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WORK ZONES AND THEIR IMPACT ON USER COSTS

by
Ghulam H. Bham
James E. Hicks

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Pavement Management

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16. Abstract

This report defines a work zone, its capacity, and how it is estimated. The importance of capacity is also mentioned since it is directly used in the calculation of user delay due to a work zone. The impact of delay on user costs is also discussed.

A methodology is presented which relates queue delay with ADT. Queue delay due to a work zone is calculated using a plot between time, cumulative volume, and capacity. The area between the curves represents queue delay.

Three software packages are evaluated for calculation of user delay and cost due to a work zone. None of them were adequate for calculating delay due to queue formation.

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Enhancement to Illinois Pavement Management

List of IHR-540 Reports

FHWA-IL-UI-261 Performance of Original and Resurfaced Pavements on the Illinois Freeway System. Documents the survival in terms of mean age and ESALs and their distribution of both original pavements and resurfaced pavements from the 1950's to 1994.

FHWA-IL-UI-266 Work Zones and Their Impact on User Costs. Provides a brief review of the current state-of-practice concerning highway work zones (for rehabilitation activities) and their impact on user delays and costs.

FHWA-IL-UI-267 Evaluation and Improvement of the CRS Prediction Models. Evaluates two CRS prediction models and provides a new improved two-slope method that greatly improves the prediction of future CRS for a given pavement section.

FHWA-IL-UI-268 Field Performance of CRCP in Illinois. Documents the performance of many designs of CRCP on the Interstate highway system (over 2650 directional miles) constructed over the past 50 years and provides a performance prediction model that may be useful for various design and management purposes.

FHWA-IL-UI-269 Interstate 80 Pavement Rehabilitation Corridor Study. Documents the past and present, and forecasts the future performance and rehabilitation needs of the pavement sections on the Interstate I-80 highway corridor in Illinois.

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1. INTRODUCTION

The numbers of freeway construction and rehabilitation projects continue to increase in the United States because of the aging highway infrastructure. Consequently, work zones are quite common. These work zones have negative impacts on highway users, including effects from additional signs, narrowed lanes, barriers close to the travel way, trucks entering the construction area, reduced speed limits, and workers near the open lanes. Travel times are affected, and work zones are a safety hazard as well. Researchers have devised various methods and strategies to minimize delay and congestion caused by these work zones [1,2].

There are two main strategies for lane closure on work zones: crossovers and partial lane closure [3]. In a crossover arrangement, all lanes in one direction are closed and two-way traffic is maintained side by side. They are constructed to bring both directions of traffic to one side of the highway. The other side is completely closed for construction. In a partial lane closure, one or more lanes in one direction (side) of the highway are closed. The rest of the lanes remain open. The selection of the strategy depends on the situation and the nature of work. Research has also been done to develop a systematic method for selecting appropriate lane closure strategies [1,2,3].

This report defines a work zone, its capacity, and how it is estimated. User costs due to work zones are also discussed. Three software packages were evaluated to analyze work zones. A methodology is presented that relates queue delay with ADT. At the end, conclusions and recommendations are made.

2. WORK ZONE DEFINITION

Work zones are divided into various areas: advance warning, transition, and activity (Figure 1). The advance warning area occurs before any lane closure and is the region where drivers are informed about lane closure and work activity. The transition area is the region where traffic is channeled from its normal path to a new path [19]. This region is characterized by the use of tapers. The activity area is the region where the construction activity occurs and traffic operates in a restricted pattern [19]. This region is often identified as the active work area.

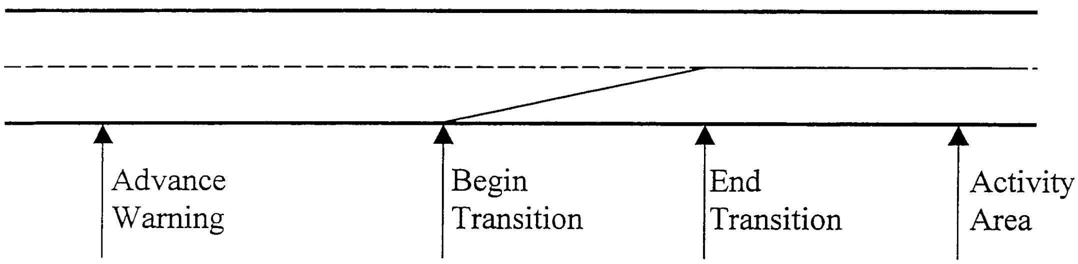

Figure 1. Areas of a Work Zone.

3. CAPACITY OF WORK ZONES

The capacity of a work zone is simply the number of vehicles that can flow through a section of work zone during a given time period and prevailing traffic conditions. Capacity is the principal determinant of the magnitude of impact of a work zone on a given section of freeway at a given time [5]. If capacity exceeds the prevailing demand, delay is minimal. When demand exceeds capacity, a queue forms and delay can be significant.

Studies on work zone capacity in the US were mainly done in Texas and North Carolina. The former study recommended an average base capacity of 1600 passenger cars per hour per lane (pcphpl) for all freeway work zone lane closure configurations [5]. Passenger cars per hour per lane can be converted from vehicles per hour using passenger car equivalent. A passenger car equivalent of 1.7 was used for heavy vehicles, as recommended by the Highway Capacity Manual [10]. The Texas study was mainly done on short-term work zones and in urban areas.

