

**Development of Traffic Delay Assessment Tool
for Short-Term Closures on Urban Freeways**

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ABSTRACT

A certain amount of delay in work zones is typically assumed to be unavoidable, often considered a “cost of doing business” when making roadway improvements. As such, developing a method to predict delay, such that appropriate countermeasures to minimize this delay can be implemented, is critical to successful work zone management. Predicting work zone delay in an effective and efficient manner should not require extensive data collection or long and complex coding efforts. In other words, the procedure should be customizable for local data availability, easy to use, and allowable for straightforward interpretation by practitioners.

To this end, WZCAT (Work Zone Capacity Analysis Tool) analytical software program was developed as a tool to predict delays and queues for short-term (daily) work zone closures. WZCAT bases its queue-length predictions on a simple input/output model, with the capacity of the work zone controlling the throughput. The purpose of this study was to evaluate and enhance WZCAT with field data as well as summarize various aspects of traffic flow and queuing patterns during work zone operations on selected urban freeways.

According to the field observation, significant traffic volume changes on exit/entrance terminals upstream of work zones and the stabilization of vehicle queue after initial queue development were found. A Demand Adjust Factor (DAF) developed and applied to WZCAT-R to include this in an effective and efficient manner. WZCAT-R produces effective results for queue prediction, and can be an effective and reliable tool in prediction of work zone delay and queue development and help engineers proactively plan work phasing, lane restrictions, and potential detour routes in an effort to move traffic more efficiently.

INTRODUCTION

Most states spend millions of dollars each year resurfacing, rehabilitating, and reconstructing their roadways. Roadway construction work zones are established to safely perform the needed work while maintaining a sufficient amount of daily traffic flow through the construction area. Inevitably, delays occur in and around the work zone due to associated restrictions in traffic flow. Such delays cost the economy millions of dollars each year in lost productivity, potential decreases in safety, and increased emissions from slowing and/or idling vehicles. Considering that some level of delay in roadway work zones is typically unavoidable, developing a method to predict the delay such that appropriate countermeasures can be established is critical to successful work zone management. Reliable prediction of work zone delay and queue development may help engineers proactively plan work phasing, lane restrictions, and potential detour routes in an effort to move traffic more efficiently.

A Federal Highway Administration (FHWA) Final Rule on Work Zone Safety and Mobility, published on September 9, 2004, requires all state and local governments that receive federal-aid funding for roadway improvements to develop and implement procedures to assess and manage work zone impacts on individual roadway construction projects. Each state must comply with the provisions no later than October 12, 2007. To measure the traffic impacts of work zone operations in an effective and efficient manner, an evaluation methodology is needed to provide accurate prediction results without the need for extensive data collection or long and complex modeling efforts. In other words, the procedures for evaluating the impacts of work zones should be both customizable for local data and user-friendly.

To this end, the Work Zone Capacity Analysis Tool (WZCAT) software program was developed to predict delays and queues for short-term (daily) work zone closures. WZCAT is a relatively simple input-output model that predicts the delay associated with proposed roadway lane closures and computes a predicted queue development as a function of delay. Based on a pre-coded average vehicle length, WZCAT provides a graphic output of the predicted queue development and queue dissipation throughout the duration of the construction work zone.

The purpose of this study was to validate and calibrate the WZCAT with field data collected from work zone operations on Southeast (SE) Wisconsin freeways. A total of eight work zones were observed on SE Wisconsin freeways between July 2005 and November 2005. Work zones were randomly selected based on the type of closures and geographic locations throughout the SE Wisconsin freeway system. Because of the extensive network of permanent volume and speed detectors, existing detector locations upstream, downstream, and within the selected work zone locations were used as traffic operations data sources for before, during, and after work zone activity analysis.

LITERATURE REVIEW

Most previous construction work zone traffic flow studies have focused on calculating reduced capacity due to lane closures. For example, Benekohal et al. showed a methodology to determine work zone capacity based on several factors such as work intensity, lane width, and lateral clearance (1). It was concluded that each characteristic impacted vehicle operating speed. Sarasua et al. evaluated Interstate highway capacities for short-term work zone lane closures and found 1,460 passenger cars per hour per lane (pcphpl) as a base threshold value for work zone capacity (2). Karim and Adeli used a radial basis function neural network to improve the accuracy of estimation for work zone capacity and modified traffic demand (3). They used 40

work zone samples to train the model and tested with 27 sets of field data. As for work zone capacity, the difference was normally less than 10 percent for 17 samples but 10 samples showed 20 to 71 percent error which is relatively high. Further investigation revealed that this is largely due to significant impact from the percentage of heavy vehicles.

Because most deterministic traffic flow models calculate delay and queue length based on estimated work zone capacity under the assumption that traffic flow in a work zone is a function of the queue discharge rate, the accuracy of the model's results depend on good estimates of work zone capacities. Schneil et al. evaluated the accuracy of commercially available macroscopic and microscopic traffic simulation tools such as CORSIM and SimTraffic for work zone traffic analysis using four work zones in Ohio (4). The study showed that it is very difficult to calibrate microscopic models for work zone traffic estimations and the models significantly underestimated the length of queues and delay time. It also showed work zone capacity estimation was found to be much more accurate than the maximum queue estimation. The study failed to find an acceptable reason for this discrepancy, although the study did mention a relaxed car-following driver behavior and instabilities of the vehicle queue.

Several commercially available software packages have been specifically developed for work zone delay estimation. QuickZone, a work zone delay estimation tool developed by Mitretek Systems and sponsored by FHWA, allows analysis of the impact of work zone delays on a roadway. QuickZone requires input data such as work zone location, projected detour routes, anticipated volumes of traffic, and construction dates and times. QUEWZ98, a microcomputer analysis tool for planning and scheduling freeway work zone lane closures, analyzes traffic conditions on a freeway segment with and without a lane closure in place and provides estimates of additional road user costs and queuing resulting from a work zone lane closure.

Generally, most studies reported in the literature attempted to capture the precise impact of various work zone characteristics on freeway capacity using various techniques; however, there is little research on determining anticipated demand changes due to work zone operations on urban freeways and the associated impacts. Ullman (5) addressed queue stabilization due to natural diversion effect at short term freeway work zone lane with field data observation and later, he developed a theoretical approach to explain the phenomena (6).

Furthermore, it was noticeable that a wide array of methodologies exist for evaluating work zone impacts, ranging from simple customized worksheets to commercially available packages requiring extensive input data. The WZCAT program developed by WisDOT was designed to provide sufficient analysis detail while minimizing the depth of required input data by packing into a simple input/output user interface. An easy-to-use tool like WZCAT would help transportation professionals better manage the impacts of work zones if the tool was effective and accurate in its prediction capabilities. Therefore, validation of WZCAT's work zone queue length prediction capabilities was needed.

