Final Report

Developing a Realistic-Prototyping Road User Cost Evaluation Tool for FDOT

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16. Abstract

The objective of this project is to develop a realistic-prototyping RUC (Road User Cost) calculation tool that is user-friendly and utilizing limited number of data inputs that are easy to use. The tool can help engineers to estimate RUC on specific construction projects for determining the incentive/disincentive values for contractors. The development of such a tool is necessitated by the need to simplify data requirements for RUC calculations, making the RUC calculations more geographical related, by designing a user-friendly software tool.

In addition to the review of existing literature related, comparisons were performed among FDOT methodologies, and also among the existing tools (such as the Arizona Department of Transportation (ADOT) DOT model, the Queue and User Cost Evaluation of Work Zones (QUEWZ) model and the Quick Zone model. The above models were developed by the ADOT, the Texas Transportation Institute, and the Federal Highway Administration.

The new RUC calculation procedure is developed based on concepts and methods published in recognized sources such as American Association of State Highway Transportation Officials (AASHTO)'s *User Benefit Analysis of Highway and Bus-Transit Improvements*," "Red Book" and the Transportation Research Board's *Highway Capacity Manual*(HCM). Data from seven projects are collected to validate the new procedure by comparing it with the ADOT model and the QUEWZ model.

The validations show that the new procedure can generate consistent results that are comparable with those produced by the Arizona model and the QUEWZ model, while using a small set of localized data inputs.

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EXECUTIVE SUMMARY

Background

Highway construction inherently causes traffic disruptions and potential safety problems to the traveling public. Motorists incur additional costs when driving through typical construction work zones. These additional costs, referred to as the work zone road user cost, are the estimated daily costs to the traveling public resulting from the construction work being performed.

Current literature indicates that DOTs use varying methodologies to estimate RUC. Surveys within the FDOT (Florida Department of Transportation) Districts reveal that methodologies used include absolute road user costs while others use additional costs. Some districts consider the value of travel time (VOT) only, while others consider additional cost factors such as vehicle operating cost (VOC) and accident cost (AC). Some districts compare road conditions before and after construction to derive road user costs, while others compare road conditions during and after construction.

Feedback from these Districts has identified the need to simplify data requirements for RUC calculations, localize RUC calculations, and develop a more user-friendly tool that is currently not available to FDOT. It is very important to simplify data requirements for RUC calculations because many previous studies have focused on the lifecycle cost analysis of highway construction projects while using RUC as only one of many

performance indicators. Such studies sometimes require very detailed data input for analysis, which may not be necessary for other occasions such as the determination of incentives or disincentives. In addition, it is often difficult for district engineers to obtain data for detailed analysis. The localization of RUC calculations is also critical because many methods developed in previous studies were based on empirical data or assumptions. Thus, there is a need to develop an RUC estimation procedure for Department personnel to determine incentive or disincentive values.

Objectives

The objective of this study is to develop a realistic-prototyping RUC evaluation tool that requires limited input of easily accessible data, e.g., information specified by drawings, Specifications and MOT (Maintenance of Traffic) plans, together with some other maintained data such as average wage rates, while allowing for reliable and consistent data to quickly estimate the RUC of a project.

Benefits

The benefits of this study are delivered mainly through the software tool, which was developed with the following key features:

- Simple data input: The new tool requires only a limited number of data inputs (seventeen types of project-specific data and nine types of default data) which can be easily obtained with minor analysis, including facility data, traffic data, work zone schedule data, and economic and project data.

- Comparable calculation results: The new tool can produce RUC calculations for different types of facilities in different project settings (e.g., urban streets versus rural limited access highways), detours, and construction schedules. This makes the tool more flexible than some existing tools,

- User-friendly interfaces: The software considers ease of use as a top priority. For example, it presents 24 checkboxes for users to define a lane closure schedule, thus allowing the software to dynamically update the display of the total RUC whenever a user changes the data input.

- Realistic modeling of calculation scenarios: The new tool uses recognized methods (e.g., the HCM and the AASHTO "Red Book") to develop a base model and adjusts the base model with the user's judgment of specific project conditions. This strategy helps to simplify the requirements for data input, while producing comparable results.

