# Estimating Work Zone Road User Cost for Alternative Contracting Methods in Highway Construction Projects

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**Abstract:** Highway construction often causes an additional road user cost (RUC) to motorists due to traffic flow interruption and congestion in work zones. Consequently, facility owners, such as the Florida Department of Transportation (FDOT), are often interested in using alternative contracting methods such as A+B contracting to expedite construction. Although many of these contracting methods rely on the RUC to determine incentives or disincentives, no standard method for RUC calculation is available to FDOT district engineers. In addition, existing methods are neither practical nor user-friendly for determining incentives or disincentives. This study intends to develop a RUC calculation procedure for the FDOT that focuses on using data that are easily accessible to FDOT district engineers, such as drawings and maintenance of traffic plans. The procedure is developed based on traffic analysis methods published in the *Highway Capacity Manual*, previous studies on user benefit analysis and work zones, and empirical data specific to Florida. Case studies are used to illustrate the procedure and to compare it with two other existing models, the Arizona model and the queue and user cost evaluation of work zone model, through correlation analysis, comparison of calculation assumptions, and data input analysis. This study shows that the suggested procedure produces consistent RUC estimates.

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## Introduction

Highway construction usually causes traffic disruption or safety problems for the traveling public. When motorists must drive through construction work zones, additional cost is often incurred due to the reduction of work zone capacity, decrease of travel speed, increase in travel time, potential increase of accident rates, and negative impact on the natural environment (Ellis et al. 1997). The additional cost, also called the "road user cost" (RUC), is typically referred to as the estimated daily cost to the traveling public resulting from highway construction (Daniels et al. 1999). In addition, the RUC has a sense of relativity; i.e., the cost is incurred due to the loss of benefits that would otherwise be enjoyed by the traveling public if the project were completed sooner (AASHTO 2003).

To provide the benefits of highway improvements to the traveling public as soon as possible, alternative contracting methods such as A+B contracting are used by departments of transportation in various states to expedite construction. Many of these contracting methods rely on the RUC to determine incentives or disincentives (Arditi et al. 1997; Gillespie 1998).

It is important to perform RUC calculations based on sound scientific and engineering principles because of the legal implications related to contracting practices, such as A+B contracts. For example, U.S. contract law states that incentives or disincentives must be based on reasonable estimates of the costs attributable to the delayed completion of a contract. The Federal Highway Administration Technical Advisory T5080.10 requires that incentives or disincentives be "based upon estimates of such items as traffic safety, traffic maintenance, and road user delay costs." In addition, Florida Statute 317 requires a detailed analysis for incentive amounts exceeding $10,000. Therefore, it is critical that the Florida Department of Transportation (FDOT) districts use a method that is based on accepted engineering methods or standards.

Studies of RUC are not new. Many studies have calculated various aspects of RUC at the federal and state levels (Wang and Goodrum 2005). Examples of these are MicroBENCOST (McFarland et al. 1993), the queue and user cost program of work zone (QUEWZ) (TTI 1998), Texas Transportation Institute road use cost tables (Daniels et al. 1999), the West Virginia highway user benefit analysis system (Jaraiedi et al. 2000), QuickZone (Mitretek Systems 2005), the Kentucky user cost program (KyUCP) (Rister and Graves 2002), the Arizona RUC model (ADOT 2002), and the *AASHTO Red Book* (AASHTO 2003). Many of these studies also developed software tools for RUC calculations.

A previous FDOT study (Ellis et al. 1997) recommended that the FDOT should institute a taskforce to address the methodology and cost factors for RUC calculations deemed appropriate by FDOT. This study therefore focuses on issues that the previous study recommended—specifically, simplifying data requirements according to the needs of FDOT district engineers, localizing

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RUC calculations, and developing a more user-friendly tool for FDOT district engineers. Simplifying the data requirements for RUC calculations is significant because many previous methods required extensive data input that either may not be necessary in other situations, as in determining incentives or disincentives, or are difficult for district engineers to obtain. These methods need extensive data input because they are typically developed to perform life-cycle cost analyses on highway construction projects and use the RUC as only one of many performance indicators. Localizing RUC calculations is also critical because many of the models developed in previous studies are based on empirical data or assumptions that may not be appropriate in other situations, e.g., built-in speed and volume patterns.

Thus, there is a need to develop a RUC estimating procedure for FDOT district engineers to determine incentives or disincentives. This paper introduces two surveys to determine the current RUC calculation methods used by FDOT district engineers. The new suggested procedure and a validation of the procedure are then presented.