The North Carolina study, conducted in mid 1990's, determined capacity values for both urban and rural areas. The North Carolina study proposed a capacity of 1200 vehicles per hour per lane (vphpl) for rural sites and 1500 vphpl for urban sites [6]. The proposed capacity value was for a configuration of 2 normal lanes to 1 open lane. Since work zone capacity is affected by intensity of work activity in a work zone, this was taken into account.

Data from both studies is presented in Table 1. Work zone capacity for a 3 to 1 lane configuration is different in the two states. The difference is also observed for a 2 to 1 lane configuration. The North Carolina study determined both the end of transition and the active area capacity. The end of transition capacity is 200 vehicles per hour higher than the activity area capacity because work zone capacity tends to decrease near active work areas.

Table 1. North Carolina and Texas Work Zone Capacity [6]

Number of Lanes			North Carolina				Texas[1]
Normal	Open	Rural or Urban	End of Transition Capacity (vphpl)	Activity Area Capacity (vphpl)	Intensity of Work Activity	Comparison of Activity Area to End of Transition Capacity (%)	End of Transition Queue Discharge (vphpl)
2	1	Rural	1300	1210	Heavy	93	Unknown
2	1	Urban	1690	1560	Moderate	93	1575
2	1	Urban	1690	1490	Heavy	88	1575
3	1	Urban	1640	1440	Moderate	88	1460

[1]Based on updated capacity values [4]

The effects of different variables on work zone capacity are as follows [5]:

i) Intensity of work zone activity

The intensity of work zone activity increases with the number and size of vehicles, number of workers, magnitude of noise and dust, and the proximity of work to the open travel lanes.

ii) Traffic composition (percentage of heavy vehicles in the traffic stream)

Work zone capacity needs to be adjusted for presence of heavy vehicles because capacity decreases in the presence of heavy vehicles.

iii) Presence of entrance ramps near the beginning of the lane

Work zone capacity is affected by entrance ramps within the taper area or immediately downstream of the beginning of the full lane closure. Work zones should be set up to avoid entrance ramps within the taper area or near the beginning of the lane closure to avoid capacity reducing effect of ramps.

iv) Type of study site (rural or urban) [6]

Work zone capacities on rural sites were found to be lower than urban work zone capacities. The lower values emphasize the dramatic influence of driver familiarity on traffic operations within work zones.

v) Cross section of the traveled way (lane width and lateral clearance to obstructions)

Lane width and lateral clearance both affect the capacity of work zone. Reduced lane width and obstructions in lateral clearance reduce the capacity of a work zone.

In addition to the Texas and North Carolina studies, studies have been conducted in California and in Illinois. The study in California was very limited. In Illinois, researchers studied the effect of intensity and location of work activity on mean speeds through a work zone [7,8]. The only other capacity data is from an FHWA study for 2 to 1 lane closure [9]. In this study, the capacity values reported were very low because of various site conditions [5].

3.1. Importance of Work Zone Capacity

The traffic handling capacity is the main concern in planning work zones. When the capacity of the work zone is higher than the demand volume, delay is minimal. However, when demand exceeds capacity, delay increases, which ultimately results in the formation of a queue and thus higher user costs. Therefore, capacity has a direct relationship with delay and user cost, and it is of utmost importance to estimate capacity accurately to calculate user delay and cost.

Capacity information also helps engineers in determining the number of open lanes required during construction. This will also help them in adjusting the construction schedule to reduce delay and user costs, and perform better traffic control tasks.

3.2. Calculation of Estimated Work Zone Capacity

To estimate work zone capacity accurately, adjustments are applied to the base capacity of work zones. The following equation recommended by Texas Transportation Institute (TTI) is used to estimate work zone capacity [5]:

$$c = (1600 \text{ pcphpl} + I - R) \times H \times N$$

where

c = estimated work zone capacity (vph),

pcphpl = passenger car per hour per lane,

I = adjustment for type and intensity of work activity (pcphpl),

R = adjustment for presence of ramps (pcphpl),

H = heavy vehicle adjustment factor (vehicles/passenger car), and

N = number of lanes through a work zone.

The recommended values for the base capacity and the various adjustments are as follows:

I = range (-160 to +160 pcphpl), depending on type, intensity, and location of work activity;

R = minimum of average entrance ramp volume in pcphpl during lane closure period for ramps located within channelization taper or within 152 m (500 ft) downstream of the beginning of full lane closure, or one-half of the capacity of one lane open through a work zone (i.e., 1600 pcphpl/2N); and

H = as given in Highway Capacity Manual [10] for various percentages of heavy vehicles and passenger car equivalents.

These values are particular for the state of Texas, and therefore may not apply directly to Illinois. The limitation of applying Texas data to the rest of the nation is that the Texas freeway network has an extensive frontage road system, which permits vehicles to bypass congested segments of highways. Most other freeway systems in the United States do not have continuous frontage roads [6]. Aggressive drivers in Texas can exit the freeway system in favor of a frontage road; in other states, they remain in the traffic stream. In Texas, such drivers may also influence surrounding vehicle behavior. Therefore, capacity values suitable for the Texas freeway system may be higher than those for the state of Illinois.

4. USER COSTS

According to a World Bank report [11], the three main components of life cycle costs of a roadway are construction, maintenance, and user costs.