- Easy management of data: By using a windows-based technology, data needed for calculations are contained within the standalone software environment.

Conclusions

In this study, a work zone RUC calculation tool has been developed for FDOT engineers. The tool can help the engineers to estimate RUC on required construction projects for determining incentive/disincentive values. The development of such a tool provides a standard that can be used by FDOT for RUC calculations. Based on a review of existing literature on RUC and calculation methods, as well as comparisons of existing tools such

as the ADOT model, the QUEWZ model, and the Quick Zone model, this study developed a new procedure for RUC calculations based on the concepts and methods discussed in the AASHTO "Red Book", the HCM, and other recognized literature. The new procedure can generate comparable results to those produced by the Arizona model and the QUEWZ model while using localized and limited number of data inputs that are easily accessible to the District users.

Based on the procedure, a software tool is developed using the Microsoft .NET Framework. The windows-based tool facilitates the process of RUC calculations by providing engineers with many user-friendly features, such as simple data input and dynamic tracking of changes in calculations.

Improving accident cost analyses, including more cost factors in vehicle operation costs calculations, fine-tuning the directional volume and work zone capacity estimation, using a better method to estimate the impact of detours and diversions on RUC calculations, and better managing and sharing data used for calculations are some areas that can be considered for further improvements of the software in future.

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1   INTRODUCTION

1.1   Problem Statement

Highway construction inherently causes traffic disruptions or potential safety problems to the traveling public. When motorists must drive through construction work zones, additional costs are often incurred due to capacity reduction, a decrease in travel speed, an increase in travel time, potentially increased accident rates, and a negative impact on the natural environment (Ellis et al. 1997). The additional costs for motorists, referred to collectively as the work zone RUC, are the estimated daily cost to the traveling public resulting from construction work being performed (Daniels, Stockton and Hundley 1999).

Many studies have been performed on various aspects of RUC calculations at the Federal and State level (Wang and Goodrum 2005). A previous FDOT study (Ellis et al. 1997) recommended that the FDOT should have a taskforce to address methodology and cost factors for RUC calculations. Feedback from the Districts has also identified the need to simplify data requirements for RUC calculations, localize RUC calculations, and develop a more user-friendly tool that is currently not available to FDOT. Simplifying data requirements for RUC calculations is very important because many previous studies have focused on lifecycle cost analysis of highway construction projects, while using RUC only as one of many performance indicators. Such studies sometimes require very detailed data input for an analysis, which may not be necessary for other goals such as the determination of incentive or disincentive values. In addition, it is often difficult to obtain data for such a detailed analysis. Localization of RUC calculations is also critical because many of those models developed in previous studies are

based on empirical data or assumptions that may not be appropriate in other situations, e.g., built-in travel time and volume patterns. Besides, many of these assumptions are implicit to users, which may cause users to apply the RUC calculation methods inappropriately. Thus, there is a need to develop a RUC estimating procedure to use in determining incentives or disincentives for contractors.

1.2   Objectives

The objectives of this project are to develop a realistic-prototyping RUC evaluation tool that 1) is more user-friendly (e.g., easy to use and limited data requirements) and built upon more sophisticated computer technology than spreadsheets or DOS-based tools, and 2) requires limited input of easily accessible data, e.g., information specified by drawings, Specifications and MOT (Maintenance of Traffic) plans, together with some other maintained data such as average wage rates, while allowing for reliable and consistent data to quickly estimate the RUC of a project.

1.3   Methodology

The study is composed of three parts: a study of existing RUC evaluation methods used by FDOT districts, the development of a RUC calculation procedure, and the development of a software tool.

In addition to a review of the relevant literature, the study of the existing RUC evaluation methods also includes two surveys. The first survey was performed via email with the Districts. The intention of the survey is to determine whether the Districts are using the

QUEWZ or the MicroBenCost for RUC calculations and, if not, what tools are being used instead. The second survey was performed to compare the methods used by the districts. In the second survey, FDOT Engineers are asked to perform RUC calculations based on a sample project from District Five using their standard methods.