## Current Practice in FDOT Districts

According to the FDOT construction project administration manual, the daily incentives or disincentives for A+B type contracts may be determined using an approved process, such as the QUEWZ model or MicroBENCost software. In order to determine the RUC calculation methods used by FDOT districts, two surveys were performed.

The first survey was done via electronic mail with district engineers. The intention of the survey was to determine whether the districts were using QUEWZ or MicroBENCost for RUC calculations, and if not, what tools were being used instead. The results of the survey revealed that different analytical tools, such as the Arizona model, were being used. Three districts responded that they did not use existing tools, such as QUEWZ or MicroBENCost, because these tools did not generate satisfactory results or were difficult to use. In addition, one district stated that its experience with using existing RUC evaluation methods revealed problems, including the following:

1. Data used by those methods were not easily accessible to the engineers;
2. A preliminary evaluation of QuickZone was not encouraging due to its complexity;
3. The calculations of certain parameters of existing RUC methods (e.g., travel time) did not seem appropriate;
4. The tools were not user friendly or were very time consuming; and
5. Many of the aforementioned tools were DOS or spreadsheet-based.

Based on the observation that different methods were used by different FDOT districts, a second survey was performed to compare these methods. In the second survey, FDOT district engineers were asked to perform RUC calculations for a project using their standard methods. A summary of the survey results is shown in Table 1.

The calculation results varied significantly among the districts. The differences reflected the understanding of RUC by district engineers, factors included in the calculations, calculation methods used, and the use of calculation results. For example, some districts used "absolute" cost, whereas others used "additional" cost when referring to RUC. Some districts only considered the value of time, whereas others considered additional factors, such as vehicle operating costs and accident costs. Some districts compared the highway condition before and after construction for deriving RUC, whereas others compared the condition during and after construction. The district engineers even used different economic data to calculate the RUC of the same project. The results varied significantly from district to district, and were therefore difficult to compare.

**Table 1.** Comparison of Road Use Cost Calculations in FDOT Districts

| Type | Method | Analysis | Factor |
|---|---|---|---|
| I | Arizona model | During versus after | VOT |
| II | TTI look up table (MicroBENCOST) | Before versus after | VO, VOC, AC |
| III | Customized formula | During only | VOT, VOC |
| IV | Not using any specific method | N/A | N/A |

Note: VOT=value of time; VOC=vehicle operation cost; AC=accident cost; and TP=turnpike.

However, there were some obvious commonalities among the methods used by the districts. First, all the methods were simple. Second, cost factors, such as the impact on the environment or business, were not considered. Third, simple volume and speed relationships were assumed, and queuing and detouring were not considered.

Based on an understanding of existing RUC calculation methods used by FDOT districts, this study intends to develop an RUC calculation procedure that maintains the above-mentioned commonalities, simultaneously improving the consistency of RUC calculations among districts.

## Suggested Calculation Procedure

The RUC is a unique cost to motorists in that there is no actual cost against which the estimated RUC can be validated. Therefore, it is important that the calculation process be based on recognized methods or procedures.

According to Ellis et al. (1997), major cost components in the RUC can be classified into quantifiable and nonquantifiable effects. Quantifiable effects include monetary and nonmonetary factors; monetary factors include the value of time, vehicle operation costs, and accident costs, and nonmonetary factors include environmental impact and comfort. Most existing models, such as the Arizona, QUEWZ, and QuickZone models, consider only monetary factors. Consequently, three components are typically included in RUC calculations, which are expressed as follows:

$$\mathrm{RUC} = \mathrm{VOT} + \mathrm{VOC} + \mathrm{AC} \tag{1}$$

where VOT=value of time; VOC=vehicle operating cost; and AC=accident cost.

In the following, this paper addresses some issues related to the design of the procedure, including general issues, the procedures for estimating VOT, VOC, and AC, and the use of the traffic distribution to estimate the traffic volume during construction.

### *General Issues*

Previous studies, e.g., Daniels et al. (1999), suggested that the RUC can be derived using one of three comparison methods:

1. A phase-by-phase approach;
2. A before-versus-after construction approach; or
3. A during-versus-after construction approach.



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Obviously, the during-versus-after construction approach represents the worst case. To district engineers, the estimated RUC serves as an upper limit for determining incentives or disincentives. Therefore, this study uses the during-versus-after construction approach for all types of RUC calculations because the worst-case scenario represents the largest RUC estimates, and incentives or disincentives are typically a portion of the RUC estimates.

