

Analysis of Three Estimation Techniques for Road User Cost

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Abstract

The objective of this paper is to produce a detailed review of QuickZone, QUEWZ and Arizona Model with a focus on the road user cost components, the underlying algorithms and the basic assumptions. The calculation processes are discussed. Suggestion for further study is given.

Key Words

QUEWZ, QuickZone, Arizona Model, RUC, Work Zone

1. Introduction

Major contracting and bidding methods in highway construction projects, including the Incentive/Disincentive clauses, the A+B contract (construction cost + time) and the lane rental, typically require the proper evaluation of road user cost based on sound scientific and engineering principles.

1.1 Overview of Estimation Techniques

Both manual and computerized calculation techniques have been developed to quantify the road user cost. A recently developed simulation tool is called QuickZone, which is spreadsheet based traffic impact analysis software. With the work zone configuration information simulated by a network editor, QuickZone estimates the reduced capacity per lane according to 2000 Highway Capacity Manual (HCM). From a deterministic queuing model, the resulting corridor delay and the queue extent are quantified. Finally, an embedded algorithm produces the road user cost by hour at different stages of the project. Another software tool is QUEWZ which models the road user cost caused by lane closure using DOS environment. The required data input includes the directional lane closure configuration, the hourly work activity schedule, approaching traffic volumes and other major variables. Based on the QUEWZ capacity, average speed, queue and the

time delay calculation, the final road user cost is given. Meanwhile, a simplified technique is developed to facilitate the estimation. One example is the Arizona Model, which is a spreadsheet with an embedded daily value calculation formula. Although all the above estimation tools can be used to calculate the road user cost, the underlying concept, assumptions and algorithm are very different.

1.2 Road User Cost Analysis

In general, the road user cost includes many components as shown in Figure 1. When it comes to the calculation of the additional cost associated with a work zone, normally the monetary factors including vehicle operating costs, accidental costs and time costs are considered. For the techniques discussed above, the consideration of road user cost is different, which would be detailed in the calculation.

Different techniques analyze the work zone road user cost in different approaches. QuickZone compares the situations during construction and before construction. In order to analyze the impact of the lane closure, the QUEWZ Model compares the average speed and the queue length changes with and without lane closure. The Arizona Model just compares the traffic flow under construction versus after construction, according to conditions such as the travel speed limit, the work zone length and lane open number (Texas, 1999).

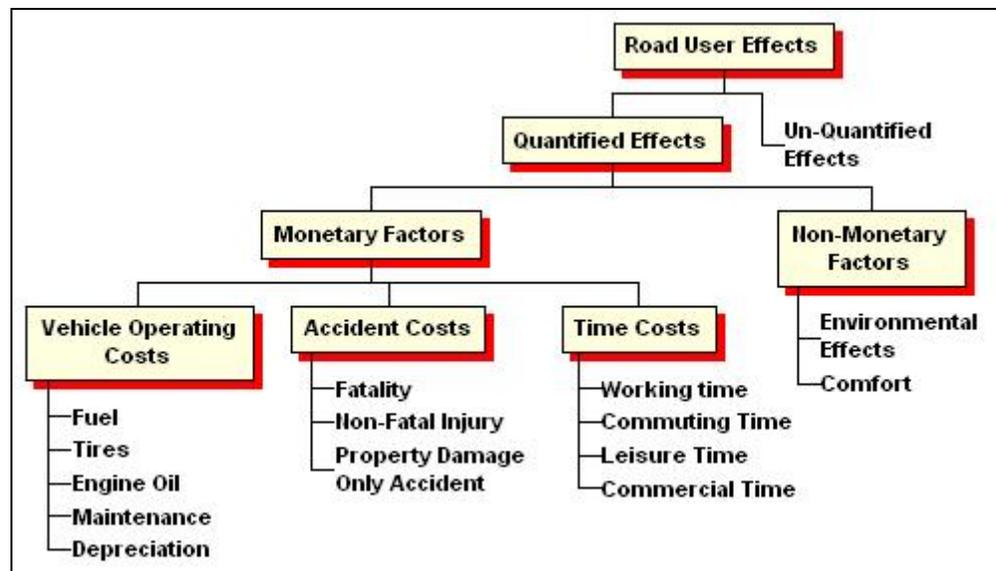


Figure1. Road User Cost Components

2. Underlying Concepts

2.1 QuickZone Model

The road user cost in QuickZone includes five components: travel time cost, vehicle operating cost, inventory cost (for freight), economic cost and miscellaneous costs. The calculation of each component is based on the built-in algorithms as following:

2.1.1 Travel time cost

Travel time cost (C_t) is calculated by the built-in equation as following:

$$C_t = w \times m \times \Delta t \times ADT$$

Where

- w : Individual value of time
- m : Average vehicle occupancy
- Δt : Delay per vehicle
- ADT : Daily volume.

Inside the formula, individual value of time and average vehicle occupancy are fixed. The individual value of time is shown in Table 1. For example, the value of time is \$24.19 /hour for business cars and \$20.68 for trucks in the local travel. The average vehicle occupancy according to the trip purpose is also a fixed number: 1.14 for work and 2.05 for social/ recreational (Florida, 2005). In QuickZone, the maximum number and average number of users are calculated from the built-in deterministic queuing model which quantifies the corridor delay and the queue extent from the capacity decrease due to the construction in the work zone. The capacity is estimated based on the procedures in 2000 HCM. The time delay used in the procedure compares the time difference of during construction and prior to construction. During and after construction comparison is not included. For added capacity projects, it will be inaccurate to just consider the time difference of during construction and after construction.

Table 1: Individual Value of Time

	Hourly Wage		% hourly wage	Value of Time	
	Cars	Trucks		Cars	Trucks
Local Travel					
Personal	\$17.35	-	50%	\$8.68	-
Business	\$24.19	\$20.68	100%	\$24.19	\$20.68
Intercity Travel					
Personal	\$17.35	-	70%	\$12.15	
Business	\$24.19	\$20.68	100%	\$24.19	\$20.68

2.1.2 Vehicle operating cost

The built-in equation for vehicle operating cost (C_v) is as following:

$$C_v = c \times d \times v$$

- c : Vehicle Operating Cost Per Mile
- d : Extra Distance Traveled on Detour
- v : Daily Volume

Cost per mile is fixed in the formula: 17.3 cents for passenger cars and 43.3cents for trucks. From the formula, we can see that vehicle operating cost is only considered in the condition of detour, which would overlook the vehicle operating cost for the vehicles to travel through the work zone.

2.1.3 Inventory cost

The formula for the Inventory Cost (C_i) is:

$$C_i = a \times p \times r \times t \times v$$

a : Average payload

p : Payload value per ton

r : Hourly discount rate

t : Delay per vehicle

v : Daily freight volume.

Inventory Cost is composed of average payload, average payload per ton and the hourly discount rate. The value of average payload is fixed as \$35000, which is based on the information from FHWA. Payload value per Ton varies in each state. For example, in Wyoming, the value is \$ 600 per ton; 30cents per lb. Inventory cost considers the impact of the work zone for the freight.

2.1.4 Economic cost

Economic Cost refers to the impact on the local business of the construction. It is evaluated by the following formula.

$$EconomicCost = DailyBusinessRevenue \times \%VolumeTakingDetour$$

The formula is developed based on a modeling study of effects of bypasses in Texas. It is found that the loss in revenue is over 1% for each 1% of diverted volume. The formula assumes that the local business would lose the same percentage as the percentage of detour. It may over estimate the real situation.

2.1.5 Miscellaneous costs

In QuickZone, there is a special component called miscellaneous cost, which considers the project specific cost which is not in the range of the road user cost. For the incentive and disincentive clause, sometimes the cost other than normal road user cost need to be considered when the existence of the construction brings extra cost other than road user cost, for example, in Virginia, the \$500 daily cost of operating a temporary parking lot while a heavily used commuter lot was under construction was applied to an incentive/disincentive clause.