DATA COLLECTION

Traffic and queue length field data were collected from eight different freeway work zone locations. All work zones were temporary closures with lane closures placed between 8 AM and 3 PM. As presented in Figure 1, operating speed and volume data were collected using existing freeway loop detectors. Traffic flow at the end of the work zone was videotaped using a portable video camcorder. The video records were analyzed using "Car Count version 0.9," a software

program that provides automated methods for calculating headway, volume, and heavy vehicle ratios. The video data also provided another source of traffic volume and operating speed data.

Vehicle queue length was measured and recorded every 10 to 30 minutes throughout the duration of the work zone closure. Initially, the measurement was obtained by a trained spotter in a vehicle that followed the end of queue on the opposite side of the freeway. This method was later replaced by a slightly more precise method using a GPS equipped vehicle. A GPS equipped vehicle was continuously driven upstream of work zone (free flow area) to the end of work zone. Location (latitude, longitude) and speed (mph) data determined from GPS data were downloaded and transferred to a laptop computer every 1 to 4 seconds. Typically, the GPS vehicle passed through the entire work zone area and vehicle queue at least twice per hour. Table 1 summarizes eight work zones observed during the project.

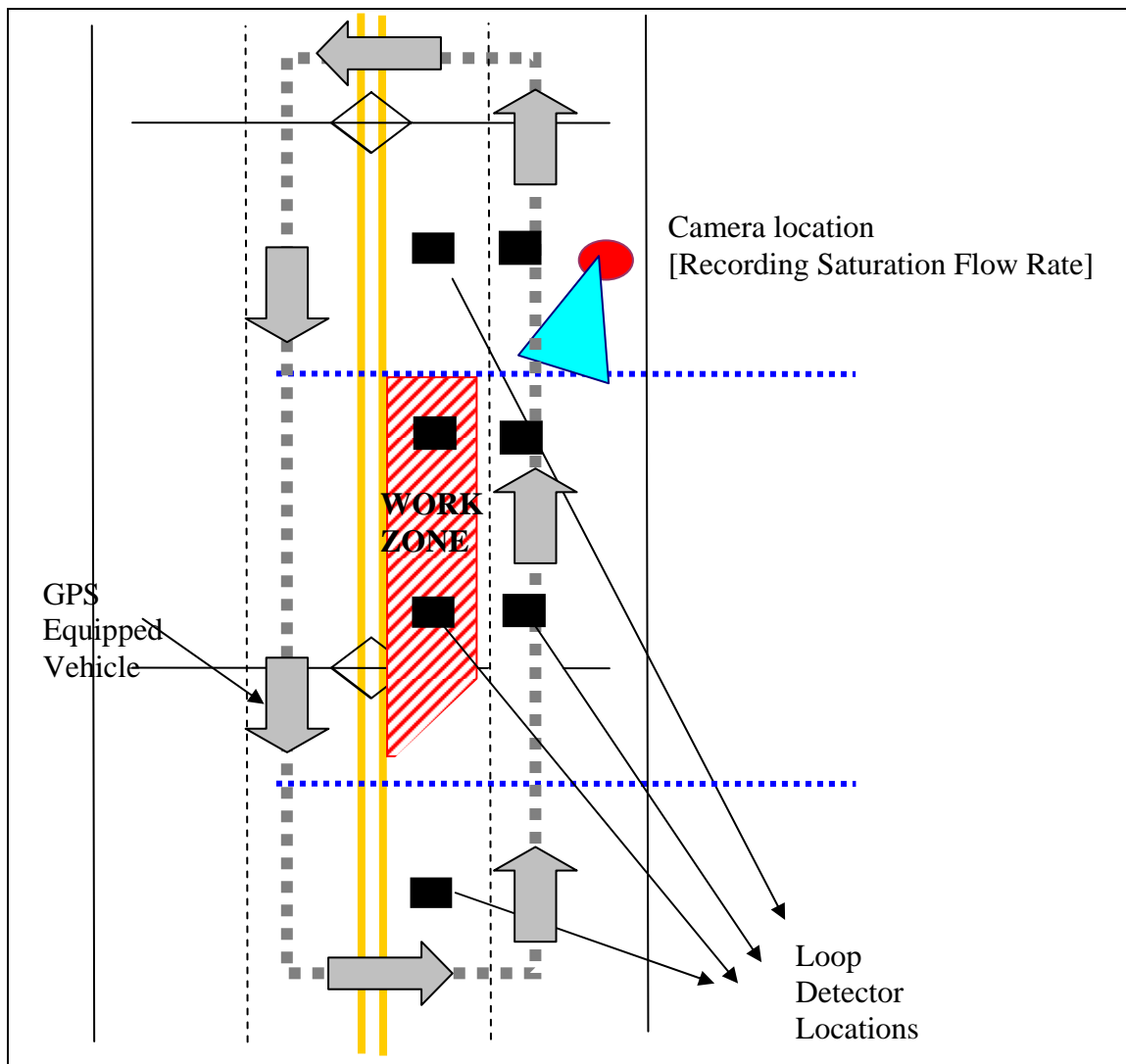


Figure 1 Traffic data collection in work zone.

TABLE 1 Summary of Work Zones

	WZ1	WZ2	WZ3	WZ4	WZ5	WZ6	WZ7	WZ8
Location (On Highway)	I94 WB	I43 SB	I94 WB	I94 EB	I43/I94 SB	I894/US45 NB	I94NB	I94 WB
AADT	75,600	43,000	75,600	81,600	61,800	74,600	39,100	84,000
Lane Closure 1	Two Right Lanes Closed	Left Lane Closed	Right Lane Closed	Left Lane Closed	Left Lane Closed	Two Left Lanes Closed	Left Lane Closed	Two Left Lanes Closed
Lane Closure 2 (# of Lanes/ Open Lanes)	3>1	2>1	3>2	3>2	3>2	3>1	3>2	3>1 and 4>2
WZ Length	1.88 mile	0.8 mile	1.2 mile	0.62 mile	0.25 mile	0.5 mile	1.5 mile	1.17 mile
WZ TIME	8:30 AM to 2:30 PM	9:40 AM to 2 PM	9 AM to 2 PM	9 AM to 2 PM	9 AM to 2 PM	9 AM to 2 PM	9 AM to 2 PM	9 AM to 2:00 PM
WZ Duration (Hour)	6	4.2	5	5	5	5	5	5
WZ Activity	Maintenance	Inlet Repair	Guardrail Repair	Lighting	Barrier Wall Repair	Maintenance	Maintenance	Bridge Maintenance
WZ Intensity* (3-High 1-Low)	3	3	2	1	1	3	3	2

*Subjective measurement based on visual observation (1=no worker presence 2=workers in active work area 3=workers in active work area and close to open lane) (1).

