

**ON THE ACCURACY OF COMMERCIALY AVAILABLE MACROSCOPIC AND MICROSCOPIC  
TRAFFIC SIMULATION TOOLS FOR PREDICTION OF WORKZONE TRAFFIC**

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**ABSTRACT**

The Ohio Department of Transportation (ODOT) has identified the maintenance of traffic (MOT) as a top priority to serve the motoring public as part of a department strategic initiative. A key component of this strategy is to ensure that traffic flows efficiently through work zones. This paper describes work that was performed for ODOT to determine if commercially available traffic simulation models could be calibrated to yield accurate queue length and delay time predictions for planning purposes in freeway work zones. Four work zones on multi lane freeways were selected by ODOT for collection of the calibration data. Traffic flow video records were obtained at the four selected work zones using two ODOT video recording vans equipped with 15 m masts. Traffic flow parameters were extracted from the video records using the Mobilizer-PC software package. The traffic simulation/prediction tools that we investigated included the Highway Capacity Software (HCS), Synchro, Corsim (under ITRAF and TRAFVU), NetSim, and a macroscopic model called QueWZ92. Simulation models were constructed with all models for the selected work zones, and the simulated queue lengths and delay times were compared to the data that was extracted from the field data with Mobilizer-PC. The results of this study indicated that the microscopic simulation packages could not be calibrated to the oversaturated conditions that existed at the work zones. The calibrated microscopic simulation packages underestimated the actual length of the queues that formed in the real world. The macroscopic QueWZ92 produced more accurate estimates than the microscopic packages.

## INTRODUCTION

To aid in mitigation of long delay times in work zones ODOT intends to use simulation and modeling approaches to forecast the effects of freeway work zones on traffic flow [1]. This process requires a tool that accurately models the traffic through proposed work zones. ODOT identified several commercially available analysis tools, including Synchro, CORSIM, QueWZ92, Highway Capacity Software (HCS), and an ODOT proprietary spreadsheet, that could be used to model traffic flow for various work zone situations. None of these software packages were designed with the intent of modeling work zones operating at or above capacity, with the exception of QueWZ92 and the ODOT spreadsheet.

ODOT recognized that further research was needed to determine the most accurate commercially available tool. The objective of the work reported in this paper was to collect work zone queue length and delay time data and, if possible, to use this data to calibrate the above mentioned simulation/forecasting tools.

Four work zones in the state of Ohio were selected by ODOT. Data collection included video footage recorded by two ODOT video vans with 15 m masts. The first video van filmed traffic within the initial lane taper or crossover of the work zone, providing a video record of the observed capacity at the choke point of the work zone. The second video boom-van filmed traffic approaching the work zone in free flow condition several miles upstream from the work zone. The video records provided the information to obtain the traffic demand schedule of the roadway. We also observed and manually recorded the queue length every ten minutes throughout the formation and dissipation of queues. These queue length measurements were accomplished by a trained spotter in a vehicle that was moving back and forth with the queue end but on the opposite side of the freeway. Accurate queue length measurements were thereby obtained.

The video records from the work zones were analyzed using the Mobilizer-PC traffic flow analysis program. Mobilizer-PC provided a method of continuous analysis for each individual entity (vehicle) in the field of view, and produced parameters such as speed, headway, vehicle type, and density. Following the analysis through Mobilizer-PC, models for each work zone were created using all

the tools that we evaluated. The results of the analyses by each model were then compared to the observations made in the field. We attempted to calibrate the microscopic tools to achieve queue lengths and delay times that resembled those in the field data. All microscopic tools underestimated the queue length and it was not possible to further calibrate the microscopic tools to obtain reasonable estimates of queue lengths and delay times. Of those tools investigated, and in spite of attempts to calibrate the microscopic tools, we found that QueWZ92 provided the best prediction of the work zone capacity.

Our literature review did not locate any other work where commercially available simulation/prediction packages were compared for use in work zone queue length and delay time estimation. The work presented in this paper may be useful for planners in highway agencies to select appropriate modeling tools for estimation of queue lengths and delay times in work zones. Most macroscopic simulation models are not adequate for oversaturated travel conditions such as they exist in work zones that are causing traffic backups. QueWZ92, however, was specifically designed for work zones and appears to have no problem providing fairly accurate capacity estimates. One disadvantage of a macroscopic model such as QueWZ92 is the lack of flexibility to account for complex work zone arrangements. In this paper, we provide calibration parameters that seemed to have offered good results for use with QueWZ92.

## REVIEW OF THE TECHNICAL LITERATURE

A model entitled Queue and User Evaluation of Work Zones (QUEWZ), which is the predecessor of the QUEWZ92 model, was developed by Memmott and Dudek [2] due to the limitations in several of the previously developed methods. A capacity study was conducted by Dudek and Richards [3] at twenty-eight work zones on Texas freeways. For predicting the Construction Congestion Cost ( $CO^3$ ) associated with work zones Carr [6] stated that speed, backup and diversion delays should be considered at work zones. Smith and Demetsky [7] discussed the application of 4 modeling approaches to traffic flow forecasting. They developed and tested models for the freeway traffic flow forecasting problem, in an attempt to estimate traffic flow 15 minutes into the future. Golias et al. [8] proposed a multivariable model and a single-variable model for estimating vehicle lane usage in suburban and interurban multilane highways. The Highway Capacity Manual provides the various levels of service (LOS) found on freeway sections and contains a look up table for calculating passenger car equivalents for trucks based on specific upgrades [9]. The capacity and the level of service (LOS) at freeway construction zones are to be determined for the planning and scheduling of work zone traffic control, according to Rouphail and Tiwari [10]. We conducted a detailed review of the following macroscopic and microscopic software tools [1]:

- HCS
- TRAF/CORSIM
- Synchro/SimTraffic
- QueWZ92
- ODOT queue length calculation spread sheet

For a detailed discussion of these tools, their capabilities and limitations please refer to [1].

## METHOD

Four work zone locations were selected and observed for obtaining actual field data, and the values obtained in the field are compared to the results provided by the analyses performed with each tool.