2.2 QUEWZ Model

QUEWZ has two output options: the lane road user cost option and the lane closure schedule option. In the road user cost calculation, the input data including lane closure configuration, work activity schedule, approaching traffic volume and other variables have been processed through four modules of the QUEWZ model as following. The calculation in each module is based on various assumptions.

2.2.1 Capacity estimation

In the estimation of the work zone capacity, there are three assumptions used in the QUEWZ-98 Model. Firstly, the capacity of the normal situation is assumed to be 2000 vehicle per hour per

lane (vphpl). Secondly, when the lane is closed for the work zone but the work activities is not started yet, the capacity is assumed to be 90% of the normal capacity, 1800 vehicle per hour per lane. The normal capacity value and the 90% percentage are embedded in the software. Since these values are from the field observations conducted in Texas, it may not be applicable for other states.

In the work zone with activities going on, QUEWZ uses the following formula to get the capacity.

$$C = (1600 pcp hpl - I - R) * H \text{ and } H = 100 / [100 + P * (E - 1)]$$

C is per lane capacity (vphpl); I is the adjustment factor for the work activity type and intensity, with the value range (-160, 160) pcp hpl. R is the adjustment factor for the presence of ramps with value range (0, 160) pcp hpl. E is the passenger car equivalent (veh/pc). The base work zone capacity is 1600 pcp hpl, which is built into the model. The user can adjust the value for the work type, intensity and the percent of the heavy vehicles (H). The value H is based on the percentage of heavy vehicles (P) and the passenger car equivalent for heavy vehicles (E). The default value for P and E is 8% and 1.7. From the formula, we can get the capacity value as 1515 vphpl.

2.2.2 Speed –Volume relationship

In the data input of the approaching traffic volume, there are two options: directional hourly volume and AADT. To use the AADT option, QUEWZ uses directional, hourly distribution factor based upon the day of the week and the location of the work zone to change AADT to directional hourly volume. The directional, hourly and daily distribution factors are calculated based on the data from the ATR (Automated Traffic Recorder) stations on Interstate highways in Texas for the month of October in 1985. The data needs to be adjusted in other locations.

Based on the above input data of volume, the average speed in the work zone is calculated by the built-in speed-volume relationship in QUEWZ, which is based on the calculation equation from HEEM (Highway Economic Evaluation Model). When the volume is equal or less than the service D/E breakpoint volume, the relationship between average speed and approaching volume is linear. However, when the volume goes beyond the service D/E breakpoint volume, the speed-volume relationship becomes curvilinear. The speed-volume relationship is embedded in the software. Meanwhile, the speed of the trucks is assumed to be 90% of the car speed in the model.

2.2.3 Queuing and diversion

With the estimation of the work zone capacity and the approaching volume, the queue effect is calculated based on the formula from the HCM 1985 relationships for each time interval. To simplify the calculation, it is assumed that the approaching traffic volume keeps unchanged after the queue is formed and the traffic is only diverted after the queue reaches the excessive value.

Excessive queuing is defined to calculate the volume of the traffic which would be diverted to other alternative roads. It is defined in two ways: the critical length of the queue in miles and the maximum acceptable delay to motorists in minutes. The default critical length of queue is 2.0 miles, which is based on an average ramp spacing of 0.4 miles and an average maximum of 5 ramps in queue. The default maximum acceptable delay is 20 minutes. These numbers could be changed.

QUEWZ assumes that if the queuing has reached the defined excessive value, the driver would divert to other alternatives. In order to estimate the additional road user cost for diverting traffic, QUEWZ made the following assumptions: (1) the length of the alternative route equals the length of the work zone plus the critical length of queue. (2) The travel time for diverting traffic equals the time for a vehicle at the end of the critical length of queue to travel through the queue and the work zone.