The user cost is approximately 90% for a 2-lane highway serving around 1000 vehicles per day [11]. User costs consist mainly of vehicle ownership, vehicle operating cost, and delay cost (i.e., cost due to delay in travel time). User delay cost can also be related to the roughness of the pavement as well as disturbance to normal traffic flow associated with maintenance and rehabilitation activities. As pavement surface deteriorates with time, its surface cracks and deforms. This affects the rideability of the pavement, increasing roughness and adding to user discomfort and vehicle operating cost. Highway users reduce their speed, resulting in longer trip times that also contribute to higher user cost.

Various researchers have developed algorithms to estimate additional costs to road users per day of construction activity as part of a broader economic evaluation of highway improvement alternatives [11,12,13], but some of them are not at a sufficient level of detail to be used in work zone planning and scheduling.

5. PROGRAMS FOR EVALUATION OF WORK ZONES

This section describes existing computer models for the estimation of road user costs on highways and freeways. Three models were evaluated: QUEWZ [12,14,15], spreadsheet from Pennsylvania Department of Transportation, PennDOT [16], and MicroBENCOST [17].

5.1. QUEWZ (Queue and User Cost Evaluation of Work Zones)

QUEWZ is a computer model developed in 1982 to be used as a tool for planning and scheduling freeway work zone operations. The model analyzes traffic flow through lane closures in freeway work zones. It estimates queue length and additional road user costs that result from work zones. A newer and updated version of QUEWZ, QUEWZ-92, is now available. Comparison of user cost calculated using QUEWZ-85 and QUEWZ-92 is presented in Table 2 and graphically in Figure 2. The lines in the figure show an exponential increase in user cost with an increase in volume to capacity ratio (v/c). QUEWZ-92 shows a constant increase in the value of user cost as compared to QUEWZ-85. In Table 2, the values are compared using constant increase in ADT for varying volume to capacity ratio.

Table 2. Comparison of User Cost ($), QUEWZ-85 vs. QUEWZ-92

ADT	v/c	QUEWZ-85 User Cost ($)	QUEWZ-92 User Cost ($)
4000	0.30	35	54
6000	0.44	100	134
8000	0.59	224	286
10000	0.74	439	550
12000	0.89	788	980
14000	1.03	1,846	2,282
16000	1.18	4,044	4,800
18000	1.33	9,610	11,465
20000	1.48	25,447	31,993
22000	1.62	56,313	72,431

User cost is estimated when one or more lanes are closed in one direction of travel or when a crossover is used. Hourly and daily user costs are estimated, and when vehicle demand exceeds capacity, the model also estimates the length of queue. The model is designed for freeway operations. Two vehicle types are used: passenger cars and single and combination trucks.

The model uses both hourly volumes and average daily traffic (ADT), so it can calculate both hourly and daily user costs. Thus, the model can give more accurate results, since the daily peaking pattern can have a significant impact on average speeds and queues during the day.

The model deals with both types of lane closures: crossover and partial lane closures. A maximum of six lanes can be handled in this model.

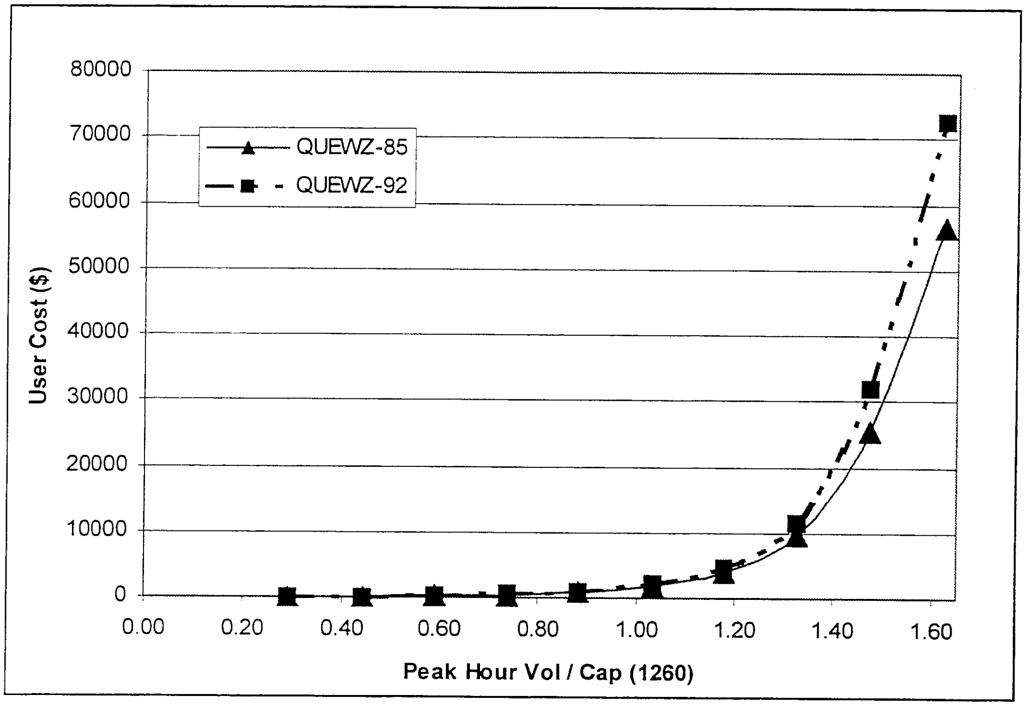

Figure 2. Comparison of User Cost ($), QUEWZ-85 vs. QUEWZ-92

The diversion algorithm provided in the older model is improved and now provides better information on the maximum acceptable (or likely) queue length in miles and maximum delay in minutes. A new graphical output option has also been added to provide schedule for the time of day during which a particular number of lanes may be closed without causing excessive queuing and delay. The newer model for estimation of work zone capacity has also been incorporated as an option.