### Work Zone Locations

#### *I-70 Westbound, Columbus, Ohio*

An aerial view of the I-70/SR256 interchange before construction began is shown in Figure 2a. The work zone was approximately 12 km (7.4 miles) in length. The construction zone included a crossover 1.61 km (1 mile) after the I-70/SR-256 interchange, where two lanes of the westbound traffic were shifted to the eastbound side of the freeway. Within the crossover, lane width was reduced from 3.66 m (12 ft) to 3.52 m (11.5 ft). Concrete Jersey barriers separated the three-lane eastbound traffic and the westbound traffic throughout the 10.3 km (6.4 miles) of the crossover. At the I-70/James Road interchange, the westbound traffic shifted back the original westbound portion of the freeway. During the construction phase, we observed that, majority of the traffic on I-70 has merged into the left lane before the SR256 intersection to compensate for the merging traffic from SR256 along the right side of the road.

#### *I-70 Eastbound, Cambridge, Ohio – 3.05 m (10 ft) lane*

This work zone was approximately 0.97 km (0.6 miles) in length along I-70 eastbound (and) near Cambridge, Ohio, and included the area surrounding an overpass bridge. An aerial view of the work zone is given in Figure 2b. Throughout the construction zone, only the left lane was open for eastbound travel. The eastbound traffic had to merge onto a 3.05 m (10 ft) lane edged by two lines of concrete barriers. The entire work zone had a 2.88% uphill grade. There were an on ramp and an off ramp located just before the taper of the work zone, which did not seem to have a significant effect on the total flow of the work zone.

#### *I-70 Eastbound, Cambridge, Ohio – 3.66 m (12 ft) lane*

A second observation was conducted at the Cambridge work zone during a subsequent phase of construction. This time, the recently reconstructed right side of the bridge was opened to traffic while the left lane was closed. This configuration layout was symmetrical to the original configuration with respect

to the centerline, except that the open right lane had a width of 3.66 m (12 ft), which is 0.61 m (2 ft) wider than the previously open left lane.

#### *Highway 2, Westbound, Sandusky, Ohio*

Figure 2c illustrates the beginning of the analyzed work zone and the location of the second van. The first video van recorded the free flow conditions 4 km (2.5 miles) upstream the start of the work zone. The distance between the two video vans was 4.5 km (2.8 miles). The work zone starts with the tapering of the right westbound lane at the highway 6 intersection, where the on-ramp from highway 6 westbound was closed. This first right lane closure was 8.5 km (5.3 miles) in length. Another construction zone was 4.6 km (2.9 miles) downstream the analyzed work zone, which had a left lane closure. No queue formation was observed at the second work zone during the drive-through.

#### **Recording Equipment and Analysis**

Two ODOT video vans were used for this task. The first video van recorded the free flow traffic approaching the work zone before the end of the queue. This video record was used to obtain information regarding the traffic volume, the speed, and the average headways of the vehicles. The second video van was located within the work zone, and the traffic in the taper or crossover was recorded. The recordings yielded a true figure for the capacity of the work zone at the bottleneck. The outriggers of the vans were used for picture stability. MOBILIZER-PC is a software-based video detection and tracking system, which uses video inputs from a camera or a VCR. The vehicles are tracked throughout the field of view and displayed in real time on the computer screen. The Mobilizer-PC can also determine the queue lengths, the number and type of vehicles, the headway gaps, and the throughput. The continuous observation and automatic analysis provides excellent statistics for the flow conditions of the work zones.

A trained spotter was used to measure and record the geographic location of the end of the queue. The spotter used a vehicle on the opposite side of the freeway to keep up with the ever moving end of the queue. Exact time/location logs were kept of the queue and these logs were later synchronized with the traffic flow data extracted from Mobilizer PC.

## RESULTS

Each of the selected flow analysis tools (TRAF/CORSIM, Synchro, QueWZ92) was used to build a model of the work zones, which were recorded in a previous task. The models were evaluated with regard to how closely their predictions of delay times and queue lengths match with the corresponding observed quantities, using the same traffic volume and saturation flow parameters. Parameters in the respective simulation/prediction tools were adjusted to calibrate to the real world data. However, we were not able to calibrate the microscopic models sufficiently to agree with the queue lengths and delay times observed in the real world. The microscopic packages underestimated the real world queue lengths and delay times. Detailed discussions of the performance of each tool together with their inadequacies are provided in this section of the paper.

### Field Observations

The following three parameters were used to describe the work zones in terms of associated delays.

- Capacity (vehicles per hour) – Defined as the number of vehicles the work zone could accommodate without queue formation. Capacity was calculated by taking the average of the hourly flow rates as observed with the Mobilizer-PC, in case of a queue formation. Importantly, the hourly flow rates associated only with the times of queue were used to guarantee an accurate capacity calculation. For a work zone to work at its capacity, there must always be vehicles waiting to enter the work zone.
- Queue length (km) – The queue length recordings were taken every 10 minutes by a spotter located in a separate research vehicle.
- Travel time (minutes per mile) – At different times of the day and for various queue lengths, we measured the total travel time through the work zone.

Table 1 summarizes the parameters obtained in the field for each work zone.



### **Work Zone Model Outputs**

All tools under evaluation (HCS, TRAF/CORSIM, Synchro/SimTraffic, QueWZ92, ODOT queue length calculation spread sheet) were applied to the four work zone conditions. We went through an elaborate calibration effort of the microscopic simulation packages (TRAF/CORSIM, Synchro/SimTraffic). SimTraffic allows the user to change factors through the parameters that describe drivers' preferred headway, the method of lane selection, and the range of speed in the model. During the first modeling iterations, these parameters were set to their default values, but in later models were calibrated by changing the appropriate parameters. For the microscopic simulation tools, we were unable to calibrate these parameters far enough to obtain reasonable estimates of the queue length and delay time for both microscopic packages. Both microscopic simulation packages underestimated the queue length and delay times.

We also calibrated the QueWZ92 model and found that its capacity estimate was rather close to that observed in the real world. Thus we decided to focus on using QueWZ92 in this paper because we felt that the reader would not benefit much from seeing model run data from microscopic packages that were in disagreement with the data observed in the field. The intent of this paper is to give the reader a way to use a tool to estimate capacity, queue lengths, and delay times at work zones more accurately.