Daniel et al. (1999) suggested classifying highway projects into different categories; following this recommendation, this study classifies projects according to project settings (e.g., urban versus. rural) and types (e.g., urban arterials, two-lane highway, multilane highway, and freeway) similar to the classifications used by the *Highway Capacity Manual* (TRB 2000).

## Value of Time

The determination of the value of time depends upon the opportunity cost of time, the context of travel, the characteristics of the travelers (especially wage rates) and, perhaps, the types of vehicles involved (AASHTO 2003). According to *AASHTO Red Book* (2003), the value of time is given by the following formula:

$$\Delta H_c = M_c O_c \left[ \frac{1}{S_0} - \frac{1}{S_1} \right] \tag{2}$$

where $\Delta H_c$=value of travel time by user class $c$ (\$/vehicle km); $M_c$=unit value of time for user class $c$ (\$/h); $O_c$=occupancy rate of vehicles of user class $c$; and $S_0, S_1$=speed without ($S_0$) and with ($S_1$) the improvement (km/h).

This formula suggests that the value of time is determined by the difference of travel speed during and after construction. However, Daniels et al. (1999) suggested that there are three types of delays that affect the determination of the value of time:

1. Reduced roadway capacity, which slows travel speed and increases travel time;
2. Delay in the opening of a new or improved facility, which prevents users from gaining travel time benefits; and
3. Detours and rerouting, which add to travel time.

The reduction in roadway capacity can be directly associated with the value of time by using the formula because capacity reduction will result in traffic slow-down and congestion (Ellis et al. 1997; Greenwood et al. 1995). The delay in opening a new or improved facility can be treated as an extended effect of an increased daily value of time. Thus, it can be indirectly reflected using the formula. However, the detouring and rerouting effect cannot be addressed by this particular formula alone.

Existing RUC models such as QuickZone (Mitretek Systems 2005) can perform queuing, detouring, and rerouting analysis, but this and other models require extensive information to develop a network surrounding a subject work zone, and it is often time consuming and difficult for district engineers to obtain all necessary data. For economic analysis, the effect of queuing, detouring, and rerouting is sometimes ignored, e.g., in the Bureau of Public Roads formula (AASHTO 2003). Thus, this study also chooses not to address the effects of queuing, detouring, and rerouting on RUC calculations.

$M_c$, the unit value of time for class c, is often estimated using historical data. Typically, two classes are used to consider $M_c$: passenger cars and trucks, e.g., the Arizona model or the QUEWZ model.

Gan et al. (2005) developed a software tool to estimate $O_c$, the occupancy rate of vehicles for user class c. Based on the average occupancy rates in Florida in the last decades, a linear regression model was developed (Wang 2007) to project the average occupancy rate for Florida in 2007, which is 1.41.

The speed calculations in various settings, e.g., urban arterials and multiple lane highways, can be performed using procedures published in the *Highway Capacity Manual* (TRB 2000).

## Traffic Distribution

In Eq. (2), $\Delta H_c$ represents the value of time per vehicle. In order to derive the value of time for all vehicles passing through a work zone, it is necessary to estimate the average daily volume of vehicles for the time period during which the RUC is analyzed. Therefore, an average hourly traffic distribution per day needs to be developed.

Normally, the traffic volume data available to FDOT district engineers are in the format of annual average daily traffic (AADT). In this study, the average hourly traffic distribution is computed based on the traffic volume data in the database of Florida Traffic Information, which records hourly traffic volume data using two types of site monitors set up in the Florida highway system: telemetered and portable sites. Telemetered sites keep track of hourly directional traffic volume at a location for an entire year, and portable sites record hourly traffic volume for one or two days at a particular location.

In order to get an average hourly traffic distribution, 210 telemetered sites, with 30 different locations for each facility type, were randomly selected from the database. For each facility type, over 20,000 24-h traffic counts were retrieved from the database and analyzed. The average hourly traffic volume per day is estimated as the mean of hourly traffic counts from the sample (Wang 2007). Examples of the results are shown in Fig. 1. The hourly traffic pattern shown in Fig. 1 reflects the average traffic volume of both directions, because AADT is bidirectional.