A factor to update cost calculations is needed to update the user costs from December 1990 to current prices. The consumer price index can be used for this purpose.

The additional user cost due to work zone in QUEWZ is then the sum of component costs because of the following [12]:

i) delay costs and change in vehicle running costs,

ii) speed change cycle costs in slowing down and returning to the approach speed,

iii) costs if a queue forms as delay cost, vehicle running costs, and speed change cycle costs.

Accident costs are not calculated in this model. The model also does not give user delay as an output.

5.2. PennDOT Spreadsheet (User Delay Cost)

The PennDOT program is comprised of a number of spreadsheets. It performs pavement design as well as life cycle cost analysis. One of the spreadsheets calculates user delay costs on work zones. It is divided into three parts. The first part consists of information on traffic. It consists of initial ADT, design year ADT, percentage of cars and trucks, the design life, directional factor for traffic, the traffic pattern group, and the current construction cost index. The traffic pattern group is based on the functional classification of the highway, and so is the hourly percentage of total vehicles.

The second part of the spreadsheet consists of information on the work zone. Inputs include length of restricted flow, detour length (if any), initial and reduced speeds, and the number of lanes, normal and maintained (restricted). The outputs are the roadway capacity and the idling, stopping, and time cost for the number of stops.

The third part of the spreadsheet gives the final output of user cost because of delay. The inputs are the activity year and the duration when the work zone is in place. The input is also in terms of when the maintenance and protection of traffic is in effect. The output is in terms of percentage of daily traffic delayed and the ADT delayed in one direction. The number of stopped and delayed vehicles is also calculated. The breakdown of delay cost is in terms of cars and single and combination trucks. The user delay cost is further categorized as idling, stopping, and corresponding time costs.

The percentage of daily traffic delayed by the construction in each direction is determined by summing the hourly percentages of total vehicles for the hours that maintenance and protection of traffic is in place during the day [16]. One hundred percent of the traffic is delayed if maintenance and protection of traffic is in place all day. The number of hourly vehicle stops in one direction is determined by multiplying the hourly percentages of total vehicles and the ADT in one direction, then subtracting the roadway capacity in one direction and adding the previous hour's total [16].

The spreadsheet calculates user costs as a linear function of peak hour volume over capacity, which is theoretically and practically incorrect. The graph of user cost versus volume to capacity ratio is shown in Figure 3. The delay cost for PennDOT should increase exponentially instead of increasing linearly. This spreadsheet, therefore, does not take into account all the components of delay and its use is not recommended.

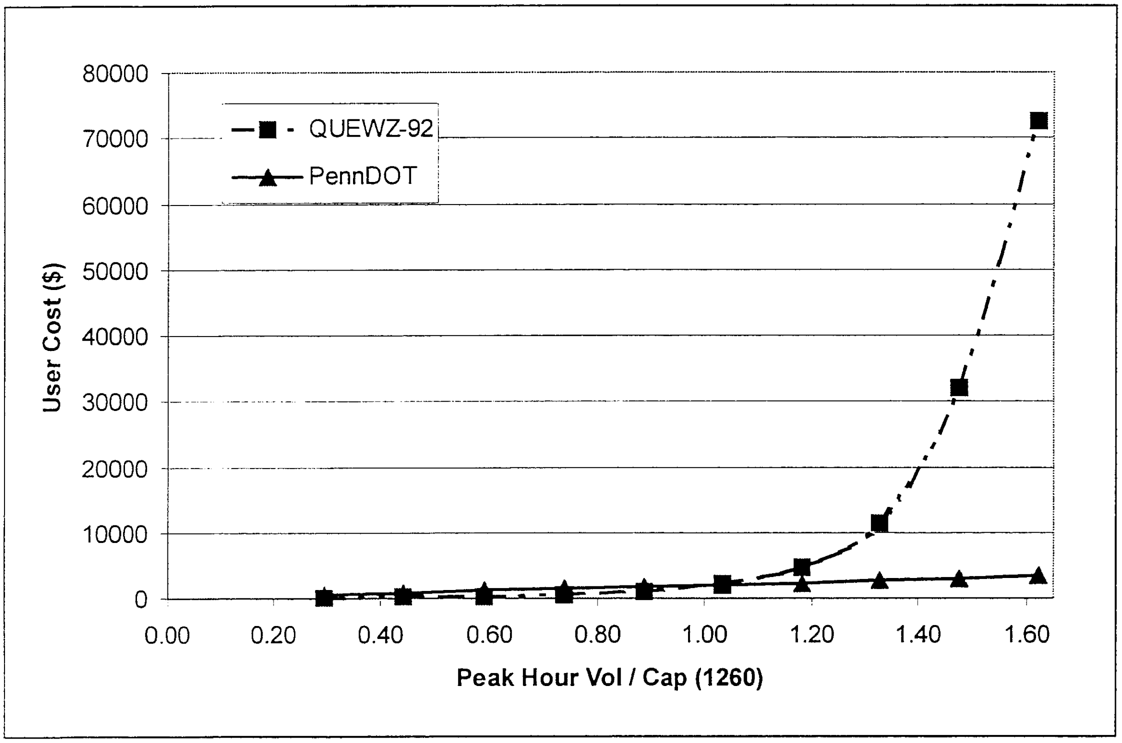

Figure 3. Comparison of User Cost ($), PennDOT and QUEWZ-92

Comparison of user cost calculated using PennDOT's spreadsheet and QUEWZ-92 is presented in Table 3. The user costs calculated by PennDOT shows a uniform increase, whereas the user cost calculated by QUEWZ-92 shows rapid and sudden increases. A large difference in user cost is, therefore, observed for an ADT of 22000.

