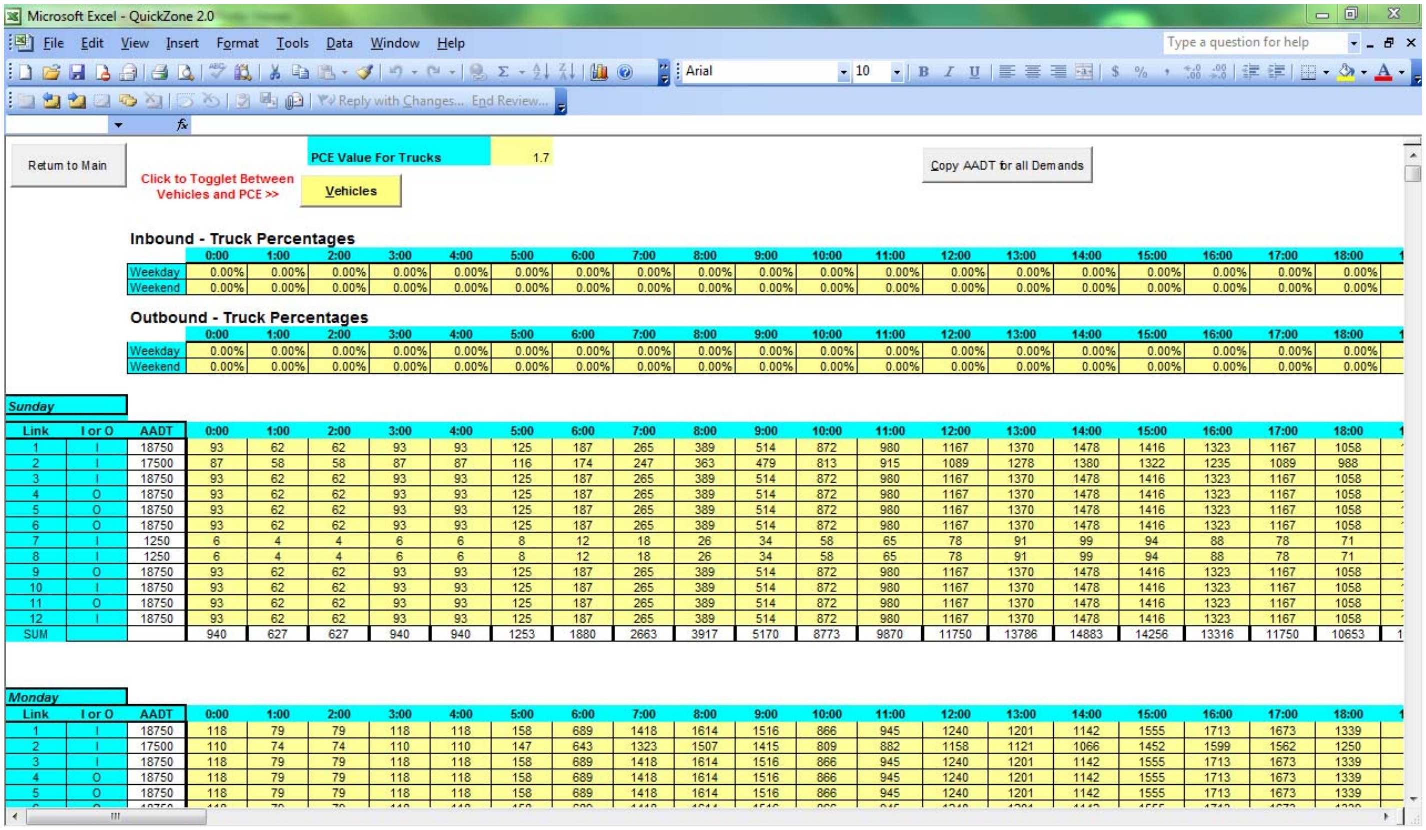
Node Number	X	Y
1	1.00	1.00
2	2.00	1.00
3	4.00	1.00
4	5.00	1.00
5	3.00	0.00
6	0.00	1.00
7	6.00	1.00
8		
9		