#### *QueWZ92 - Cambridge 3.05 m (10 ft) lane*

Initially, the work zone parameters (shown in Table 2a) for this work zone were entered. With these initial parameters, the estimated work zone capacity was 1307 vehicles per hour per lane (vphpl). After this calculation, QueWZ92 allows to readjust the constants "I" (Work Zone Intensity), "R" (Presence of Ramps), and "E" (Passenger Car Equivalent). As the work zone activity get more intense, drivers need to allocate more attentional resources to the work activity and less to the task of driving, and therefore reduce their speeds, and consequently the capacity of the work zone decreases. The constant 'I' can take any value between negative 160 and 160, which is +/- 10 percent of the original 1600 passenger cars per hour per lane (pcphpl) base capacity. For work activities that are significantly minor or more intense than average, the only guidance is to increase or decrease the base capacity [11]. The Cambridge work zone can be categorized as an average activity work zone but especially the semi-truck

operators noticeably reduced their speeds through the 3.05 m (10 ft) wide lane enclosed by concrete barriers. Therefore, the work zone intensity, 'I', for the Cambridge work zone was reduced by 10 percent (160 pcphpl). The passenger car equivalent for the Cambridge site was determined as 3.0 passenger cars per heavy vehicle [9]. Considering the adjustment factor changes, the work zone capacity is reduced to 878 vehicles per hour per lane. QueWZ92 uses a density parameter of 132 vehicles per mile per lane to determine the length of the queue forming on the roadway before the work zone. Using the estimated capacity of 878 vehicles per hour and the directional hourly volume observed in the Cambridge video data, the resulting maximum queue was estimated as 4.83 km (3.0 miles).

#### *QueWZ92 – Cambridge 3.66 m (12 ft) lane*

QueWZ92 accounts for the number of lanes, however, it does not consider which side of the road (left or right lane) is closed in a two-to-one lane work zone. During the initial phase of construction at Cambridge, the left lane remained open, and during the second phase of construction, the open lane was shifted to the right. The QueWZ92 software considers the two work zone configurations to be identical. Furthermore, QueWZ92 does not have a specific parameter for lane width, and therefore, identical models needed to be used for these two distinct phases. We discussed the options to model this scenario with a developer of QueWZ92, and a suggestion was to adjust the work zone intensity factor to manipulate the system for changes in lane width. This type of a manipulation seemed to be an intuitive solution, since the proximity to the workers is one of the factors in the determination of the magnitude of work zone intensity. As lane width increases, the distance between drivers and workers will also increase. Hence, the only parameter to alter in the Cambridge 3.05 m (10 ft) lane model to convert to a Cambridge 3.66 m (12 ft) lane model was the work zone intensity. In the Cambridge 3.05 m (10 ft) lane model, the work zone intensity factor was 160. This largest possible value was selected to represent the extreme proximity of the vehicles to the surrounding concrete barriers and the resulting decrease in the speed. Many references including the Highway Capacity Manual 1997 suggest 3.66 m (12 ft) as an appropriate lane width of freeway sections. Since the Cambridge site was widened to the standard 3.66 m (12 ft) width, the work zone was determined to have a medium intensity, and the corresponding work zone intensity value was set at zero (work zones of greater than average intensity are given positive values, work zones of less than average intensity are given negative values). With this adjustment, the QueWZ92 model predicted the capacity of the one open lane to be 975 vehicles per

hour. However, during the observation of the 3.66 m (12 ft) lanes, the percentage of heavy vehicles was slightly less than the previously observed percentage. Consequently, the parameter for heavy vehicle percentage was reduced from 32% to 28%, which yielded a capacity estimate of 1025 vehicles per hour and a maximum resulting queue length of 4.5 km (2.8 miles). It is important that users of QueWZ92 obtain accurate percentage estimates for heavy vehicles, especially if the work zone is on a grade.

#### *QueWZ92 – Columbus*

The input entered in Quewz92 for Columbus work zone is shown in Table 2b. The initial capacity estimate was 1535 pcphpl, or a total of 3070 pcph for the two open lanes. The workers and equipment appeared only in a small area inside the work zone. Also, the construction lanes were 3.5 m (11.5 ft) wide, which was close to the recommended width of 3.66 m (12 ft). Therefore, the work zone intensity factor was chosen to be -100, which increased to the capacity of the work zone. The passenger car equivalent was 1.5 (passenger cars per heavy truck) for the given configuration of this work zone [9]. During the construction, the only open ramp was the SR256 ramp. Due to the considerable amount of traffic entering the freeway from this ramp, the ramp volume was added to the mainline volume to obtain the final volume count, and the corresponding ramp presence factor was kept at zero. After these adjustments, the QueWZ92 gave a final estimate of 1650 vehicles per hour per lane. Two lanes were open throughout the construction site, giving a total capacity estimation of 3300 vehicles per hour and a resulting maximum queue length of 3.38 km (2.1 miles).

#### *QueWZ92 – Sandusky*

Values of the input parameters for the Sandusky work zone are shown in Table 2c. The initial capacity estimate was 1412 vphpl. The Highway Capacity Manual suggests a passenger car equivalent of 2.1 (passenger car per truck) for a configuration on a flat, 8.5 km (5.3 miles) long two-lane highway as in the case of Sandusky work zone. The work zone activity parameter was specified as zero. The open lane had a width of 3.66m (12 ft), and consequently, the work zone intensity factor was adjusted to zero. After the adjustments, QueWZ92 yielded a final capacity estimate of 1323 vphpl, which is fairly close to the actual observed capacity of 1250 vphpl.