Table 3. Comparison of User Cost ($), PennDot vs. QUEWZ-92

ADT	v/c	PennDot User Cost ($)	QUEWZ-92 User Cost ($)
4000	0.30	579	54
6000	0.44	869	134
8000	0.59	1,157	286
10000	0.74	1,447	550
12000	0.89	1,736	980
14000	1.03	2,031	2,282
16000	1.18	2,346	4,800
18000	1.33	2,674	11,465
20000	1.48	3,076	31,993
22000	1.62	3,550	72,431

5.3. MicroBENCOST

MicroBENCOST is the most comprehensive program available for calculating user costs for a variety of applications. It is also used for analyzing benefits and costs for a wide range of highway improvements. In addition, it can allocate corridor traffic and calculate forecasted traffic volumes. The program can analyze several general categories of projects: added capacity, bypass, intersection/ interchange, pavement rehabilitation, bridge, safety, and highway railroad grade crossing. In addition to these major categories, MicroBENCOST can be used to analyze work zones and incidents in conjunction with any of these project types.

MicroBENCOST can also be used in conducting an evaluation of transportation alternatives, especially for pavements. It has been used by the Tennessee Department of Transportation to calculate road user costs [18].

The program can compare the motorist costs in the existing situation (i.e., without improvement) to costs if the improvement is made. In all cases, the without-improvement alternative includes an existing route and an optional alternate route.

The main drawback of using MicroBENCOST is that it cannot analyze crossovers in work zones as a lane closure strategy. The program is also not easy to use since it has a large number of input variables.

In summary, the three models described were found to be inadequate and deficient for the purpose of calculating delay and subsequent user cost. The methodology described in the following paragraphs was thus adopted.

6. DELAY AT WORK ZONE

Since delay is one of the major concerns of highway users, it serves as the basis of our methodology in evaluating work zones. The method is based on deterministic queuing approach. Limited research on calculation of delay in work zones has focused on deterministic queuing delay. The basis of the approach is that, delay due to queuing occurs when the demand of traffic exceeds the capacity of a work zone. This is also the approach used in the Highway Capacity Manual [10] to calculate delay at work zones. This approach was selected since it is easy to use and involves mainly hourly traffic volume and capacity of work zone to calculate delay.

During low volume conditions, the delay incurred by each vehicle is minimal. But as demand approaches capacity, this delay increases for each vehicle. Queue forms as demand exceed capacity, and delay compounds for each vehicle. The following paragraphs discuss different components of work zone delay [12].

6.1. Delay Through the Lane Closure Section

Delay through the lane closure section occurs due to reduction in speed. When the volume is low, the traffic only slows down at the section where there is major work activity. An adjustment distance of 0.1 miles on each side of the work zone is added to account for reduction of average speed through the closed section. If the closed section is itself only 0.1 miles long, then it is assumed that traffic will slow down during the entire length of work zone. The following equations are used to estimate the effective length of closure (CLL) in miles of reduced average speed [12]:

$$CLL = 0.1 + (WZD + 0.1)(V/C_{WZ}),$$

If $WZD <= 0.1$ or if $(V/C_{WZ}) > 1$,

Then $CLL = WZD + 0.2$

and $DWZ = CLL(1/SP_{wz} - 1/SP_{AP})\ (VLL)$

where

WZD = length of restricted capacity around the work zone in miles,

V/C_{WZ} = ratio of demand volume to capacity of work zone,

DWZ = delay going through work zone at reduced speed,

SP_{WZ} = speed through work zone,

SP_{AP} = approach speed, and

VLL = hourly vehicle volume.

6.2. Delay Due to Queue Formation

If demand exceeds capacity of the work zone, queue starts forming. An assumption is made that there is no diversion of traffic and the demand of traffic does not change. The vehicles are assumed to arrive at a constant rate and enter the work zone during a given hour. The average delay for each hour a queue is present (DQUE), in vehicle hours, is the average of the accumulated vehicles in the queue at the beginning of hour i ($ACUM_{i-1}$) and at the end of the hour i ($ACUM_i$):

$$DQUE_i = (ACUM_{i-1} + ACUM_i)/2$$

where

$ACUM_i = ACUM_{i-1} + VL_i - CAPW_i$,

$CAPW$ = restricted capacity through work zone (vph) for hour i, and

VL_i = vehicle demand during hour i.