## Vehicle Operating Cost

Ellis et al. (1997) summarized the typical components of the VOC:

1. Fuel consumption;
2. Tire wear;
3. Oil consumption;
4. Maintenance parts and labor; and
5. Depreciation and interest.

Depending on the availability of data, different calculations take different factors into consideration. This study as yet only considers fuel consumption. The *AASHTO Red Book* (AASHTO 2003) formulates the change of fuel costs either as a function of speed or as a function of delay. This study uses the former

$$\Delta C(S)_{\text{fuel}} = (\text{gal}_{c,\text{speed }1} - \text{gal}_{c,\text{speed }2}) P_c L \tag{3}$$

where $\Delta C(S)_{\text{fuel}}$=change in fuel cost as a function of speed for vehicle class $c$ (\$); $\text{gal}_{c,\text{speed1}}$=liters per kilometer for vehicle class $c$, preimprovement speed; $\text{gal}_{c,\text{speed2}}$=liters per kilometer for vehicle class $c$, postimprovement speed; $P_c$=fuel price per liter for vehicle class $c$ (\$); and $L$=length of the work zone under study.

Based on the average travel speed during and after construction, $\text{gal}_{c,\text{speed1}}$ and $\text{gal}_{c,\text{speed2}}$ can be determined using tables such as Table 2. The average travel speed is calculated based on procedures in the *Highway Capacity Manual*. The Florida average fuel cost can be obtained from the AAA website (http://www.fuelgaugereport.com). The default fuel cost was \$0.74 per liter for the year 2007.



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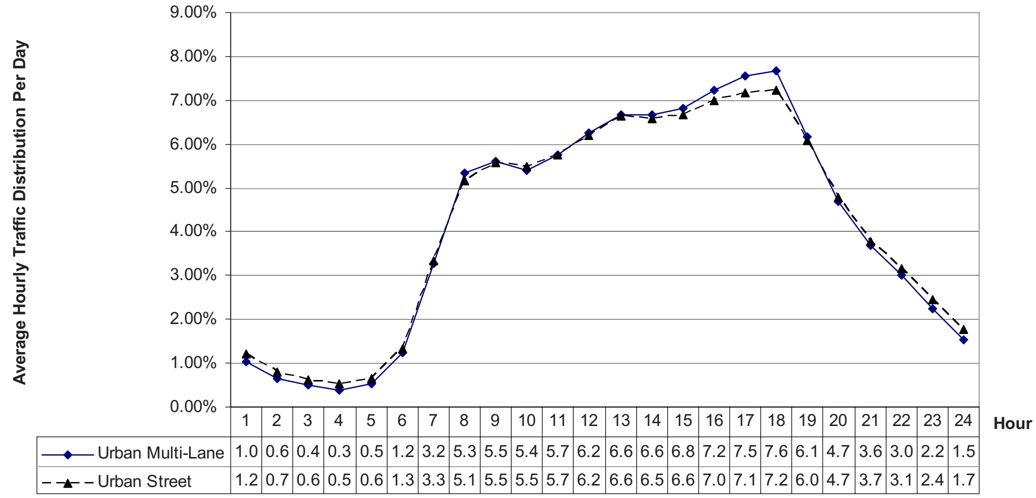


**Fig. 1.** Sample of traffic distribution patterns by facility types

### *Accident Cost*

Daniels et al. (1999) proposed the following formula for calculating accident cost:

$$\mathrm{AC} = \mathrm{FA} + \mathrm{NFA} + (\mathrm{PDO})x \tag{4}$$

where FA=fatal accidents; NFA=nonfatal injury accidents; PDO=property damage only accidents; and $x$=adjustment factor for unreported PDO accidents.

However, the challenge is that not only do few studies discuss the accident cost in work zones, but often existing crash-related data do not support the analysis of accident cost related to work zones. Thus, this study developed the following customized formula for determining the accident cost in work zones:

$$A_{\mathrm{wz}} = \frac{AR_{\mathrm{wa}}\mathrm{AADT}L}{1{,}000{,}000} \times C \tag{5}$$

where $A_{\mathrm{wz}}$=additional accident cost in a work zone; $A$=crash rate, per million vehicle miles; $R_{\mathrm{wz}}$=proportional change of the accident rate in a work zone; $L$=length of the work zone; and $C$=average crash dollar value.

A wide range of $R_{\mathrm{wz}}$ estimates exists. For example, Graham et al. (1977) reported on preconstruction and during-construction crashes according to 79 long-term construction projects. They indicated an average increase of 7.5% in crashes in the presence of work zones during construction. Khattak et al. (1999) reported that for freeway construction, the crash rate of the during-construction period was 21.5% higher than the rate of the preconstruction period. Huebschman and Gracia (2003) found that the increase in crash rate during construction was 27.5% based on 17 interstate projects.