Figure A4: Sample Input Screenshot of QuickZone, Node Data



Link #	A Node	B Node	Lanes	Capacity (VPL)	Length (Miles)	FreeFlow Speed (mph	Jam Density (V/mi/L)	I or O	Type	Position	Description
1	1	2	2	800	1	45	190	I	M	2	
2	2	3	2	800	2	45	190	I	WZ	1	
3	3	4	2	800	1	45	190	I	M	2	
4	2	1	2	800	1	45	190	O	M	1	
5	3	2	2	800	2	45	190	O	M	2	
6	4	3	2	800	1	45	190	O	M	1	
7	2	5	1	300	1.5	35	190	I	D1	0	
8	5	3	1	300	1.5	35	190	I	D1	0	
9	1	6	2	800	1	45	190	O		1	
10	6	1	2	800	1	45	190	I		2	
11	7	4	2	800	1	45	190	O		1	
12	4	7	2	800	1	45	190	I		2	
13											
14											
15											
16											
17											
18											
19											

Figure A5: Sample Input Screenshot of QuickZone, Links



PCE Value For Trucks	1.7

Inbound - Truck Percentages

	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	13:00	14:00	15:00	16:00	17:00	18:00
Weekday	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Weekend	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Outbound - Truck Percentages

	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	13:00	14:00	15:00	16:00	17:00	18:00
Weekday	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Weekend	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