A graphical representation of the technique is presented in Figure 4 [12]. T_1 to T_3 represents hours 1 to 3, along the horizontal axis. Similarly, V_1 to V_4 along the vertical axis represent the number of accumulated vehicle demand at any given time. For example, V_1 represents the total number of vehicles in the first hour, while V_2 represents the total number of vehicles in the first two hours. C represents work zone capacity. C_1 represents vehicle capacity for the first hour, C_2 represents vehicle capacity for the first two hours, and so on. The shaded area in the figure represents the queue delay, or the excess of vehicle demand above capacity. There is no queue at the beginning of the first hour, so $ACCUM_0 = 0$. The queue at the end of the hour is, $ACCUM_1 = V_1 - C_1$, so the average delay during the first hour is given by:

$$DQUE_1 = 0 + (V_1 - C_1)/2 = (V_1 - C_1)/2$$

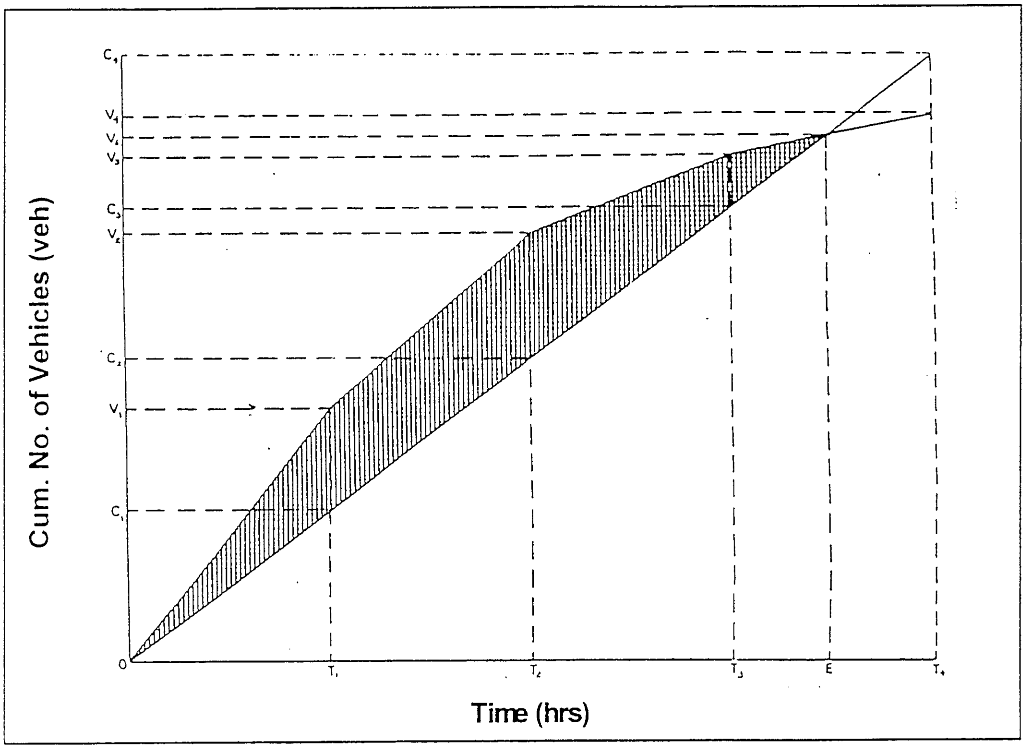

Figure 4. Calculation of Queue Delay (veh-hrs) [12]

The average delay for each of the next two hours can be calculated in exactly the same fashion. However, in the fourth hour the queue dissipates; therefore, an adjustment must be made for that portion of the hour when the queue was present. E, the time when the queue dissipates, can be calculated by solving the following equation. The left side of the equation is the capacity line during the fourth hour, and the right side is the volume demand line during the same hour.

$$(E - T_3)(C_4 - C_3) = (E - T_3)(V_4 - V_3) + (V_3 - V_3)$$

Therefore,

$$E = T_3 + (V_3 - C_3) / ((C_4 - C_3) - (V_4 - V_3))$$

Therefore, if the queue dissipates during hour 1, the delay calculation is modified by the proportion of the hour that a queue was present ($PQUE_i$)

$$PQUE_i = (V_{i-1} - C_{i-1})/[(C_i - C_{i-1}) - (V_i - V_{i-1})] = ACUM_{i-1}/(CAPW_i - VL_i)$$

Average delay is then calculated as

$$DQUE_i = (ACUM_{i-1}/2) \,.\, PQUE_i$$

Total delay is thus calculated as

$$TD = DQUE + DWZ$$

Total delay is calculated using hourly demand of traffic. Hourly demand of traffic can be calculated using percentage of ADT or AADT, as shown in Table 4. (This distribution is also presented in Figure 5).

Table 4. Hourly Demand of Traffic using AADT, Sunday [20]

Hours		% of ADT During hour		Traffic Volumes (ADT)										
				2000	4000	6000	8000	10000	12000	14000	16000	18000	20000	22000
0-1	1	1.8	0.018	36	72	108	144	180	216	252	288	324	360	396
1-2	2	1.5	0.015	30	60	90	120	150	180	210	240	270	300	330
2-3	3	1.3	0.013	26	52	78	104	130	156	182	208	234	260	286
3-4	4	1.3	0.013	26	52	78	104	130	156	182	208	234	260	286
4-5	5	1.5	0.015	30	60	90	120	150	180	210	240	270	300	330
5-6	6	1.8	0.018	36	72	108	144	180	216	252	288	324	360	396
6-7	7	2.5	0.025	50	100	150	200	250	300	350	400	450	500	550
7-8	8	3.5	0.035	70	140	210	280	350	420	490	560	630	700	770
8-9	9	4.2	0.042	84	168	252	336	420	504	588	672	756	840	924
9-10	10	5.0	0.050	100	200	300	400	500	600	700	800	900	1000	1100
10-11	11	5.4	0.054	108	216	324	432	540	648	756	864	972	1080	1188
11-12	12	5.6	0.056	112	224	336	448	560	672	784	896	1008	1120	1232
12-1	13	5.7	0.057	114	228	342	456	570	684	798	912	1026	1140	1254
1-2	14	6.4	0.064	128	256	384	512	640	768	896	1024	1152	1280	1408
2-3	15	6.8	0.068	136	272	408	544	680	816	952	1088	1224	1360	1496
3-4	16	7.3	0.073	146	292	438	584	730	876	1022	1168	1314	1460	1606
4-5	17	9.3	0.093	186	372	558	744	930	1116	1302	1488	1674	1860	2046
5-6	18	7.0	0.070	140	280	420	560	700	840	980	1120	1260	1400	1540
6-7	19	5.5	0.055	110	220	330	440	550	660	770	880	990	1100	1210
7-8	20	4.7	0.047	94	188	282	376	470	564	658	752	846	940	1034
8-9	21	3.8	0.038	76	152	228	304	380	456	532	608	684	760	836
9-10	22	3.2	0.032	64	128	192	256	320	384	448	512	576	640	704
10-11	23	2.6	0.026	52	104	156	208	260	312	364	416	468	520	572
11-12	24	2.3	0.023	46	92	138	184	230	276	322	368	414	460	506
		100.0	1.000	2000	4000	6000	8000	10000	12000	14000	16000	18000	20000	22000