*Synchro and SimTraffic – Cambridge 3.05 m (10 ft) lane*

The Cambridge work zone was modeled with Synchro, using nine links and four nodes (intersections). In Synchro, manipulating the “headway factor” controls the parameters for the lane width and the grade. The headway factor is a multiplicative factor that increases or decreases the magnitude of the headway gap curves, which are used in SimTraffic to describe the various driver types. So as to account for a narrow 3.05 m (10 ft) width and a grade of 2.88%, the headway factor was increased, which also increased the headways of the vehicles in the simulation. Volume was added to the system through the data access feature of SimTraffic. To specify the simulated volume in SimTraffic, a separate file was created using Microsoft® Excel. The traffic flow was recorded for five hours (2:00 PM – 7:00 PM) containing 20 equal intervals (15 minutes each) to obtain the volume. The traffic mix was specified as 32% heavy traffic. The first simulation estimated a maximum queue length of 485 m (1593 ft) in the left lane, and 279 m (915 ft) in the right lane. Further iterations involved adjusting SimTraffic and Synchro parameters such as the speed and the headway factor to improve the accuracy of the model predictions. The speed was decreased from the observed free flow speed of 45 mph (72 km/h) to the observed queuing speed of 20 mph (32 km/h). The headway factors were adjusted for the link representing the work zone as well as surrounding links representing deceleration and acceleration areas. In the SimTraffic model, the driver parameters such as the positioning distance, the positioning advantage, and the optional advantage were specified. These three parameters describe when the drivers choose to merge to the open lane of the work zone. The parameters were set such that the drivers would merge as early as possible to represent the driver behavior in the real world. Even though the speed was reduced to the minimum observed value of 20 mph (32 km/h), the headway factor was increased to the upper limit of 3.0, and each of the driver merging behavior parameters were adjusted to the limit, the models still could not accurately predict the queue lengths. The estimated queues, reaching a maximum of less than one mile were both far less than the length of the queue observed in the field, which reached a maximum of 9.7 km (6 miles).

We could not calibrate Synchro in a meaningful way to replicate the situation found in the real world. In our opinion, it makes no sense to change model parameters such as speed or headway to unreasonable values that were not present in the real world data, in an attempt to increase the queue length to values near of what was observed in the field. Synchro was not designed to deal with work

zones at capacity. A more refined behavioral state machine with a better car following and lane merging model would seem to be needed.

#### *Synchro and SimTraffic – Cambridge 3.66 m (12 ft) lane*

The calibrated model of the 3.05 m (10 ft) lane at Cambridge was modified slightly to model the 3.66 m (12 ft) lane. The major difference was changing the lane closure to the left lane instead of the right lane. In addition, the volume database was edited to match the actual observed volume of the 3.66 m (12 ft) lane. Modeling the 3.05 m (10 ft) lane required that the parameters associated with the headway factor and the driving behavior were set at their maximum values for Synchro and SimTraffic. The predicted queue lengths were still considerably smaller than the actual queue lengths. Compared to the actual observed queue length, the model for the 3.05 m (10 ft) lane produced a very optimistic estimation, thus the parameters for headway factor and driver behavior were kept at their upper limits. The resulting model yielded a queue length estimation of 6.48 km (4.02 miles). Although this result more closely represents the actual observed queue length, it is still 3.22 km (2 miles) shorter than the field observation.

#### *Synchro and SimTraffic – Columbus*

For the Columbus site, the traffic mix was set at 6% heavy vehicles as per our observational field data. The headway factor parameters were ranging from the default value of one to the maximum value of three. Speeds were adjusted to reflect the observed speeds ranging from 40 km/h (25 mph) up to the speed limit of 89 km/h (55 mph) during queue formation. Even with the lowest observed speed and the maximum headway factor, the model produced a maximum queue length less than 3.2 km (2 miles), which was over a mile shorter than the actual observed value.

#### *Synchro and SimTraffic – Sandusky*

The headway factor was set at its maximum value to represent the headway of 5 seconds, a lane width of 3.66 m (12 ft) and a grade of zero. The free-flow speed was set at the median value observed by the free-flow camera as 109 km/h (68 mph). The maximum queue length estimation of Synchro for the Sandusky work zone was 2.6 km (1.6 miles), which was an underestimation of the actual observed queue length of 3.7 km (2.3 miles).

*CORSIM – Cambridge (3.05m and 3.66m Lanes)*

The CORSIM package does not account for differences in lane width when modeling freeway sections. Therefore, the models for the 3.05 m (10 ft) lane and 3.66 m (12 ft) lane were virtually identical. Similar to the headway factor used in Synchro, ITRAF uses a parameter called “car following sensitivity” to adjust for headways associated with various lane widths and similar factors, which may cause the drivers to diverge from their normal following distances. The input file generated by CORSIM does not include an estimation of queue length or work zone capacity. The only related result is the travel time and the delay time in minutes per vehicle mile. When the parameter of car following sensitivity was set to the maximum allowed value of 1000% (of the normal), and the speeds were reduced to the minimum observed value of 32 km/h (20 mph), the estimated travel time was 2.04 minutes per vehicle per mile. During the field observation, researchers traveled through the work zone, and noted a travel time of nearly 6 minutes per mile. Conclusively, similar to the Synchro model for this work zone, CORSIM significantly underestimates the associated work zone delays.

*CORSIM – Columbus*

The car following sensitivity was initially left at the default value of 100%, and the speeds were set to reflect the observed value of 48 km/h (30 mph) within the choke point of the work zone. Using these parameters, the estimated travel time was 4.04 minutes per vehicle mile. The travel time was observed as 4.16 minutes per vehicle mile. The CORSIM model produced a very close estimate for the total delay time associated with the Columbus work zone.

*CORSIM – Sandusky*

The car following sensitivity parameter was set at its default value of 100%, and the corresponding speeds for each link were set within the range of observed values of 64-89 km/h (40-55 mph) within the choke point of the work zone. With the aforementioned setup, the CORSIM package estimated a travel time of 1.23 minutes per vehicle mile. This estimate yield by CORSIM closely represents the actual travel time of 1.22 minutes per vehicle mile measured during the field observation.

*ODOT Spreadsheet – Cambridge 3.05 m (10 ft) lane*

Three major parameters were used to model the work zones using the ODOT Spreadsheet. First, the observed capacity was entered as 866 vehicles per hour (from field data, Table 3a). Then, the density was determined to be 65 vehicles per lane per mile according to the output of Mobilizer-PC. Finally, the observed hourly flow rates during the queue formation were entered. Note that, since the vehicle queue was formed only in the left lane, the number of lanes available for queued vehicles was assumed to be one even though there were two open lanes to form a queue before the work zone. The ODOT spreadsheet estimated the resulting queue to have a maximum length of 9.12 km (5.7 miles), which was a slight overestimation of the actually observed queue length of 8.8 km (5.5 miles) as shown in Table 3a.