WORK ZONE CAPACITY ANALYSIS TOOLS (WZCAT)

WZCAT was developed using the principles of the Delay Enhanced (DelayE) software program developed in the late 1990s (7). The DelayE concept is based on a deterministic queuing analysis, the foundation of the basic input/output analysis. WZCAT was developed as an add-on program that operates within Microsoft Excel. As shown in Figure 2, WZCAT in its current version executes an input-output analysis to estimate traffic queue development and associated delay due to work zone activities as follows:

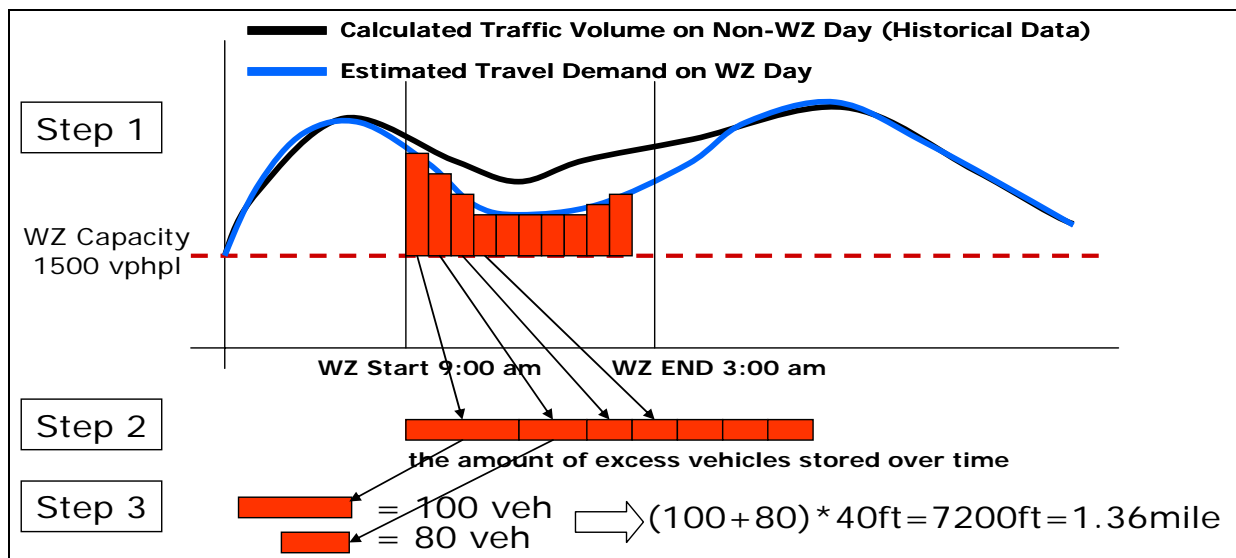


FIGURE 2 WZCAT queue estimation.

Step 1: WZCAT compares the expected travel demand at the work zone location to the work zone capacity. If demand exceeds capacity, the excess is assumed to be stored in a queue upstream of the work zone.

Step 2: Input-output analysis is used to keep track of the amount of excess vehicles stored over time.

Step 3: Vehicular delays and queue lengths are computed by using the estimates of stored number of vehicles and approximate average vehicle lengths in the queue.

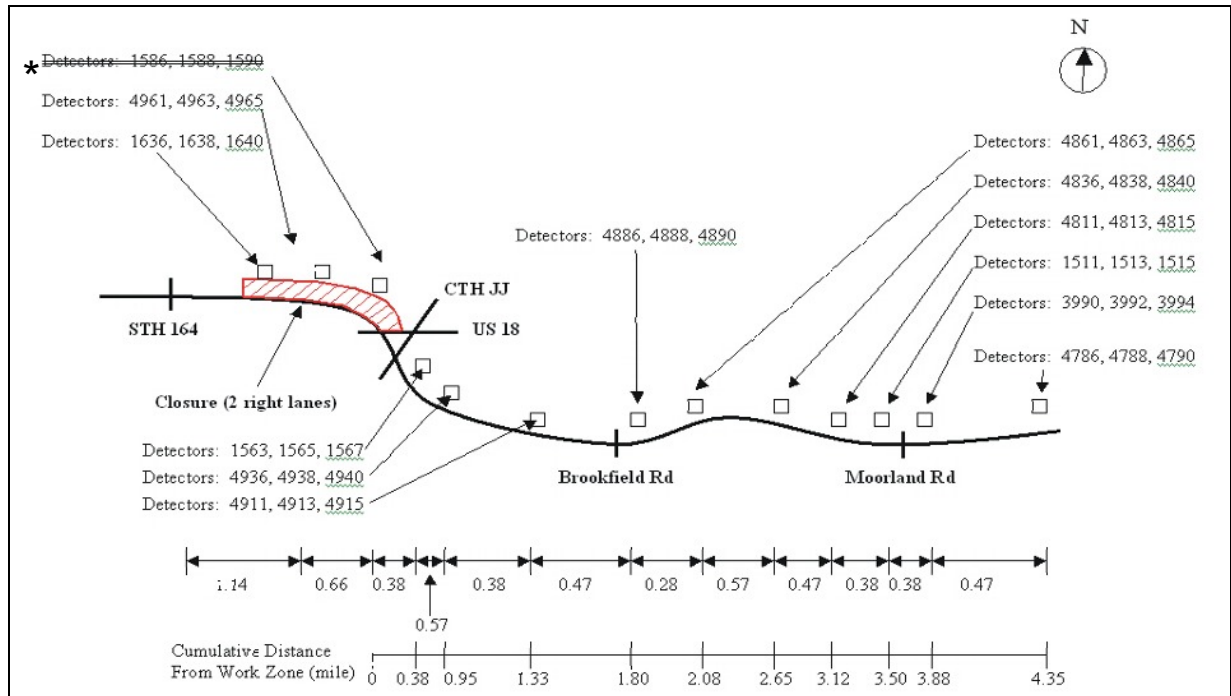
Since WZCAT relies on a simple input-output analysis, a good estimation of work zone capacity and travel demand is critical to calculating traffic delay. WZCAT calculates work zone capacity by Highway Capacity Manual (8) methods and provides an option to use an empirical value for work zone capacity which was acquired from reviewing other states work and field observations in Wisconsin. Also, WZCAT allows users to input a customized value for work zone capacity as needed; however, only single fixed value can be used for the entire duration of work zone. Currently, WZCAT does not include suggested parameters for travel demand reductions; however, anticipated travel demand could be captured through a robust manipulation of historical data.