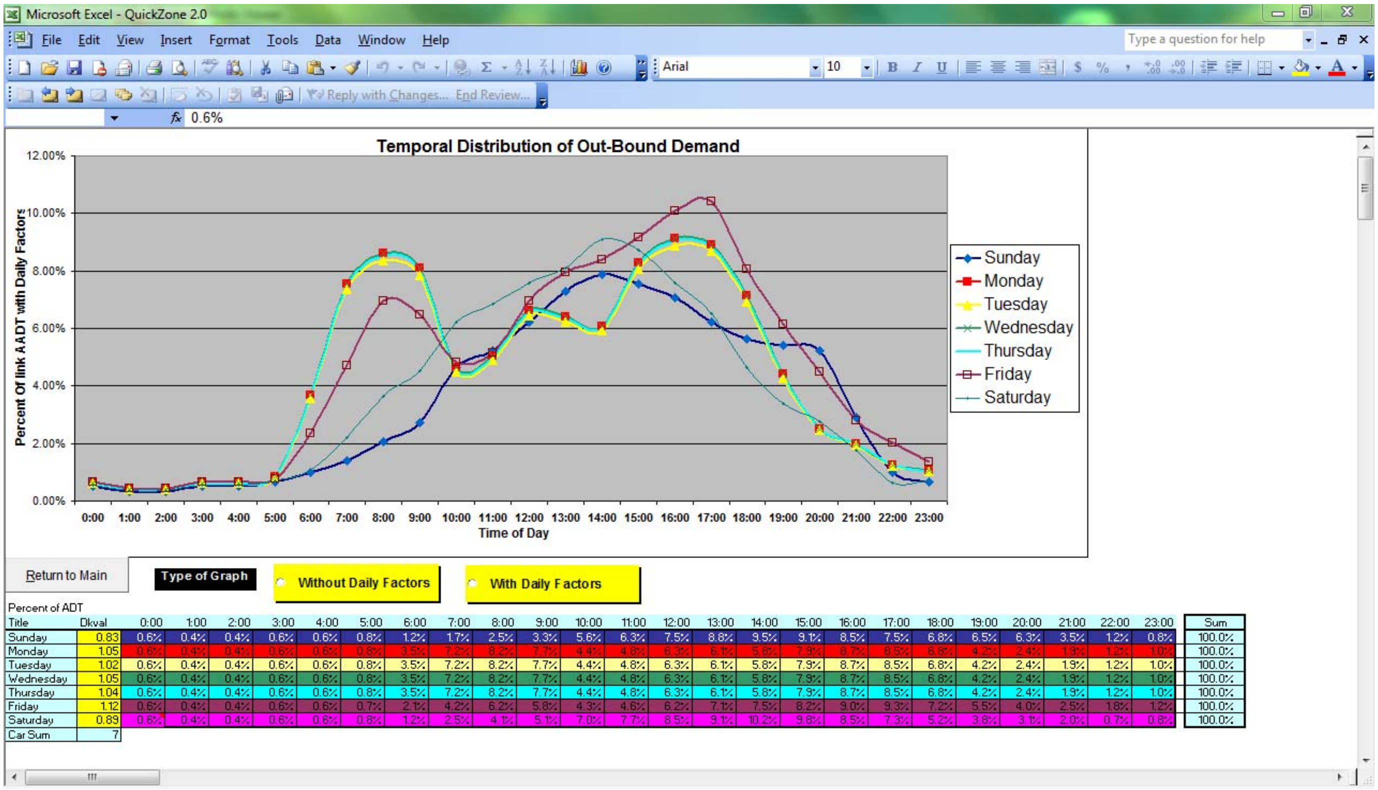
Sunday

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	13:00	14:00	15:00	16:00	17:00	18:00
1	I	18750	93	62	62	93	93	125	187	265	389	514	872	980	1167	1370	1478	1416	1323	1167	1058
2	I	17500	87	58	58	87	87	116	174	247	363	479	813	915	1089	1278	1380	1322	1235	1089	988
3	I	18750	93	62	62	93	93	125	187	265	389	514	872	980	1167	1370	1478	1416	1323	1167	1058
4	O	18750	93	62	62	93	93	125	187	265	389	514	872	980	1167	1370	1478	1416	1323	1167	1058
5	O	18750	93	62	62	93	93	125	187	265	389	514	872	980	1167	1370	1478	1416	1323	1167	1058
6	O	18750	93	62	62	93	93	125	187	265	389	514	872	980	1167	1370	1478	1416	1323	1167	1058
7	I	1250	6	4	4	6	6	8	12	18	26	34	58	65	78	91	99	94	88	78	71
8	I	1250	6	4	4	6	6	8	12	18	26	34	58	65	78	91	99	94	88	78	71
9	O	18750	93	62	62	93	93	125	187	265	389	514	872	980	1167	1370	1478	1416	1323	1167	1058
10	I	18750	93	62	62	93	93	125	187	265	389	514	872	980	1167	1370	1478	1416	1323	1167	1058
11	O	18750	93	62	62	93	93	125	187	265	389	514	872	980	1167	1370	1478	1416	1323	1167	1058
12	I	18750	93	62	62	93	93	125	187	265	389	514	872	980	1167	1370	1478	1416	1323	1167	1058
SUM			940	627	627	940	940	1253	1880	2663	3917	5170	8773	9870	11750	13786	14883	14256	13316	11750	10653

Monday

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	13:00	14:00	15:00	16:00	17:00	18:00
1	I	18750	118	79	79	118	118	158	689	1418	1614	1516	866	945	1240	1201	1142	1555	1713	1673	1339
2	I	17500	110	74	74	110	110	147	643	1323	1507	1415	809	882	1158	1121	1066	1452	1599	1562	1250
3	I	18750	118	79	79	118	118	158	689	1418	1614	1516	866	945	1240	1201	1142	1555	1713	1673	1339
4	O	18750	118	79	79	118	118	158	689	1418	1614	1516	866	945	1240	1201	1142	1555	1713	1673	1339
5	O	18750	118	79	79	118	118	158	689	1418	1614	1516	866	945	1240	1201	1142	1555	1713	1673	1339