*ODOT Spreadsheet – Cambridge 3.66 m (12 ft) lane*

The capacity was set at 1075 vehicles per hour (from field data, Table 3a), Vehicles per lane per mile was set at 65 (from field data through Mobilizer-PC). Similar to the Cambridge 3.05 m (10 ft) lane model, the number of available lanes for a queue formation was set at one. The resulting estimation of the maximum queue length was 8.32 km (5.2 miles), which was an underestimation of the actually observed queue length of 9.9 km (6.2 miles) as shown in Table 3a.

*ODOT Spreadsheet – Columbus*

The capacity was entered as 2982 vehicles per hour (from field data, Table 3a), vehicles per lane per mile value was specified as 100 (from field data through Mobilizer-PC). The density was significantly higher for the Columbus work zone compared to the Cambridge work zones. The higher density was due to the smaller percentage of heavy trucks at the Columbus site (6%) compared to the Cambridge site at 32%. The resulting estimation of maximum queue length was 4.32 km (2.7 miles), which was an underestimation of the actually observed queue length of 5.1 km (3.2 miles) as shown in Table 3a.

*ODOT Spreadsheet – Sandusky*

The capacity was specified as 1250 and the vehicles per lane per mile value was entered as 52, both from the field data (Table 3a). Flow rates observed in the field during the visit to Sandusky. The percentage of heavy vehicles was observed as 19%. The estimate for maximum queue length of ODOT

spreadsheet was 4.2 km (2.6 miles), which is an overestimate of the actual maximum queue length of 3.7 km (2.3 miles) as indicated in Table 3a.

## **DISCUSSION AND CONCLUSIONS**

The results of this study, based on actual field data, show a trend of inaccuracies of queue length predictions when using the micro-simulation packages Synchro and CORSIM. Visually the micro-simulations are appealing. Vehicles can be graphically viewed traveling through the roadway system, react to other vehicles, merge into the necessary lanes and line up in a queue to enter the work zone.

Unfortunately, the results that were produced by the micro-simulations we used were not accurate estimates of the real traffic flows observed in the four work zones we observed in the field. The results generally showed a significant under-estimation of the queue lengths. The two micro-simulation packages selected for this study, CORSIM and Synchro, were not designed to model the effects of work zones on maintenance of traffic. The researchers at the National Advanced Driving Simulator (NADS) at the University of Iowa are in the early stages of developing a traffic simulation tool that has an improved behavioral state machine to account for more realistic car following and lane merging behavior in work zones at capacity. It is hoped that the improved behavioral model will yield more accurate queue length and delay time estimates in the future.

Further development of these products is required to produce more accurate results using micro-simulation techniques. The most accurate tool in predicting the capacity of a work zone was QueWZ92. Table 3 illustrates the QueWZ92 prediction errors associated with each of the work zones.

In addition to capacity estimations, QueWZ92 also produced estimations for the queue lengths based on the volume data and the predicted capacity. The queue length predictions, however, were not as accurate as those given by the ODOT spreadsheet. QueWZ92, similar to the micro-simulations, tended to underestimate the actual queue length observed in the real world. The underestimation may stem from the density parameter, which is a fixed parameter of the software. When estimating the queue length, QueWZ92 performs an initial calculation for the number of vehicles in the queue, by finding the difference between the capacity of the work zone and the traffic demand. If the capacity is greater than



the demand then no queue will form, but if demand is higher than capacity a queue will form. When demand is higher than the capacity, QueWZ92 employs a density parameter to distribute the queued vehicles throughout the available lane(s). The density parameter of QueWZ92 is fixed at 132 vehicles per lane per mile.

The actual density was found to be much lower according to the real world observations made in this study. At the Cambridge work zone (during both work zone configurations), the density was observed to be 65 vehicles per lane per mile. At the Columbus work zone the density was observed to be 100 vehicles per lane per mile. The difference in density values can be attributed to the percentage of heavy vehicles. Heavy vehicles are generally larger than passenger cars and they take up more roadway space. In reality, high percentage of heavy vehicles, as observed at the Cambridge work zone, yields a smaller density parameter.

The most accurate tool in estimating the maximum queue lengths proved to be the ODOT spreadsheet if (and only if) provided with an adequate capacity estimate such as that from QueWZ92. Table 3b shows the results given by the spreadsheet when observed capacity, density, and hourly volume rates were used as inputs. Table 3 indicates that the capacity estimation is significantly more accurate than the maximum queue predictions. This result may seem inaccurate since the maximum queue length is directly related to the capacity of the work zone along with the demand placed on the work zone. One explanation may be similar to a result of a study performed by Smilowitz, Daganzo, Cassidy, and Bertini. During this study, based on observations of traffic traveling in one direction in a single lane, researchers noted; “although stop-and-go oscillations of the bottleneck (work zone) itself were rapidly damped-out within one-half mile other instabilities upstream grew in amplitude far from the bottleneck”.

We concluded that the driver following behavior was very relaxed since the drivers perceived a low risk of being overtaken by other vehicles. As previously stated, in the work zones observed in the present study, vehicles merged into the open lane(s) well before they enter the work zone bottle neck, and did not try to pass other vehicles traveling on the adjacent lanes that were closed downstream. Consequently, the number of drivers overtaking other vehicles was minimal, producing the relaxed

following behavior and instabilities in the queue. This effect is difficult to predict and depends on the individual driver behavior, which might cause the actual observed queue lengths to be longer than the predicted queue lengths. We hypothesize that the queue could be shortened if the merge signs were not placed as far back from the work zone as they were in our study.