WZCAT accumulates vehicle input and output from a given work zone to determine queue length. The end vehicle balance on a given time interval is multiplied by an average queue headway to determine the estimated queue length. The Highway Capacity Manual suggests a default value of 40 feet per queued vehicle (8). Therefore, this 40 foot per vehicle default value is used to calculate queue length. The number represents the average space occupied by a vehicle in a queue, not the average vehicle length.

INITIAL CASE STUDY

A work zone on eastbound Interstate Highway 94 near Milwaukee, Wisconsin was selected for the initial evaluation of WZCAT. Figure 3 shows the location of the work zone and existing detector locations upstream and within the work zone. Figure 3 also illustrates the distance between detectors and the distance from the starting point of the work zone to each detector location upstream of the work zone. Two right lanes of the approximately 1.8 mile work zone were closed (three lanes total) from 8:30 AM to 2:30 PM. Field observations showed that a vehicle queue started to develop around 8:00 AM, immediately after a maintenance vehicle appeared on the side of roadway, and the queue quickly extended to the Moorland Road interchange, nearly three miles upstream from the work zone starting location.

The default capacity values of 2,200 vphpl for normal conditions and 1,500 vphpl for work zones were used in WZCAT. Additionally, the work zone hour was coded as obtained from field observations. As described, WZCAT calculates the number of queued vehicles by subtracting capacity (1,500 vph) from given demand. This calculation is conducted in six-second intervals. The number of queued vehicles were then multiplied by a 40-foot vehicle headway and divided by the number of available lanes. WZCAT assumed the vehicles would use all open lanes up to the taper area.



* Detector 1586/1588/1590 was not available on the work zone day.

Figure 3 Work Zone 1 (I94 East bound).

Since it was assumed that the saturation flow rate would remain rather constant during work zone operation hours, the study aimed to find a single detector location which was highly associated with the expected arrival rate and could generate “the observed queue” from the field given the observed work zone capacity.

For WZCAT to estimate delay, two different types of traffic volume data were collected in fifteen-minute intervals. One type of data was historical traffic volume acquired by averaging traffic volumes from the same day of the week and time period for the 12 previous weeks. The second type of data was actual traffic volumes in the work zone on the day of construction (in this case July 14, 2005), obtained from the detector locations. Ten different detector locations upstream of the work zone were used to generate separate input files to WZCAT for both the historical data and the observed traffic flow on the work zone day. That is, 20 different sets of input data were considered to identify the best location for traffic volume input to WZCAT that best matched the observed length of the queue.

Figures 4 and 5 illustrate the results from WZCAT for all detector locations using historical and actual data, respectively. As can be seen, there were significant differences between the queue length observed in the field and queue length predicted by WZCAT for both the historical and actual data. The observed queue length remained consistent at approximately 3.5 miles, while WZCAT significantly overestimated the length of the queue. Regardless of the input volume data used, large differences in the length of queue results were found, which raised more questions pertaining to travel demand.

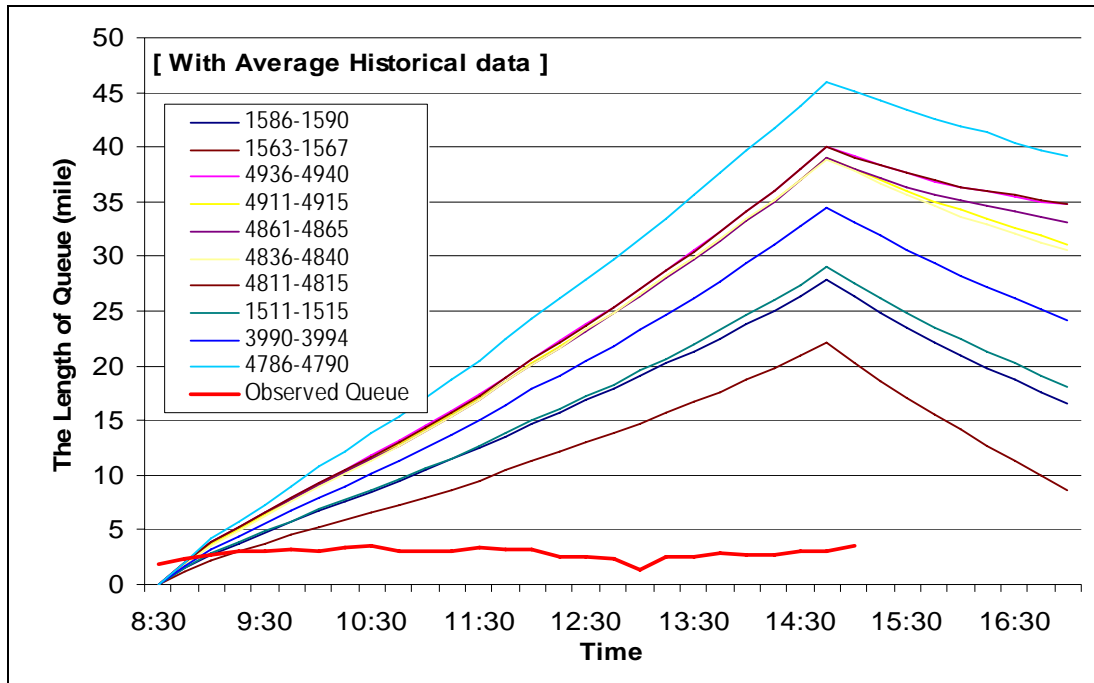


Figure 4 Estimated length of queue by WZCAT with historical data (WZ1).