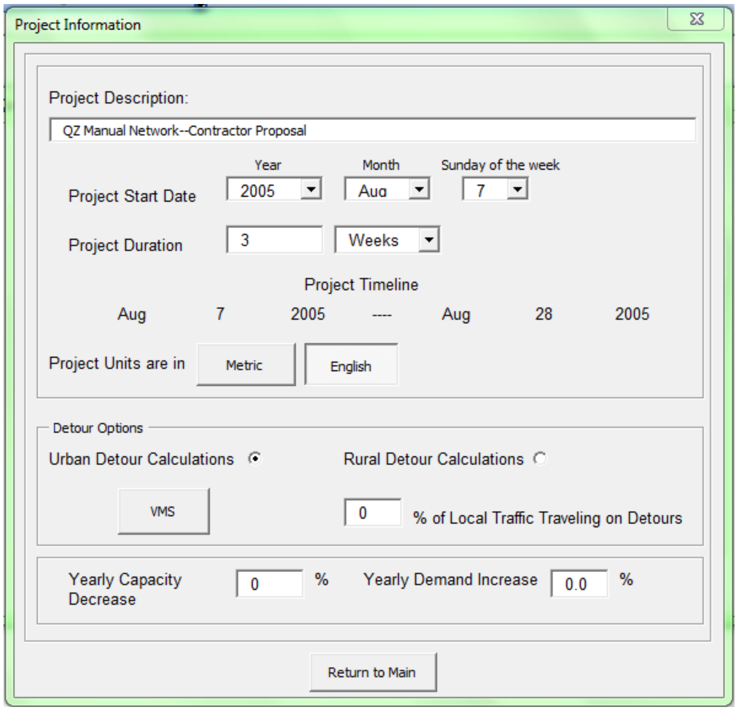
Figure A6: Sample Input Screenshot of QuickZone, Demands



Percent of ADT

Title	Dkval	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	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	Sum
Sunday	0.83	0.6%	0.4%	0.4%	0.6%	0.6%	0.8%	1.2%	1.7%	2.5%	3.3%	5.6%	6.3%	7.5%	8.8%	9.5%	9.1%	8.5%	7.5%	6.8%	6.5%	6.3%	3.5%	1.2%	0.8%	100.0%
Monday	1.05	0.6%	0.4%	0.4%	0.6%	0.6%	0.8%	3.5%	7.2%	8.2%	7.7%	4.4%	4.8%	6.3%	6.1%	5.8%	7.9%	8.7%	8.5%	6.8%	4.2%	2.4%	1.9%	1.2%	1.0%	100.0%
Tuesday	1.02	0.6%	0.4%	0.4%	0.6%	0.6%	0.8%	3.5%	7.2%	8.2%	7.7%	4.4%	4.8%	6.3%	6.1%	5.8%	7.9%	8.7%	8.5%	6.8%	4.2%	2.4%	1.9%	1.2%	1.0%	100.0%
Wednesday	1.05	0.6%	0.4%	0.4%	0.6%	0.6%	0.8%	3.5%	7.2%	8.2%	7.7%	4.4%	4.8%	6.3%	6.1%	5.8%	7.9%	8.7%	8.5%	6.8%	4.2%	2.4%	1.9%	1.2%	1.0%	100.0%
Thursday	1.04	0.6%	0.4%	0.4%	0.6%	0.6%	0.8%	3.5%	7.2%	8.2%	7.7%	4.4%	4.8%	6.3%	6.1%	5.8%	7.9%	8.7%	8.5%	6.8%	4.2%	2.4%	1.9%	1.2%	1.0%	100.0%
Friday	1.12	0.6%	0.4%	0.4%	0.6%	0.6%	0.7%	2.1%	4.2%	6.2%	5.8%	4.3%	4.6%	6.2%	7.1%	7.5%	8.2%	9.0%	9.3%	7.2%	5.5%	4.0%	2.5%	1.8%	1.2%	100.0%
Saturday	0.89	0.6%	0.4%	0.4%	0.6%	0.6%	0.8%	1.2%	2.5%	4.1%	5.1%	7.0%	7.7%	8.5%	9.1%	10.2%	9.8%	8.5%	7.3%	5.2%	3.8%	3.1%	2.0%	0.7%	0.8%	100.0%
Car Sum	7																									