Due to this variety of findings and the difficulty in deriving the increase in accident rates in Florida, a range of 7.5–27.5% is assumed in this study according to the previous studies. To calculate $A$ and $C$, tables have been developed based on crash reports collected from the safety office of FDOT. There are two types of data, crash rates and average crash dollar values (see Table 3), which are categorized according to facility type and district. $L$ can be obtained from project drawings. The crash rate represents the number of crashes per million vehicle miles traveled. The average crash dollar value is the average dollar amount per crash.

**Table 2.** Example of Fuel Consumption [L/km (gal/mi)] for Autos and Trucks by Average Speed

| Speed [km/h (mi/h)] | Autos | Trucks |
|---|---|---|
| 32 (20) | 0.127 (0.054) | 0.522 (0.222) |
| 40 (25) | 0.118 (0.050) | 0.479 (0.204) |
| 48 (30) | 0.110 (0.047) | 0.449 (0.191) |

Note: Source: *AASHTO User Benefit Analysis for Highways* (2003).

## Case Studies

Seven real projects in Miami were studied in order to examine the application of the new procedure to highway construction projects. The project data used for RUC calculations are shown in

**Table 3.** Sample of Crash Rates and Average Crash Cost

| | | District 1 | |
|---|---|---|---|
| Category | Facility type | Rate | Value |
| Freeway | Interstate urban | 0.424 | 116,396 |
| | Toll road urban | 0.000 | 0 |
| | Urban other limited access | 0.306 | 126,120 |
| Two lane | Urban two to three lanes, two way, undivided | 3.188 | 45,696 |
| | Suburban two to three lanes, two way, undivided | 0.946 | 136,389 |
| Multilane | Suburban four to five lanes, two way, divided raised | 1.427 | 101,596 |
| | Suburban four to five lanes, two way, divided, paved | 0.996 | 133,559 |



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**Table 4.** RUC Calculations Using New Procedure

| Variables | Examples 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| AADT | 15,385 | 19,297 | 52,145 | 30,951 | 42,367 | 40,498 | 9,787 |
| Vehicles during construction | 6,287 | 19,297 | 6,155 | 12,753 | 42,367 | 40,498 | 9,787 |
| FFS(during) [km/h (mi/h)] | 56 (35) | 50 (31) | 56 (35) | 63 (39) | 92 (57) | 92 (57) | 50 (31) |
| FFS(after) [km/h (mi/h)] | 64 (40) | 58 (36) | 64 (40) | 71 (44) | 100 (62) | 100 (62) | 58 (36) |
| Number of lanes (during) | 2 | 1 | 2 | 1 | 1 | 1 | 1 |
| Number of lanes (after) | 3 | 2 | 3 | 3 | 2 | 3 | 2 |
| Truck (%) | 7 | 6 | 9 | 8 | 17 | 4 | 13 |
| AWCD ($/h) | 17.11 | 17.11 | 17.11 | 17.11 | 17.11 | 17.11 | 17.11 |
| AWTD ($/h) | 35.84 | 35.84 | 35.84 | 35.84 | 35.84 | 35.84 | 35.84 |
| Length [km (mi)] | 3.222 (2.002) | 1.693 (1.052) | 2.469 (1.534) | 3.714 (2.308) | 6.320 (3.927) | 2.652 (1.648) | 3.037 (1.887) |
| Speed (during) [km/h (mi/h)] | 51 (32) | 40 (25) | 50 (31) | 55 (34) | 76 (47) | 56 (35) | 42 (26) |
| Speed (after) [km/h (mi/h)] | 60 (37) | 50 (31) | 56 (35) | 64 (40) | 100 (62) | 74 (46) | 53 (33) |
| Additional time (h) | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 |
| VOT ($) | 1,255.77 | 4,329.46 | 1,054.20 | 3,167.41 | 24,884.08 | 11,686.06 | 3,710.74 |
| Fuel cost [$/liter ($/gal)] | 0.74 (2.79) | 0.74 (2.79) | 0.74 (2.79) | 0.74 (2.79) | 0.74 (2.79) | 0.74 (2.79) | 0.74 (2.79) |
| VOC ($) | 124.01 | 242.34 | 102.20 | 234.88 | 1,236.58 | 380.65 | 281.99 |
| Accident rate (#/MVM) | 4.655 | 17.621 | 4.655 | 2.854 | 0.659 | 2.343 | 17.621 |
| Accident cost ($ accident) | 43,152.00 | 24,772.00 | 43,152.00 | 50,137.00 | 187,044.00 | 71,710.00 | 24,772.00 |
| Accident increase (%) | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 |
| AC ($) | 189.63 | 664.61 | 142.24 | 315.87 | 1,538.07 | 841.02 | 604.61 |
| **Total RUC ($)** | **1,569.41** | **5,236.42** | **1,298.64** | **3,718.16** | **27,658.73** | **12,907.73** | **4,597.34** |