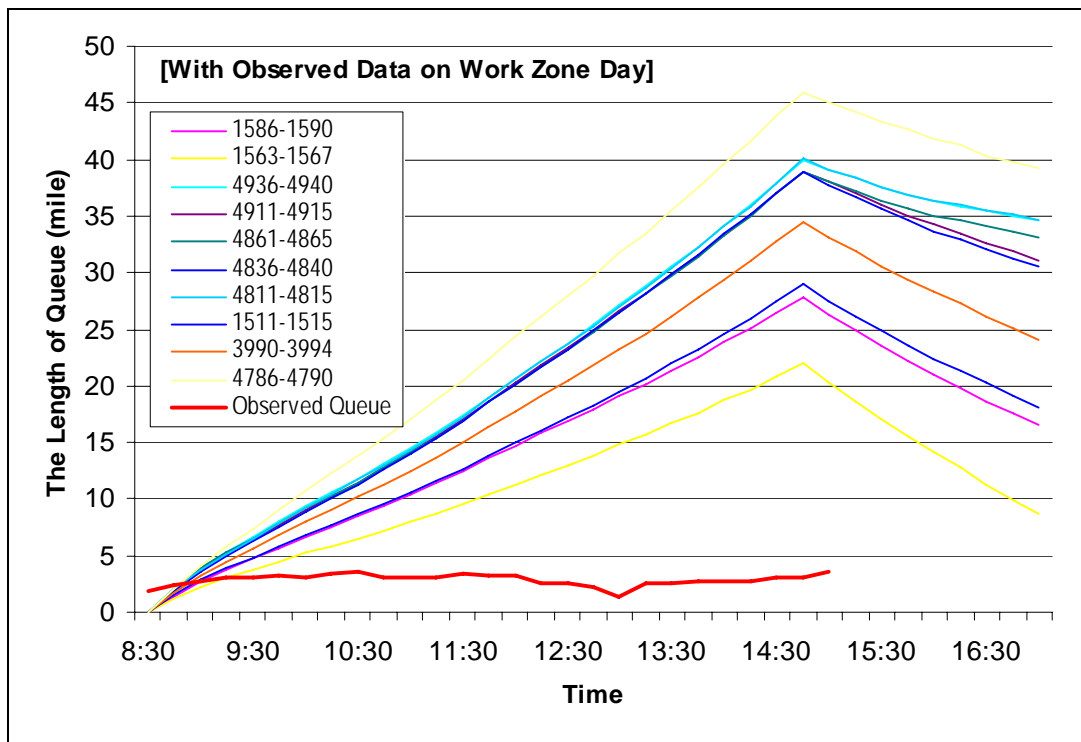


Figure 5 Estimated length of queue by WZCAT with observed data (WZ1).

It was expected the use of actual traffic volume from the work zone day as an input to WZCAT would produce a queue length somewhat identical to the observed length. However, as presented in Figure 5, WZCAT did not generate a queuing pattern similar to field observations

with any of the detector locations. Figure 6 shows the observed maximum back of queue as a comparison. A queue developed very quickly after the lane closure and stayed near the three mile maximum for all work zone hours except for a slight drop in queue length between noon and 1:00 PM. WZCAT estimated queue length was almost five times longer than the observed value. This overestimation was initially found in all other work zone simulations.

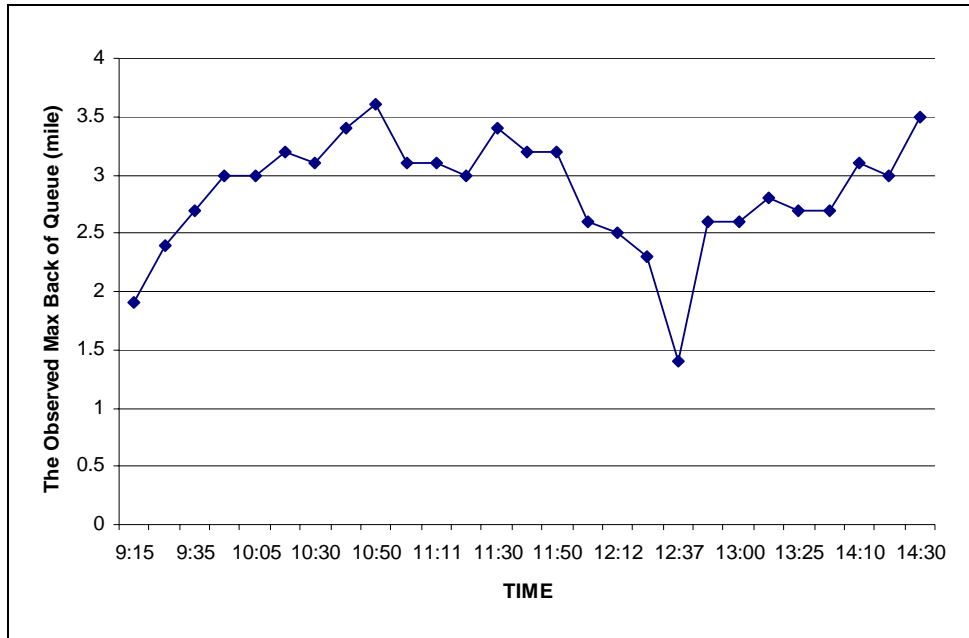


Figure 6 Observed max back of queue (WZ1).

Table 2 shows that the capacity of work zone varies as a function of several factors such as work zone length, work zone setup, etc. These variations would not significantly influence the inflated queue length outputs. Observed traffic flow through work zone remained +/- 300 vphpl of the default value in WZCAT, which further showed the relative stability of the value.

Table 2 Traffic Flow in Work Zones

	WZ 1	WZ 2	WZ 3	WZ 4	WZ5,6	WZ7	WZ8
# of open lanes	1	1	2	2	1 & 2	2	2
* WZ Capacity-Max (vph)	1223	1579	2782	2905	No data	2852	2659
WZ Capacity-Min(vph)	985	1060	2564	1900		2636	2143
WZ Capacity-Mean (vph)	1134	1279	2710	2705		2774	2643
** Saturation Flow Rate (vph)	1100	1269	2613	***3770		2750	2800
Heavy Vehicle Percentage	16%	15%	10%	9%	11%	9%	10%

* Capacity was measured at the 1st detector location upstream of work zone (Within 1500ft)

** Saturation flow rate was measured at the end of work zone

*** One on-ramp exists very close to end of work zone and on-ramp traffic added to saturation flow.

According to multiple field observation throughout this study, vehicle queues at work zone locations started to build immediately upon arrival of the maintenance vehicles on the shoulder of the freeway. When traffic control devices were actually placed to establish a work zone on the freeway, vehicle queues were already established and approaching maximum values, which were typically maintained in a relatively steady-state condition for the duration of the work zone. This was a very common pattern observed from all work zones and a noticeable distinction from the result of the WZCAT simulation. To reproduce the observed queue in WZCAT or similar simulation software, travel demand would need to be equivalent with the work zone capacity after the initial queue development. Because this is generally not the case, most software models show a growing queue while field observations show a rather stable queue length.

DELAY ESTIMATION WITH RAMP TRAFFIC

Based on the observed work zone capacity and the length of queue variation, it is reasonable to believe that traffic movements at ramp terminals are strongly associated with traffic delay due to work zone operations as traffic delay grows. Figure 7 illustrates vehicle queue growth due to work zone operation on the urban freeway over time (t_0 - t_2). The initial version of WZCAT calculates delay due to work zone operations based on two inputs. One input is “work zone capacity” which is simply the capacity measured within a work zone (c_1). The second input is demand which is traffic volume usually obtained from single detector location upstream of a work zone (d_1 - d_6). Deterministic input (d_x) and output (c_1) calculation is applied to keep track of balance of queued vehicles ($d_x - c_1$) over time.