Another interesting observation from the study is the effect of lane width on the traffic pattern of the Cambridge work zones. As mentioned previously, during the first observation of the Cambridge site, the open lane had a width of 3.05 m (10 ft) and during the second observation the open lane had a width of 3.66 m (12 ft). Also, the left lane was open during the first observation, whereas the right lane was open to the traffic during the second observation. During the first observation, another work zone was present upstream from the Cambridge site. This upstream work zone included a right lane closure, and therefore, most vehicles including the semi-trucks were already merged into the left lane when they arrived at the queue before the Cambridge work zone. During the second observation of the Cambridge work zone, the upstream work zone was not present. Thus, most vehicles remained in the right-hand lane when approaching the Cambridge work zone, which now had the open lane on the right-hand side. Hence, these two configurations produced similar merging patterns, as vehicles were generally merged into the open lane when they arrived at the queue formed by the Cambridge work zone during both observations. Consequently, any effects associated with the specific side of the lane closure are assumed to be negligible.

### **Procedural Recommendations**

It is always recommended to obtain the free flow traffic volume before the initiation of the planning of the work zone during a 24-hour weekday period and a 24-hour weekend period. The work zone planning phase requires that the traffic volume and vehicle mix (percent heavy vehicles) be known together with the work zone configuration. Since the Quewz92 software may not be easily available, we developed lookup tables tabulating the work zone capacities based on the vehicle mix, grade, work zone length, lane width, and lane closure configuration. The table for 10% heavy vehicles is shown in Table 4. The entire table can be obtained from the final report submitted to Ohio DOT [1].

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Table 1. Summary of the Observed Work Zone Parameters in the Field.

<b>Work Zone</b>	<b>Capacity (Veh/hour)</b>	<b>Max. Queue Length (miles)</b>	<b>Travel Time (min/veh/mile)</b>	<b>Percentage of Heavy Vehicles</b>
<b>Cambridge (10')</b>	866	5.5	6.4	32
<b>Cambridge (12')</b>	1098	6.2	5.8	28
<b>Columbus</b>	2982	3.2	4.2	6
<b>Sandusky</b>	1250	2.3	1.23	19

Table 2. Work Zone Input Parameters to Quewz92.

## a. Cambridge Work Zone

<b>Model Constants</b>	
Cost Update Factor	1.31
Percentage of Heavy Vehicles	32
Free Flow Speed (mph)	60 (Default)
LOS D/E Breakpoint Speed (mph)	46 (Default)
Speed at Capacity (mph)	30 (Default)
LOS D/E Breakpoint Volume (vphpl)	1850 (Default)
Volume at Capacity (vphpl)	2000
<b>Lane Closure Configuration</b>	
Number of Directions	1
Total Lanes Inbound	2
Total Lanes Outbound	2
Open Lanes Inbound	1
Open Lanes Outbound	2
Length of the Lane Closure (miles)	0.8

## b. Columbus Work Zone

<b>Model Constants</b>	
Cost Update Factor	1.31
Percentage of Heavy Vehicles	6
Free Flow Speed (mph)	60 (Default)
LOS D/E Breakpoint Speed (mph)	46 (Default)
Speed at Capacity (mph)	30 (Default)
LOS D/E Breakpoint Volume (vphpl)	1850 (Default)
Volume at Capacity (vphpl)	2000
<b>Lane Closure Configuration</b>	
Number of Directions	1
Total Lanes Inbound	3
Total Lanes Outbound	3
Open Lanes Inbound	2
Open Lanes Outbound	3
Length of the Lane Closure (miles)	7.4

## c. Sandusky Work Zone.

<b>Model Constants</b>	
Cost Update Factor	1.31
Percentage of Heavy Vehicles	19
Free Flow Speed (mph)	60 (Default)
LOS D/E Breakpoint Speed (mph)	46 (Default)
Speed at Capacity (mph)	30 (Default)
LOS D/E Breakpoint Volume (vphpl)	1850 (Default)
Volume at Capacity (vphpl)	1412
<b>Lane Closure Configuration</b>	
Number of Directions	1
Total Lanes Inbound	2
Total Lanes Outbound	2
Open Lanes Inbound	1
Open Lanes Outbound	2
Length of the Lane Closure (miles)	5.3

Table 3. Capacity and Queue Estimations and Corresponding Errors for Suggested Tools.

## a. Estimations of Quewz92 Model for the Work Zones Capacity.

<b>Work Zone</b>	<b>Actual Capacity (Veh/Hour)</b>	<b>Estimated Capacity (Veh/Hour)</b>	<b>Error (%)</b>
<b>Cambridge (10')</b>	866	878	1.4
<b>Cambridge (12')</b>	1098	1025	7.1
<b>Columbus</b>	2982	3300	10.7
<b>Sandusky</b>	1250	1323	5.8

## b. Maximum Queue Estimations and Errors Associated with ODOT Spreadsheet.

<b>Work Zone</b>	<b>Actual Max Queue Length (Miles)</b>	<b>Estimated Max Queue Length (Miles)</b>	<b>Error (%)</b>
<b>Cambridge (10')</b>	5.5	5.7	1
<b>Cambridge (12')</b>	6.2	5.2	19.2
<b>Columbus</b>	3.2	2.7	18.5
<b>Sandusky</b>	2.3	2.6	13

Table 4. Lookup Table Tabulating the Work Zone Capacity Values for 10% Heavy Vehicles.