Note: AADT=annual average daily traffic; FFS=free flow speed; AWCD=average wage of car drivers; AWTD=average wage of truck drivers; VOT=value of time; VOC=vehicle operation cost; #=number of vehicles; MVM=million vehicle miles; and AC=accident cost.

Table 4. The calculation process is divided into three parts: calculating the average travel speed, calculating the daily traffic volume during construction, and RUC calculations.

The results of speed calculations are shown in Table 5. Data for "Facility Type," "Truck%," and "Work Zone Length" can be obtained from project drawings. The posted speed limit (PSL) after construction is typically labeled in the drawings as well. However, the PSL during construction sometimes needs to be estimated. The free flow speed is calculated based on the PSL and the following simplified formulas (NCHRP 1997):

$$\text{FFS} = \begin{cases} 0.88PSL + 14 & \text{if } PSL > 80 \text{ km/h (50 mi/h)} \\ 0.79PSL + 12 & \text{if } PSL \leqslant 80 \text{ km/h (50 mi/h)} \end{cases} \tag{6}$$

When the PSL during construction is not available, this study assumes an average speed reduction of 8 km/h (5 mi/h) from the after-construction PSL. In addition, users are allowed to make their own adjustment. The calculations of speed both during and after construction are based on the procedures in the *Highway Capacity Manual* (TRB 2000) according to different types of facilities. This paper does not address the details of the procedures.

The second part is the calculation of the average daily traffic volume during construction. As the work zone schedule typically specified in the maintenance of traffic of a project, the average daily traffic volume during construction can be obtained. For example, the work zone schedule may specify that construction can only take place between 10:00 a.m. and 3:30 p.m. (Table 4, Example 1). The hourly traffic distribution is first used to allocate AADT to each hour (Fig. 1). Then, according to the work zone schedule, the hourly traffic volumes during the construction hours are added, e.g., the "Total Volume During Construction"

**Table 5.** RUC Values and Actual Incentives

| Sample project | New procedure RUC | Difference | Arizona RUC | Difference | QUEWZ RUC | Difference | Actual I/D |
|---|---|---|---|---|---|---|---|
| Ex 1 | $1,569.41 | −$230.59 | $4,740.50 | $2,940.50 | $ 115.00 | −$1,685.00 | $1,800.00 |
| Ex 2 | $5,236.42 | −$14,763.58 | $6,170.56 | −$13,829.44 | | | $20,000.00 |
| Ex 3 | $1,298.64 | −$1,101.36 | $19,683.80 | $17,283.80 | $ 241.00 | −$2,159.00 | $2,400.00 |
| Ex 4 | $3,718.16 | −$281.84 | $14,122.55 | $10,122.55 | $ 559.00 | −$3,441.00 | $4,000.00 |
| Ex 5 | $27,658.73 | $2,658.73 | $43,746.38 | $18,746.38 | | | $25,000.00 |
| Ex 6 | $12,907.73 | −$7,092.27 | $19,465.15 | −$534.85 | $16,630.00 | −$3,370.00 | $20,000.00 |
| Ex 7 | $4,597.34 | −$15,402.66 | $543.86 | −$19,456.14 | | | $20,000.00 |



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for "Example 1" is 6,287 (Table 4, Example 1), which is the sum of the hourly volume between 10:00 a.m. and 3:30 p.m. That total volume is then used to estimate the RUC for all travelers driving through the work zones during construction.

Given the figures for average travel speed and daily traffic volume during construction, the cost of time delay, the vehicle operating cost, and the accident cost can be calculated according to the methods discussed previously. In the time delay calculation, the average hourly wages for passenger car and truck drivers are set to \$17.11 and \$35.84, respectively, as default Florida values in 2007. The time delay is calculated as the product of the daily traffic volume during construction, the average wage, and the additional travel time. In the operating cost module, the fuel consumption in liters per kilometer is determined using a table, e.g., Table 2, according to travel speed. In the accident cost module, the average crash rate and average cost per crash are determined based on crash reports from the safety office of FDOT (e.g., Table 3). The increase in the accident rate due to the existence of work zones is estimated based on a default value of 7.5%. The calculations of the work zone RUC for the seven case studies are presented in Table 4.