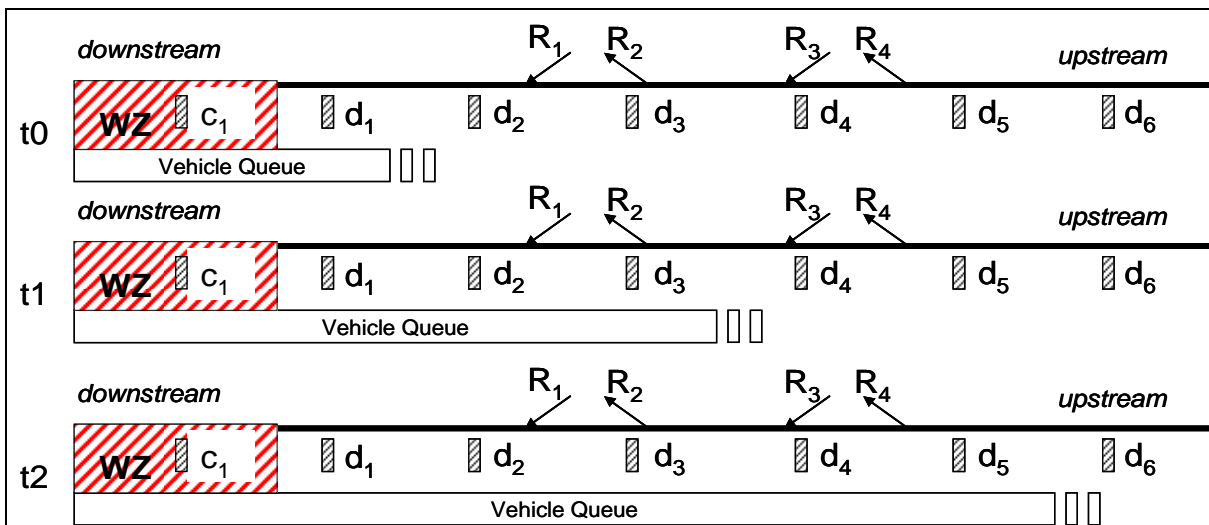


Figure 7 Queuing due to work zone operation at SE Wisconsin freeways.

Initially, the study was focused in finding a single best upstream location (d_x) that can be used as a demand estimate that produced identical queuing patterns in the field. However, it was found that this input-output calculation with two attributes (c_1 , d_x) generated the incessant growing queue which was quite different from field observations. Further reasoning found that this is because c_1 is reduced capacity due to work zone operation, so if c_1 is significantly smaller than any given d_x at time t , the balance of queued vehicles ($d_x - c_1$) at time t will always be much

greater than 0 and the summation of the balance over time will produce a continuous growth of queue. Figure 8 shows a simplified queuing pattern with work zone on urban freeways.

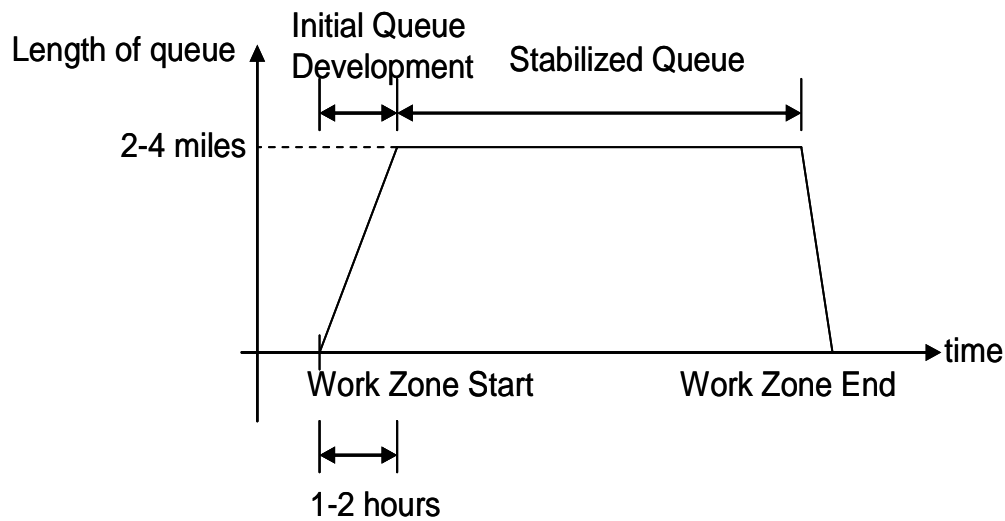


Figure 8 Vehicle queue development with work zone in urban freeways.

To replicate this observation by using WZCAT, upstream traffic flow (d_x) which is an input demand should become very close to work zone capacity (c_1) after the first 1 to 2 hours from initial work zone setup or the balance of input (d_x) and output (c_1) should be same as summation of ramp traffic (R_1 - R_4) upstream of work zone.

Table 3 shows traffic flow data obtained from loop detector locations upstream of work zone. The work zone was started at detector USH18 (221) and two lanes were closed among three existing lanes. A detail analysis of the work zone revealed three major findings:

- As it can be seen in Table 3, traffic flow at all mainline detector locations (207-219) are at least 1,000 vph higher than traffic flow at work zone (221). Therefore, deterministic queue calculation using a fixed work zone capacity and any given upstream detector location creates a continuous growth of queue as seen in WZCAT.
- WZCAT uses only a single detector location for delay calculation. This has a limitation to represent proper demand in queuing calculation as the end of queue moves because if the selected location is too close to the work zone, it will become a part of the queue soon after work zone start, and if the selected location is too far from the work zone area, incorrect demand will be used for the queue calculation until the end of queue becomes close to the location in WZCAT. Therefore, an appropriate demand for queue calculation should be obtained from the 1st detector location upstream of the queue at the beginning of the work zone and it should be changed during work zone operation as the end of queue changed.
- There are many enter/exit ramps on urban freeways, so the development of vehicle queue by any given work zone is likely to be extended beyond several enter/exit ramps. Tables 3 clearly present that the proper consideration of enter/exit ramp traffic significantly improves the performance of delay estimation to a great extent. In other words, this shows that it will not be feasible to estimate the delay due to work zone activity without considering ramp traffic even if the work zone capacity is known. Therefore, to improve WZCAT, traffic

movement at each ramp terminals upstream of work zone should be included as a part of delay calculation routine as well as good estimation on ramp traffic changes due to work zone operation.