This Lookup Table is for 10% Heavy Vehicles	Lane Width	10 ft							11 ft							12 ft								
		Grade	0%	1%	2%	3%	4%	5%	6%	0%	1%	2%	3%	4%	5%	6%	0%	1%	2%	3%	4%	5%	6%	
Closed: 1 Open: 2 Total: 3	Length																							
	0 - <0.25	2742	2742	2742	2742	2742	2742	2504	2894	2894	2894	2894	2894	2894	2642	3046	3046	3046	3046	3046	3046	3046	2782	2782
	0.25 - <0.50	2742	2742	2742	2618	2400	2056	1858	2894	2894	2894	2762	2532	2170	1960	3046	3046	3046	2908	2666	2284	2064	2064	2064
	0.50 - <0.75	2742	2742	2742	2400	2056	1800	1694	2894	2894	2894	2532	2170	1900	1788	3046	3046	3046	2666	2284	2000	1882	1882	1882
	0.75 - <1	2742	2742	2742	2214	1986	1800	1644	2894	2894	2894	2338	2096	1900	1736	3046	3046	3046	2460	2206	2000	1828	1828	1828
	1 - <1.5	2742	2742	2504	2214	1920	1800	1644	2894	2894	2642	2338	2026	1900	1736	3046	3046	2782	2460	2132	2000	1828	1828	1828
	1.5 - <2	2742	2742	2504	2132	1920	1800	1644	2894	2894	2642	2250	2026	1900	1736	3046	3046	2782	2370	2132	2000	1828	1828	1828
	2 - <2.5	2742	2742	2504	2132	1920	1800	1644	2894	2894	2642	2250	2026	1900	1736	3046	3046	2782	2370	2132	2000	1828	1828	1828
	2.5 - <3	2742	2742	2504	2132	1920	1800	1644	2894	2894	2642	2250	2026	1900	1736	3046	3046	2782	2370	2132	2000	1828	1828	1828
	3 - <4	2742	2742	2504	2132	1920	1800	1644	2894	2894	2642	2250	2026	1900	1736	3046	3046	2782	2370	2132	2000	1828	1828	1828
4 - <6	2742	2742	2504	2132	1920	1800	1644	2894	2894	2642	2250	2026	1900	1736	3046	3046	2782	2370	2132	2000	1828	1828	1828	
6 - <8	2742	2742	2504	2132	1920	1800	1644	2894	2894	2642	2250	2026	1900	1736	3046	3046	2782	2370	2132	2000	1828	1828	1828	
8 or longer	2742	2742	2504	2132	1920	1800	1644	2894	2894	2642	2250	2026	1900	1736	3046	3046	2782	2370	2132	2000	1828	1828	1828	
Closed: 1 Open: 1 Total: 2	0 - <0.25	1371	1371	1371	1371	1371	1371	1252	1447	1447	1447	1447	1447	1447	1321	1523	1523	1523	1523	1523	1523	1523	1391	1391
	0.25 - <0.50	1371	1371	1371	1309	1200	1028	929	1447	1447	1447	1381	1266	1085	980	1523	1523	1523	1454	1333	1142	1032	1032	1032
	0.50 - <0.75	1371	1371	1371	1200	1028	900	847	1447	1447	1447	1266	1085	950	894	1523	1523	1523	1333	1142	1000	941	941	941
	0.75 - <1	1371	1371	1371	1107	993	900	822	1447	1447	1447	1169	1048	950	868	1523	1523	1523	1230	1103	1000	914	914	914
	1 - <1.5	1371	1371	1252	1107	960	900	822	1447	1447	1321	1169	1013	950	868	1523	1523	1391	1230	1066	1000	914	914	914
	1.5 - <2	1371	1371	1252	1066	960	900	822	1447	1447	1321	1125	1013	950	868	1523	1523	1391	1185	1066	1000	914	914	914
	2 - <2.5	1371	1371	1252	1066	960	900	822	1447	1447	1321	1125	1013	950	868	1523	1523	1391	1185	1066	1000	914	914	914
	2.5 - <3	1371	1371	1252	1066	960	900	822	1447	1447	1321	1125	1013	950	868	1523	1523	1391	1185	1066	1000	914	914	914
	3 - <4	1371	1371	1252	1066	960	900	822	1447	1447	1321	1125	1013	950	868	1523	1523	1391	1185	1066	1000	914	914	914
	4 - <6	1371	1371	1252	1066	960	900	822	1447	1447	1321	1125	1013	950	868	1523	1523	1391	1185	1066	1000	914	914	914
6 - <8	1371	1371	1252	1066	960	900	822	1447	1447	1321	1125	1013	950	868	1523	1523	1391	1185	1066	1000	914	914	914	
8 or longer	1371	1371	1252	1066	960	900	822	1447	1447	1321	1125	1013	950	868	1523	1523	1391	1185	1066	1000	914	914	914	
Closed: 2 Open: 1 Total: 3	0 - <0.25	1371	1371	1371	1371	1371	1371	1252	1447	1447	1447	1447	1447	1447	1321	1523	1523	1523	1523	1523	1523	1523	1391	1391
	0.25 - <0.50	1371	1371	1371	1309	1200	1028	929	1447	1447	1447	1381	1266	1085	980	1523	1523	1523	1454	1333	1142	1032	1032	1032
	0.50 - <0.75	1371	1371	1371	1200	1028	900	847	1447	1447	1447	1266	1085	950	894	1523	1523	1523	1333	1142	1000	941	941	941
	0.75 - <1	1371	1371	1371	1107	993	900	822	1447	1447	1447	1169	1048	950	868	1523	1523	1523	1230	1103	1000	914	914	914
	1 - <1.5	1371	1371	1252	1107	960	900	822	1447	1447	1321	1169	1013	950	868	1523	1523	1391	1230	1066	1000	914	914	914
	1.5 - <2	1371	1371	1252	1066	960	900	822	1447	1447	1321	1125	1013	950	868	1523	1523	1391	1185	1066	1000	914	914	914
	2 - <2.5	1371	1371	1252	1066	960	900	822	1447	1447	1321	1125	1013	950	868	1523	1523	1391	1185	1066	1000	914	914	914
	2.5 - <3	1371	1371	1252	1066	960	900	822	1447	1447	1321	1125	1013	950	868	1523	1523	1391	1185	1066	1000	914	914	914
	3 - <4	1371	1371	1252	1066	960	900	822	1447	1447	1321	1125	1013	950	868	1523	1523	1391	1185	1066	1000	914	914	914
	4 - <6	1371	1371	1252	1066	960	900	822	1447	1447	1321	1125	1013	950	868	1523	1523	1391	1185	1066	1000	914	914	914
6 - <8	1371	1371	1252	1066	960	900	822	1447	1447	1321	1125	1013	950	868	1523	1523	1391	1185	1066	1000	914	914	914	
8 or longer	1371	1371	1252	1066	960	900	822	1447	1447	1321	1125	1013	950	868	1523	1523	1391	1185	1066	1000	914	914	914	