2.2.4 Components of the road user cost

For the road user cost calculation, the embedded equation for QUEWZ is as following:

$$THC = CQUE + CDWZ + CDSC + CSPC + CSPQ + OC + OCQ$$

Where

THC: Total hourly cost

CQUE: Cost of delay to queue

CDWZ: Cost of delay while going through the work zone at reduced speed

CDSC: Cost of delay due to speed change cycles

CSPC: Additional operating cost of speed change cycle with a queue

OC: Vehicle running cost

OCQ: Vehicle running cost with a queue

In the operating cost estimation, QUEWZ assumes that if there is no queue, the vehicles don't come to a complete stop (Ellis and Herbsman, 1997). When there is a queue and the vehicles would come to a complete stop, the operating cost would be considered. The travel time cost would include the time delay because of the reduced speed and the speed change cycle for the conditions with and without a queue.

Based on the calculation of the total delay of the time (THC), QUEWZ assumes the time value: \$ 12.64 per vehicle hour for passenger cars (with an average occupancy of 1.3 persons per car) and \$ 23.09 per vehicle hour for trucks. QUEWZ -98 uses user's idle emission rates in grams per hour to scale its default emission rates to the user's emission rates. The calculation is based on MOBILE5a average value.

2.3 The Arizona Model

Arizona Model is an excel spreadsheet used to calculate the daily value of the time delay because of the existence of the work zone. This manual technique is developed from Highway Capacity Manual and AADT predictions. The calculation process is based on the following assumptions.

2.3.1 The calculation formula

Arizona Model uses the following formula expressed by the following formula:

$$DailyValue = AADT \times \Delta t \times w \times f \times d$$

where:

- AADT = the Average Annual Daily Traffic;
- Δt = the additional time required by the motorist to travel through the project while under construction, as compared to when the project is completed;
- w = the average hourly wage of the motorists;
- f = a factor that takes into account impacts to local businesses and safety;
- d = the weighted duration

In this formula, the additional cost only considers two effects: the time delay and the impact on environment. The operating cost and other important components of the road user cost are not included (Arizona, 2007).

2.3.2 Time delay

In the spreadsheet, Δt (time delay) is determined by two variables: the traffic volume per lane and the posted speed. There are two main assumptions: the time-volume relationship and time-velocity relationship.

It is assumed that the time to travel from A to B does not change when ADT/lane is less than 5000. When ADT/lanes is over 5000, t would have linear increase with the slope of $t/10000$, which means that when the ADT/lane is 15000, the time required to travel through would be doubled. In the Arizona calculation spreadsheet, the comparison is between during and after construction. The two periods have different ADT/lane because of the work zone restrictions, which would lead to the difference of the travel time.

For the time required to travel through the work zone, it is simply assumed that time is equal to the quotient of distance and velocity. In the Arizona Model, the distance is inputted as the length of the traffic control condition. The velocity is represented by the posted speed limit, which is different from the average speed in the QUEWZ model. In this condition, the time delay from the queue effect and the speed change cycle to approach the work zone is excluded.

2.3.3 Wage and impact factor

The average hourly wage is calculated by the weighted sum wage of the commercial driver and the noncommercial driver as the following formula:

$$w = c \times \$18.50 + (1 - c) \times \$10.50$$

In the formula, the hourly wage of the commercial driver is \$ 18.50 and the non commercial driver is \$ 10.50. “c” is the percentage of the commercial drivers, which only refers to the truck driver, which excludes other commercial drivers, for example, the cab and the bus.

In the formula, it is suggested to use the 1.2 factor in the following situations:

- (1) There is concentrated business community. Construction would bring revenue loss to the local business.
- (2) There is history of a high number of traffic accidents.
- (3) There is a heavy pedestrian usage in vicinity.

However, the factor of 1.2 is just an assumption without any solid reference.

3. Conclusions

From the above discussion, we can find out that the road user concepts, underlying calculation algorithms and the assumptions for the variables used vary much for different techniques. The three models include different road user cost components. Meanwhile, three different analysis approaches are used. For the calculation of the variables, each model makes its own assumptions. Further study will be needed to determine components to be included in a specific condition as for Florida Department of Transportation, algorithm to be applied and assumptions for capacity, queue and daily value.

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