Table 3 Delay Calculation With/Without Ramp traffic consideration (WZ1)

Detector Locations	Work Zone Hours							
	8	9	10	11	12	13	14	15
Underwood Creek Pkwy (207) (Mainline)	4947	3505	3570	3519	3252	3602	4025	5203
Elm Grove Rd. (208) (Mainline) - dx	4961	3510	3560	3493	3255	3630	4001	5157
Sunnyslope Rd. (209) (Mainline)	4991	3542	3554	3505	3212	3631	4009	5359
Woodridge Ct. (210) (Mainline) - dx	4780	3541	3580	3489	3199	3626	4009	5253
Moorland Rd. NB (211) (Exit)	923	770	1053	1033	1236	1173	1110	860
E. of Moorland Rd. (1322) (Mainline)	3872	2809	2509	2452	1964	2724	2855	4352
Moorland Rd. SB (843) (Exit)	437	390	707	824	805.5	787	898	563
W. of Moorland Rd. (212) (Mainline)	3604	2381	1760	1586	1786	2166	1935	3871
Moorland Rd. (213) (Entrance)	471	418	347	315	428	422	356	627
E. of Calhoun Rd. (214) (Mainline)	4304	2740	2145	1981	2266	2441	2344	4873
Calhoun Rd. (215) (Mainline)	4222	2663	2160	2081	2241	2465	2396	4851
Brookfield Lakes (216) (Mainline)	4277	2569	2146	2149	2171	2526	2388	4881
Brookfield Rd. (217) (Mainline) - dx	4103	2513	2186	2114	2192	2483	2432	4895
W of Brookfield Rd. (218) (Mainline) - dx	4073	2519	2188	2087	2252	2437	2471	4907
Poplar Creek (219) (Mainline)	4118	2611	2199	2116	2327	2459	2546	4996
Barker Rd (220) (Exit)	829	843	573	607	682	789	608	723
USH 18 (221) (WZ)	2778	1184	1186	1110	1178	1149	1527	3729
Moorland Rd. NB (211) (Exit) - R4			-1053	-1033	-1236	-1173	-1110	-860
Moorland Rd. SB (843) (Exit) - R3			-707	-824	-805.5	-787	-898	-563
Moorland Rd. (213) (Entrance) - R2			347	315	428	422	356	627
Barker Rd (220) (Exit) - R1	-829	-843	-573	-607	-682	-789	-608	-723
(1) Ramp In/Out Total (R1+R2+R3+R4)	-829	-843	-1986	-2149	-2295.5	-2327	-2260	-1519
(2) dx: WZ Upstream (Veh/hr)	4073	2513	3580	3489	3199	3630	4001	5157
(3) c1: Observed WZ Cap(Veh/hr)	2778	1184	1186	1110	1178	1149	1527	3729
Delay Calculation								
WZCAT								
Queued Vehicle at time t = (2)-1500 vph	1295	1013	2080	1989	1699	2130	2501	1428
(4) ? Queued Vehicle at time t	1295	2308	4388	6377	8076	10206	12707	14135
(5) Estimated Queue Length (miles)	3.92	6.99	13.30	19.32	24.47	30.93	38.51	42.83
WZCAT with Corrected WZ Capacity								
Queued Vehicle at time t = (2)-(3)	1295	1329	2394	2379	2021	2481	2474	1428
(4) ? Queued Vehicle at time t	1295	2624	5018	7397	9418	11899	14373	15801
(5) Estimated Queue Length (miles)	3.92	7.95	15.21	22.42	28.54	36.06	43.55	47.88
Delay Calculation including In/Out Ramp Traffic								
Queued Vehicle at time t = (2)+(1)-(3)	466	486	408	230	-274.5	154	214	-91
(4) ? Queued Vehicle at time t	466	952	1360	1590	1315.5	1469.5	1683.5	1592.5
(5) Estimated Queue Length (miles)	1.41	2.88	4.12	4.82	3.99	4.45	5.10	4.83
(6) Observed Queue Length (miles)	1.9	2.7	3.3	3.6	2.7	2.6	3.1	3.5
Traffic flow at 1st detector location upstream of the end of queue:								
Work Zone Capacity:								

WZCAT-R

Two major enhancements were made to improve the delay estimation by WZCAT, leading to a version labeled as WZCAT-R. First, all in/out ramps upstream of work zone within reasonable range was included in delay calculation. Second, demand adjustment factor (DAF) was introduced to reflect travel demand increase or decrease due to work zone activities. Figure 9 shows the enhanced delay calculation with ramp traffic and DAF. As vehicle queues grow and reach a ramp location upstream of the work zone, DAF was applied to historical hourly average traffic at that particular ramp location. The aggregated traffic flow including enter/entrance ramp upstream of work zone was used as an input for deterministic input-output analysis.