Figure A7: Sample Input Screenshot of QuickZone, AADT Patterns



Project Description: QZ Manual Network--Contractor Proposal

Project Start Date: Year 2005, Month Aug, Sunday of the week 7

Project Duration: 3 Weeks

Project Timeline

Aug 7 2005 ---- Aug 28 2005

Project Units are in

Detour Options

Urban Detour Calculations ●

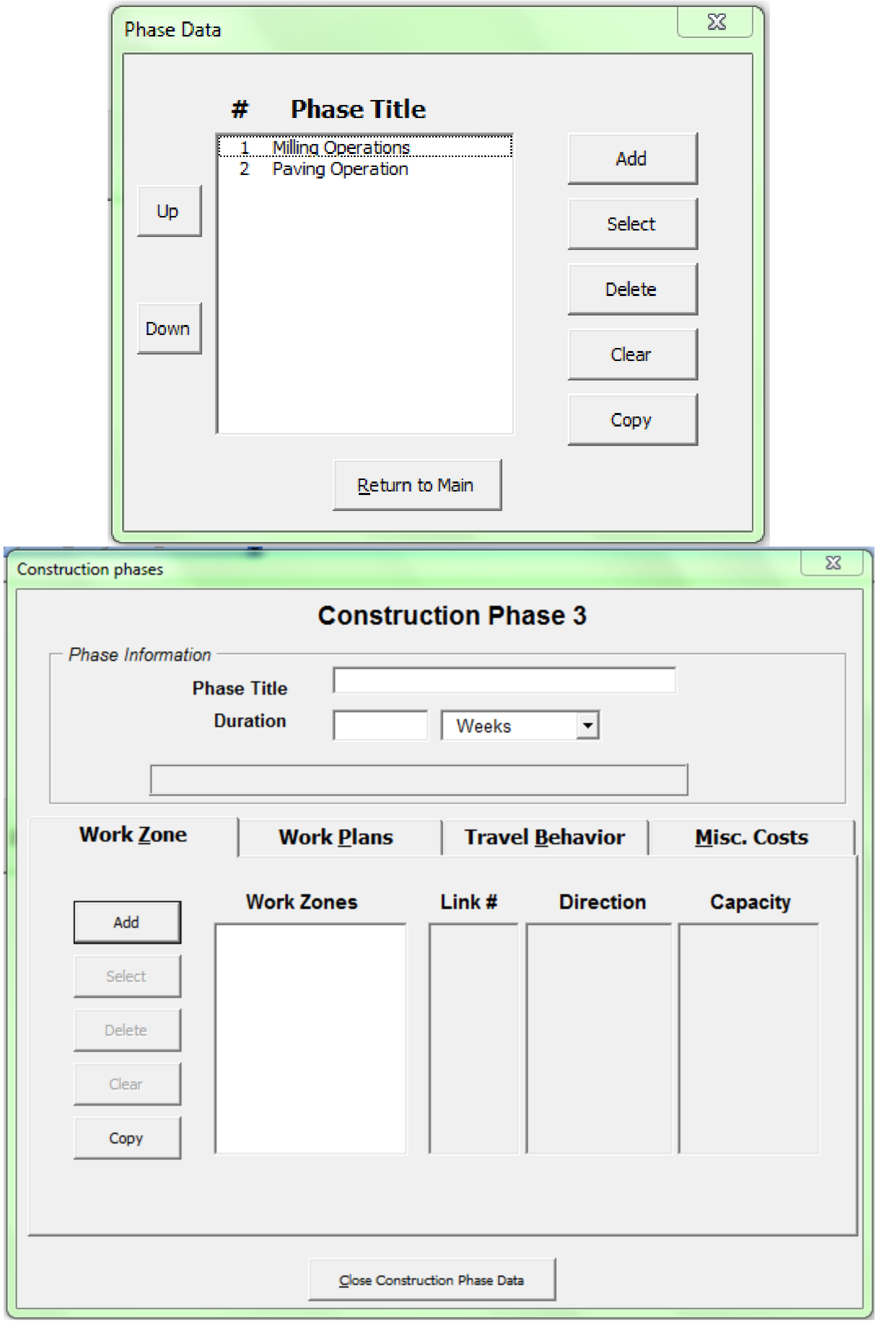
Rural Detour Calculations ○

0 % of Local Traffic Traveling on Detours

Yearly Capacity Decrease 0 %

Yearly Demand Increase 0.0 %

Figure A8: Sample Input Screenshot of QuickZone, Project Information



#	Phase Title
1	Milling Operations
2	Paving Operation

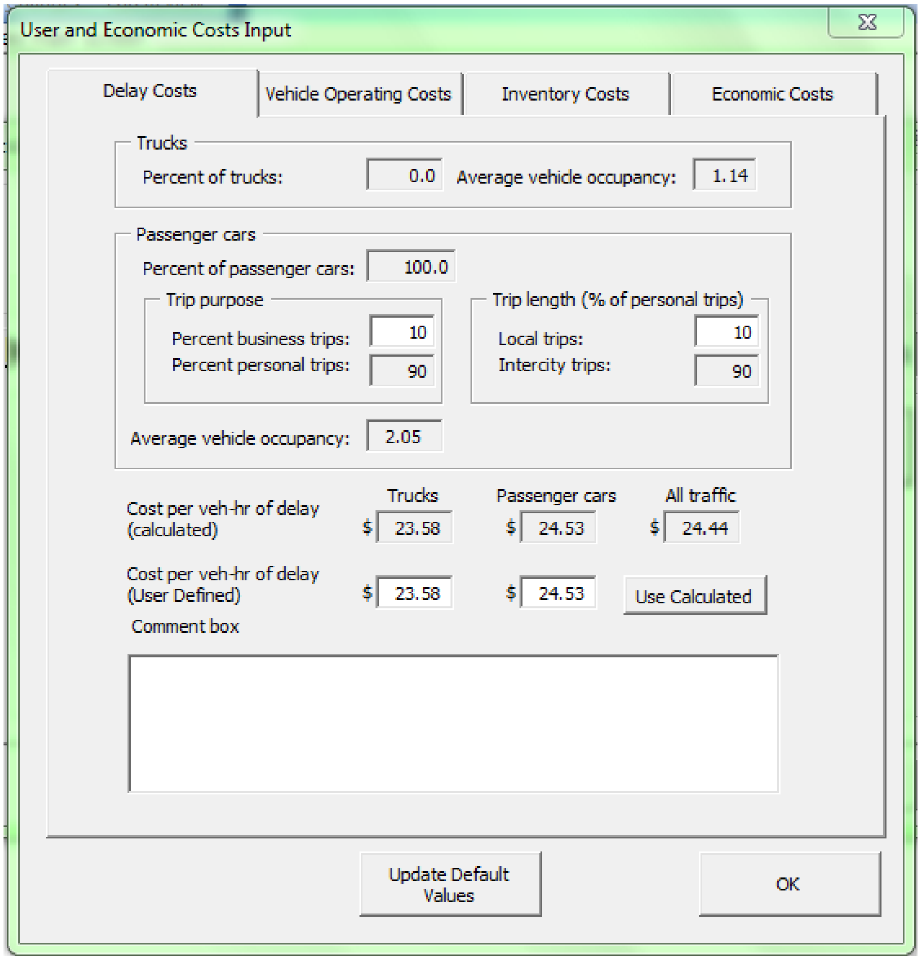
Construction Phase 3

Phase Title

Duration Weeks

Work Zones	Link #	Direction	Capacity

Figure A9: Sample Input Screenshot of QuickZone, Construction Phase Info



Trucks

Percent of trucks: 0.0

Average vehicle occupancy: 1.14

Passenger cars

Percent of passenger cars: 100.0

Trip purpose

Percent business trips: 10

Percent personal trips: 90

Trip length (% of personal trips)

Local trips: 10

Intercity trips: 90

Average vehicle occupancy: 2.05

	Trucks	Passenger cars	All traffic
Cost per veh-hr of delay (calculated)	$ 23.58	$ 24.53	$ 24.44
Cost per veh-hr of delay (User Defined)	$ 23.58	$ 24.53	

Comment box

Figure A10: Sample Input Screenshot of QuickZone, User Cost Parameters