## Comparisons

Three types of comparisons were performed to determine the advantages of using the new procedure, including, (1) comparing the results of the case studies with the actual incentives of the same projects; (2) comparing the new procedure with the Arizona and QUEWZ models; and (3) analyzing the required data input of the three models listed in comparison 2.

The comparisons do not consider QuickZone because its RUC estimating process is regarded as too complicated by district engineers for the purpose of this study. In addition, although the FDOT districts have used other customized approaches, those approaches are based on calculating an absolute RUC value, which cannot be compared with the three methods that calculate "relative" RUC values.

Due to time and resource limitations, only seven projects are used to validate the suggested procedure in this study.

### Correlation Analysis

In the correlation analysis, the results derived from the new procedure, the Arizona model, and the QUEWZ model were compared with actual incentives. The incentives were assigned to the case projects without using any of the three methods, so there are no exact matches between the results of the three methods and the actual incentives in terms of dollar values. However, a better match in terms of the patterns of the RUC and actual incentives can also indicate a more practical method, closer to what has been practiced. Thus, two measures were used in this study to evaluate the three methods: correlation coefficients derived from correlation analysis, and the difference between the RUC values derived using each of the three methods and the actual incentives (Table 5). If a method can generate results that resemble the pattern of the actual incentives and are more similar in dollar value than the actual incentives, that method is regarded as more accurate.

The QUEWZ model is not applicable to two-lane facilities, so some results are not available using QUEWZ. The correlation coefficient, $\rho_{XY}$, between two arrays of variables, i.e., the RUC calculated using one of the three methods and the actual incentives, is defined as

$$\rho_{XY} = \frac{\mathrm{cov}(X,Y)}{\sigma_X \sigma_Y} = \frac{E((X-\mu_X)(Y-\mu_Y))}{\sigma_X \sigma_Y} \tag{8}$$

where $E$=expected value operator and cov means covariance.

The correlation coefficient calculated for the RUC of the seven projects using the new procedure and the corresponding actual incentives is 0.7159. The new procedure produces values that are similar to the actual incentives in most of the case projects. For the two exceptions, Examples 2 and 7, the district engineer who offered the actual incentive data did not know the details of the incentive given for Example 2. The incentive used in the correlation analysis for that project was an estimate. In addition, the incentive used for Example 7 may be unrealistic based on the AADT of the project and road configuration information. The correlation coefficient would be 0.7975 without Example 2, and 0.9482 without Examples 2 and 7. By comparison, the correlation coefficient is 0.3257 between the results using the Arizona model and the actual incentives. Thus, the initial analysis seems to suggest that the new procedure presents a higher correlation to the actual incentives than the Arizona model. In addition, Table 5 also shows a larger variation between the results of the Arizona model and the actual incentives than between the results of the new procedure and the actual incentives.

The correlation coefficient of the QUEWZ model and the incentives is 0.9965, which means that the results from the QUEWZ model seem to be highly correlated to the actual incentives, but the RUC values derived from the QUEWZ model are much lower than the actual incentives. However, if only the four projects that are calculated by using the QUEWZ model are considered, the new procedure has a high correlation coefficient: 0.9943. In addition, the QUEWZ model generates a larger variation in terms of difference in dollar value for the four projects (see Table 5).

### Comparisons of Major Calculation Assumptions

A comparison of the RUC generated using the three models is presented in Fig. 2, with the following observations:

1. The Arizona model produces higher values than the other two models. This is due to the time–speed relationship built into the Arizona model, which assumes that travel time increases linearly as the AADT per lane increases over 5,000 vehicle per day (vpd) and the travel time is doubled when the AADT reaches 15,000 vpd. Given this assumption, the additional travel time calculated from the Arizona model is much higher than that from the new procedure and the QUEWZ model, resulting in a higher RUC.
2. The RUC calculated from the QUEWZ model shows abrupt changes from example to example. In the QUEWZ model, the RUC of Examples 1 and 4 is extremely low: \$115.00 and \$241.00, respectively. This is because the two projects are urban arterials, whereas the underlying algorithms in the QUEWZ model are developed based on freeway scenarios. The capacity of a typical freeway facility is built into the QUEWZ model, and is much higher than the capacity of typical urban streets.