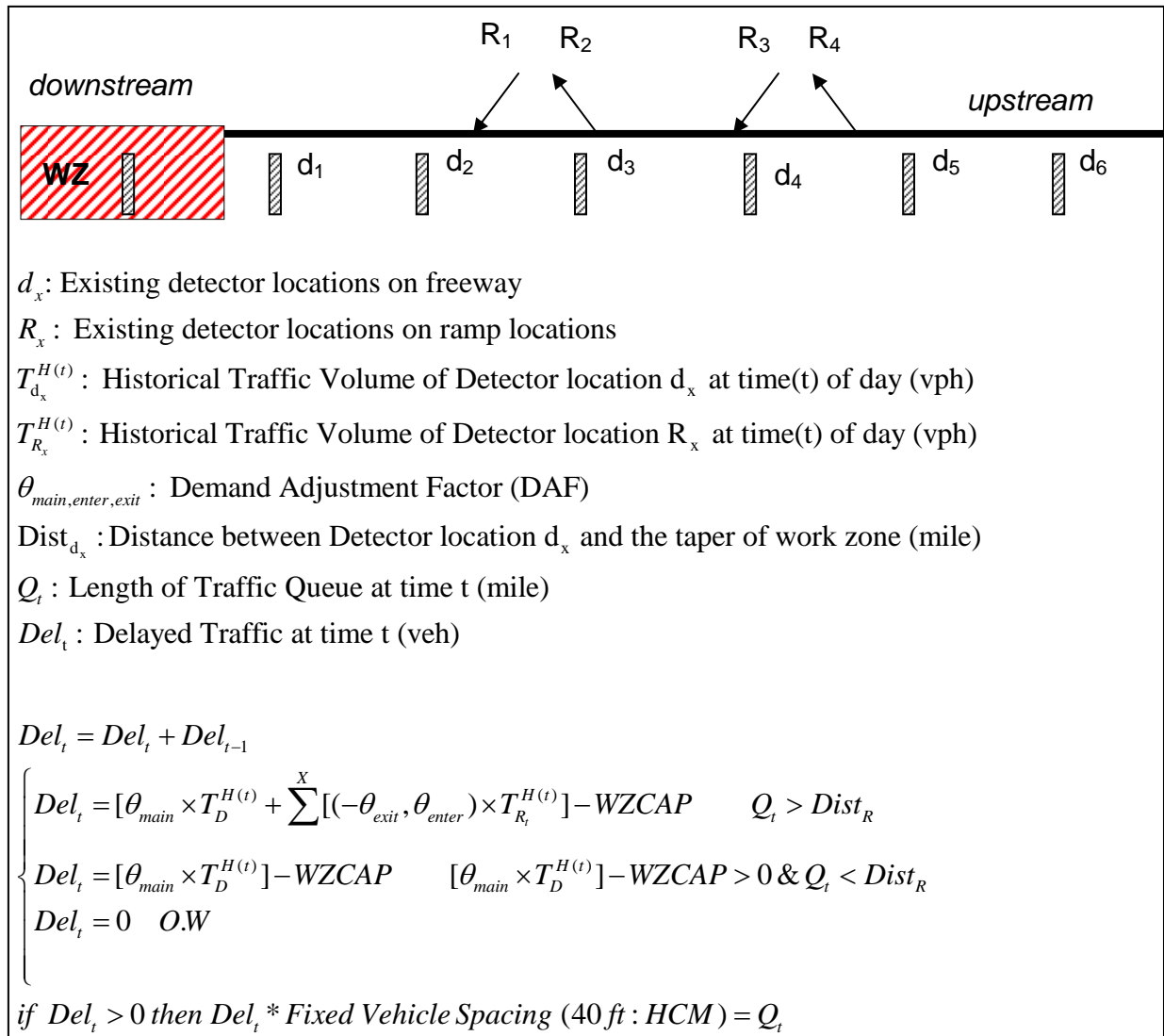


Figure 9 WZCAT-R delay estimation.

DAF aims to incorporate the significant amount of traffic volume changes on exit/entrance ramps upstream of work zones. For example, most entrance ramps located upstream of work zones showed 20 to 40 percent reductions in hourly volume due to work zone activities, compared to “historical traffic volume” which is obtained from averaging traffic

volumes from the same day of the week and time period for the 12 previous weeks. To reflect this in WZCAT-R simulation, DAF 0.6 to 0.8 was multiplied to “historical traffic volume” at the historical ramp traffic volume. Three different DAFs are applied to mainline, entrance ramp and exit ramp separately. Each DAF is further refined to apply two different stages (Initial queue development, Stabilized queue) of queue developments due to work zone operation. According to field observations in this study, first one to two hours after work zone setup can be considered as an initial queue development stage.

As for the mainline, 10 percent reduction of traffic flow due to work zone operations was considered and 0.6 to 0.8 DAF was applied to the entrance ramp and 1.5 to 1.6 DAF was applied to the exit ramp. These parameters are empirical numbers that were obtained from the field observation in this study. Interestingly, these numbers showed very minimal variation between work zones.

The WZCAT-R produces much improved results for all four work zones that were evaluated. As can be seen in Table 4, the queue estimations by WZCAT-R are very close to field observations. Mostly, WZCAT-R generated rather wider variation of queue throughout the work zone hours. Mean Absolute Percentage Error (MAPE), which measures the accuracy of predicted value, were calculated along with the Mean Absolute Deviation (MAD) to show the accuracy of predicted values produced by WZCAT-R. All MAD values for each of the four work zones were smaller than 1 mile.

TABLE 4 The Result of WZCAT-R Simulation

Time	WZ1		WZ2		WZ4		WZ8	
	WZCAT-R	Obs.	WZCAT-R	Obs.	WZCAT-R	Obs.	WZCAT-R	Obs.
8	1.21	1.9	*	*	1.64061	1.9	0.1	0.3
9	1.85455	2.7	0.71232	0.7	3.33545	2.7	1.5303	0.75
10	2.24758	3.3	1.51217	1.62	3.43333	3.3	1.09121	0.8
11	2.86636	3.6	2.81211	2.52	4.07455	3.6	1.20636	0.9
12	2.93061	2.7	3.22121	2.56	4.89727	2.7	1.82667	1.28
13	3.42788	2.6	3.15	3.15	5.35242	2.6	1.32	1.35
14	3.712	3.1	3.1	2.9	2.82636	3.1	0	0.5
15	3.877	3.5						
MAPE(%)	23.84		8.8		35.79		55.14	
MAD(Mile)	0.67		0.21		0.96		0.38	

CONCLUSIONS

A traffic delay assessment software package was developed to predict the queuing impacts of short-term work zones in urban area where many enter/exit ramps exist. Comprehensive field data were obtained from multiple work zones. The collected data included the queue length due to work zone activity, lane usage at the upstream of work zones, and traffic flow characteristics.

Traffic volumes from both the average of historical data and observed work zone day data were prepared and applied to WZCAT. Initially, WZCAT was not able to produce an identical queuing pattern to what was observed during field data collection. WZCAT significantly overestimated the length of queue. Moreover, the pattern of queuing in WZCAT was very different in that queues continued to grow and never reached the steady-state condition that was observed in the field after a short time after the work zone traffic control was deployed. Observed vehicle queue typically grew to its maximum length within the first 1 to 2 hours after

work zone setup and showed modest changes throughout the duration of the work zone remaining in a relatively steady-state condition. This pattern was observed at most work zones on urban freeways where upstream interchanges were located.

Considering the structure of WZCAT, the inflated result was not directly related to any deficiencies within the software itself. Therefore, the study focused on validating work zone capacity and travel demand which are the two major components of the input and output analysis in WZCAT. The observed capacities of the work zones remained rather constant and were close to the default value used in WZCAT while travel demand requires a more careful analysis of upstream activities.

The study found that traffic changes on exit/entrance ramp terminals at upstream of work zone contribute to the stabilization of vehicle queue. Additionally, an appropriate mainline demand for queue calculation is required from the 1st available detector location upstream of end of vehicle queue.

WZCAT-R was developed to incorporate these findings and it produces much improved results. Especially, consideration of all entrance/exit ramps upstream of work significantly improved the estimation of delay due to work zone activities on urban freeways. These traffic volume changes at ramps upstream are a very complex phenomenon and depend on drivers' perception of the downstream traffic conditions in addition to knowledge about the availability of alternate routes. However, even simplified demand adjustment parameters which can be cumulated/calibrated easily through continuous data collection efforts are very helpful to improve the accuracy of delay assessment in an effective and efficient manner. WZCAT-R produces effective results for queue prediction, and can be an effective and reliable tool in prediction of work zone delay and queue development and help engineers proactively plan work phasing, lane restrictions, and potential detour routes in an effort to move traffic more efficiently.

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