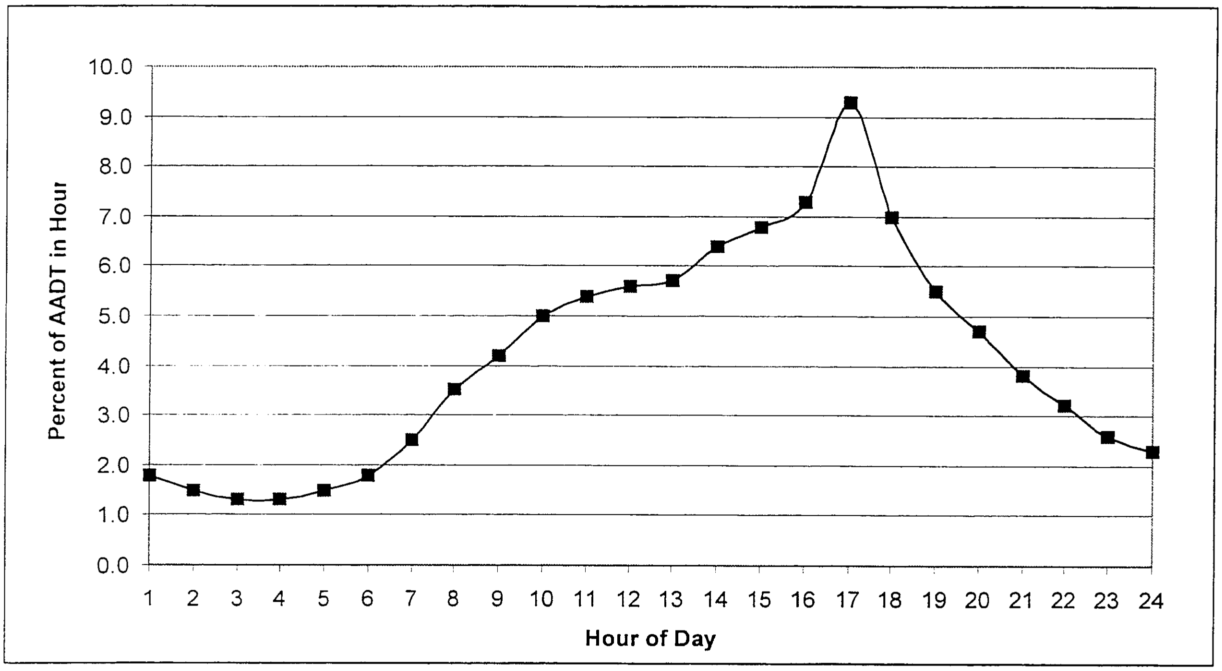

Figure 5. Hourly Distribution of AADT, Sunday [20]

For accurate calculation of delay, hourly traffic counts can be taken on specific sites of importance. Peak hour demand of traffic would be especially important since maximum delay occurs during this hour. Calculation of average queue delay at a work zone is presented in Table 5. Table 5 should be read in conjunction with Figure 6. The ADT used is 21677 vehicles per day, which is calculated for a volume to capacity ratio (v/c) of 1.6. The same distribution as given in Table 4 is used to calculate average queue delay in minutes/vehicle.

The delay value calculated can be used for planning and scheduling work zones on Interstate highways and freeways. With ADT, its growth rate, and the delay estimated for future years, we can estimate the time for maintenance and rehabilitation (M&R) activities on our highways. The Illinois Department of Transportation can thus schedule and plan M&R activities more accurately with less delay. This will be especially useful on high volume highways where excessive delays can occur.

User cost was not factored into this approach, mainly because of the perception of user cost. Different people perceive user cost differently, whereas delay values are realistic and practical. Delay is also a better measure for the existing condition and, thus, evaluation of work zone.