### Data Input Analysis

The data input of the new procedure has been simplified to include four types:

1. Lane closure configuration: e.g., facility type, number of



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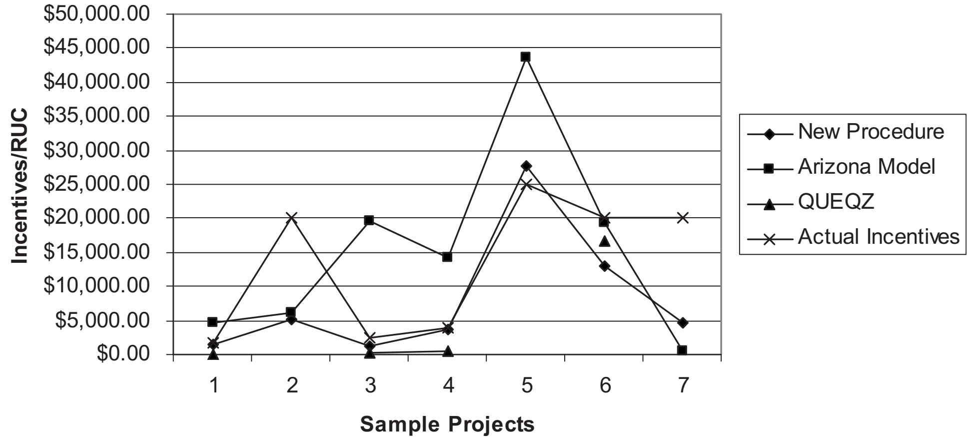


**Fig. 2.** Comparison of road user costs and actual incentives

lanes during and after construction, and length of the work zone;
2. Traffic data: e.g., AADT during and after construction and posted speed limit during and after construction;
3. Work zone schedule data: e.g., starting and ending times of construction per day; and
4. Economic data: e.g., wages of truck drivers and fuel cost.

Information, such as the facility type, number of lanes, length of the work zone, AADT, and during (or after) construction posted speed limit, is provided in project drawings; the work zone schedule data are typically available in the traffic control plan of a project.

The study shows that:
1. In the Arizona model, the input requirements are generally simple.
2. The QUEWZ model requires more data, which are not always easily available to district engineers (some of the data input, such as speed at capacity and volume at capacity, are not easy to obtain).
3. The new model simplifies the data input requirements. Most of the input data are accessible from the drawings and traffic control plans, although some data may not be easy to obtain, such as the signal cycle time and the green light time when analyzing travel time for urban streets. However, in those cases reasonable default values and assumptions may be used to simplify the analysis.

## Conclusions and Future Studies

RUC calculations can be very challenging, as the RUC can be affected by many factors and there is no actual RUC to be used for validation. Therefore, having a sound calculation procedure is critical. Such a procedure should strike a balance between practicality and the desired level of accuracy.

To provide a RUC calculation procedure for estimating incentives or disincentives, this study uses traffic analysis methods published in the *Highway Capacity Manual*, findings from previous studies on user benefit analyses and work zones, and empirical data specific to Florida. Based on seven case studies, the new procedure is compared against two existing models, the Arizona and QUEWZ models, through correlation analysis, comparisons of major calculation assumptions, and input data analysis.

The study shows that the new procedure has the following features:
1. The RUC calculations include vehicle operating cost and accident cost as well as the cost of time;
2. The procedure uses average travel speed calculated from the formulas in the *Highway Capacity Manual*, which are standardized procedures;
3. The RUC calculations use Florida-specific data, such as the average wages of drivers, fuel cost, traffic distribution patterns, occupancy rate, and crash rates; and
4. The new procedure can be applied to different types of facilities, including urban streets, multilane highways, two-lane highways, and freeways.

Thus, although different models have their strengths, the suggested procedure can generate RUC estimates that are more consistent than those generated with the Arizona and QUEWZ models, using reasonable amounts of input data to perform the calculations.

Further research in four areas is recommended to improve the new procedure. The first recommendation is to further study the impact of work zones on highway capacities and formulate the calculation of work zone capacities for urban streets, multilane highways, and two-lane highways. The second recommendation is to further study the change in the accident rate in work zones and to model the influence of the work zones on accident rates to gain a more accurate estimation of accident cost. The third recommendation is to develop software based on the new procedure to make the calculation process easy for end users. The last recommendation is to perform more validations using a larger sample.

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