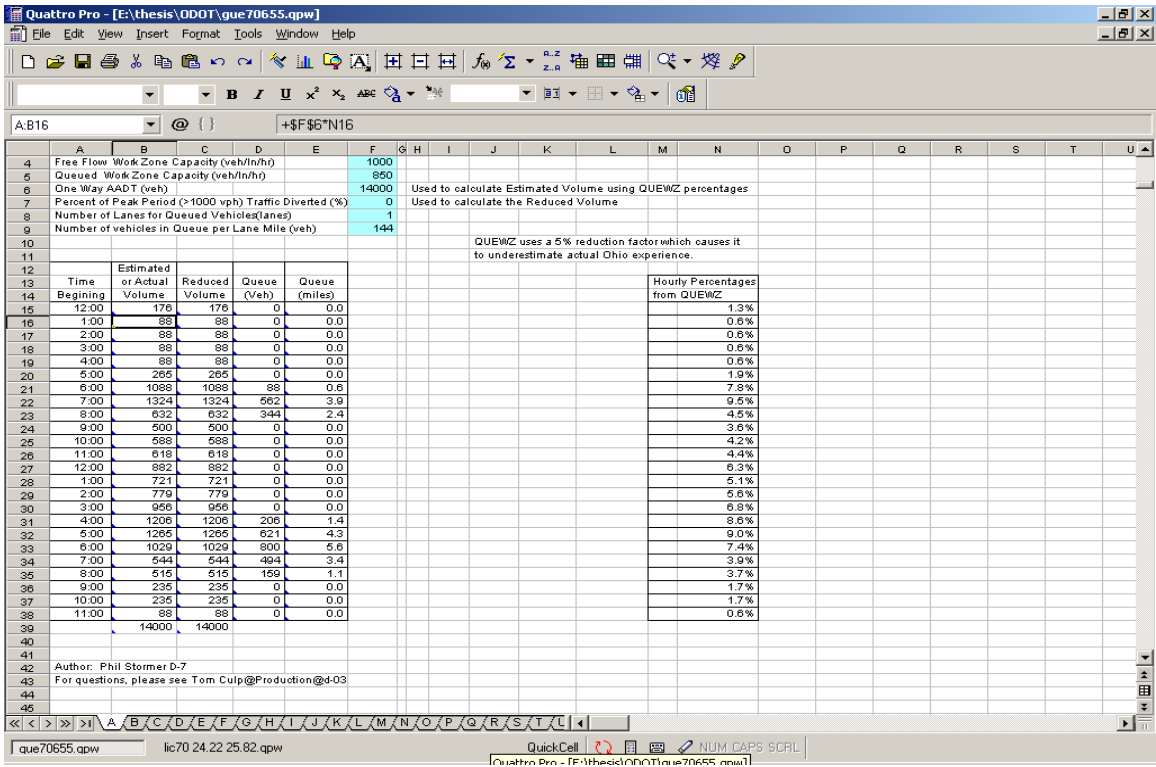
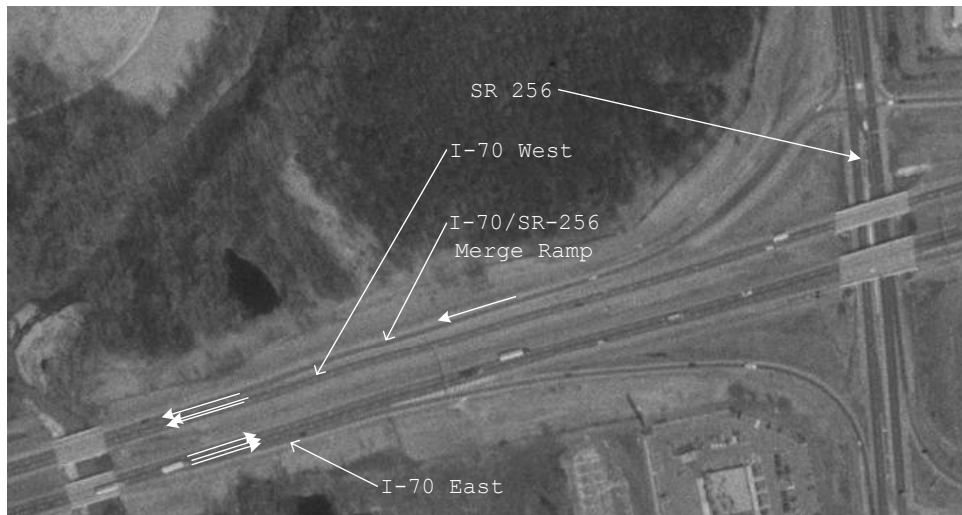
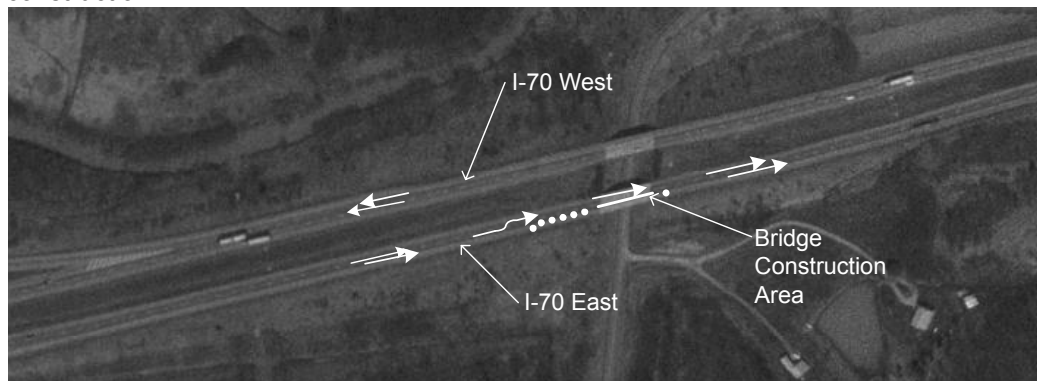


Figure 1. Screen shot of the Ohio DOT spreadsheet.





a. Columbus Workzone, Aerial view of I-70 westbound interchange site with SR-256, before construction.



b. Cambridge Workzone, Aerial view of the approximate location of the I-70 eastbound lane closure, before construction.



c. Sandusky Work Zone, before construction.

Figure 2. Aerial View of the Selected Work Zones.