Table 5. Average Queue Delay at a Work Zone

ADT = 21677			v/c = 1.6			
Time (hrs)	Capacity (vph)	Volume (vph)	Cum. Vol. (vph)			Delay (veh-hrs)
12	1260	1235.61	1235.61	X1=	12.19	41.63
13	2520	1387.35	2622.97	Y1=	1501.28	210.00
14	3780	1474.06	4097.03			478.26
15	5040	1582.45	5679.48			1017.48
16	6300	2016.00	7695.48			1524.19
17	7560	1517.42	9212.90			1619.03
18	8820	1192.26	10405.16			1464.58
19	10080	1018.84	11424.00			1125.87
20	11340	823.74	12247.74			624.58
21	12600	693.68	12941.42	X2=	21.60	102.92
22	13860	563.61	13505.03	Y2=	13359.62	
			Average Delay (mins/veh) =			36.47

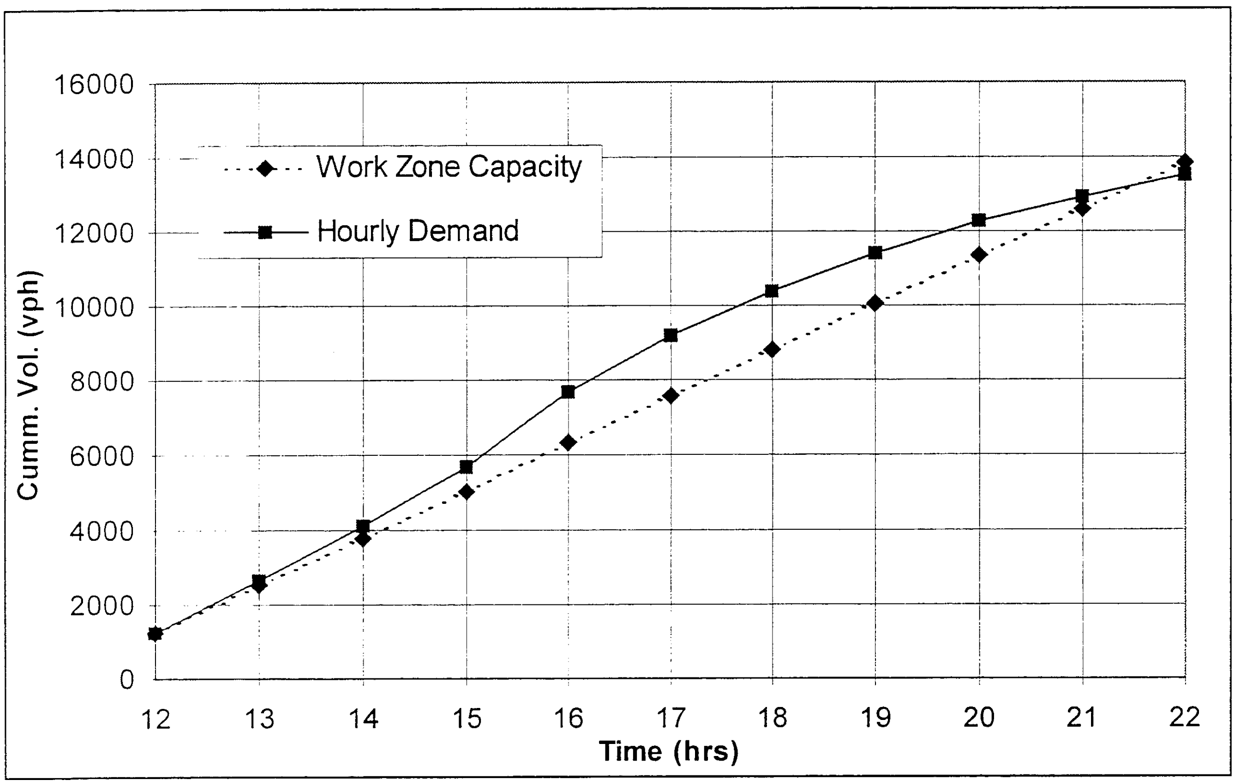

Figure 6. Deterministic Queue Delay for v/c = 1.6

7. CONCLUSION

A methodology is presented to quantify user delay on freeway work zones in relation to ADT. Hardly any data collection is required for this purpose. Data that is already available from the Illinois Department of Transportation can be used for calculating user delay. User delay was found to be more practical than user cost for evaluating work zones. It can be used in scheduling and planning future work zones to minimize user cost and disruption of traffic flow. The adopted approach gives realistic and practical values for delay in work zones.

Various methods and models were studied, but none of them were found adequate to calculate either user cost or delay. They are outdated and cumbersome to use. The PennDOT spreadsheet is not conceptually or theoretically correct, and MicroBENCOST cannot be used for crossovers in the work zone.

Traffic simulation through work zones was not tried, but it remains a viable option. FREESIM [21] is a software package that can be used for simulation of traffic movement on freeways and Interstate highways. Simulation of traffic through work zones can easily be performed using this program.

8. RECOMMENDED RESEARCH

The following are recommended areas for further research:

- Capacity of work zones. No recent studies have been conducted on the capacity of work zones in Illinois. Mainly, capacity studies were conducted in North Carolina and Texas, which may not apply to Illinois. Delay is directly related to capacity of work zones, so it is important to determine the capacity of work zones specifically in Illinois. Furthermore, the effects of lane width, lateral clearance, grade, and length of grade need to be determined.
- A better model is required for accurate estimation of delay in a work zone. Delay estimation using shock waves needs to be evaluated.
- Calculation of user delay for different lengths of work zone is important. Average queue delay calculated is not related to length of work zone.
- User delays for crossovers and partial lane closure need to be compared.

- User delays for different combinations of lane closure need to be determined and compared.
- A model for estimating length of queue and number of vehicles in the queue at a work zone should be developed.
- A model for decisive planning and scheduling of work zone closure based on work zone delay should be developed.

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