Taking the results of the surveys into consideration, along with other RUC calculation methods in the literature, the RUC calculation procedure in this work is based on theories and methods published in the HCM the AASHTO "Red Book", and other research literature, including speed estimation, and the calculations of value of time (VOT), vehicle operating cost (VOC), and accident cost (AC). Highway capacities are estimated based on procedures in the Highway Performance Monitoring Systems published by the Federal Highway Administration. However, studies on highway capacity reduction due to construction are very limited, mainly involving limited access highways (or freeways).

To achieve the objective of simplifying data input for RUC calculations, the RUC calculation procedure is classified based on facility types, e.g., urban streets or multilane highways, and project settings, e.g., urban or rural. For each type and setting, a typical case is used as a base model for speed calculations. Then two factors are provided so that users can adjust the impact of speed calculations on the RUC results. First, a speed adjustment factor allows users to adjust the speed calculations directly based on their judgment and experience in the context of a particular project. Then a general impact factor is provided for users to adjust the overall RUC results, especially for impacts on factors such as additional accident costs. This strategy

allows users to simplify the data input for calculations and maintains reasonable calculation results.

Project and economic data are collected from public sources such as FDOT, American Automobile Association (AAA), the AASHTO "Red Book", and other published literature.

Sample projects collected from District Six are used for the evaluation of the new procedure. The evaluation includes a comparative study, a correlation analysis, and a data input analysis. The comparative study is performed by comparing the new procedure with two existing models, (the ADOT model and the QUEWZ model). In addition, results generated by the new procedure and the other two models are compared with the actual incentives associated with the sample projects. The correlation analysis determines whether the new procedure can generate a better match with the data pattern of the actual incentives than the other two models. Finally, the data input analysis helps determine whether the new procedure requires fewer and more realistic data inputs.

Based on the new procedure, a software tool is then developed as a stand-alone application using the Microsoft .NET Framework. The tool provides:

- Simple data input

- Comparable calculation results

- User friendly interfaces

- Realistic modeling of calculation scenarios

- Easy data management

1.4 Organization of the Report

There are six chapters and six appendixes in this report, organized as follows,

- Chapter 1 provides a general introduction of the research project, including the research problem, objectives, methodology, and organization of the report.

- Chapter 2 presents a review of previous studies on road user cost calculations. In addition, studies on major cost components, including the value of time (VOT), vehicle operating cost (VOC), and accident cost (AC), are summarized.

- Chapter 3 compares three existing road user cost models: the ADOT model, the QUEWZ model, and the Quick Zone model. It also presents three case studies that were performed to examine the applicability of the models to different types of projects.

- Chapter 4 is devoted to discussion of the development of a new Florida-specific RUC calculation procedure, including the calculation processes, algorithms, and input data requirements.

- Chapter 5 validates the new RUC procedure using seven highway projects. The results generated by the new procedure are compared with the calculations using the ADOT model and the QUEWZ model.

- Chapter 6 presents conclusions and recommendations for future studies.

- Appendix A includes procedures for estimating highway capacities published in the Highway Performance Monitoring Systems by the Federal Highway Administration.

- Appendix B contains procedures for calculating free flow speed.

- Appendix C discusses the calculation of peak hour factors for multilane and limited access highways.

- Appendix D contains sample projects for the comparisons of three models, the QUEWZ, the ADOT model, and the Quick Zone, discussed in Chapter 3.

- Appendix E presents data from the seven projects and their calculation results from the validations discussed in Chapter 5.

2 LITERATURE REVIEW

2.1 Overview of Road User Cost Calculations

The RUC refers to the estimated daily cost to the traveling public resulting from construction work being performed (Daniels, Stockton and Hundley 1999). RUC analyses are not new. Concepts and theories presented in existing literature such as the American Association of State Highway and Transportation Officials (AASHTO) "Red Book" (2003), also known as "User Benefit Analysis of Highway and Bus-Transit Improvements," establish a theoretical foundation for the subject. The AASHTO "Red Book" provides a detailed analysis of cost factors associated with road user benefits/costs. The algorithms refer to three major cost components in RUC calculations: the value of time (VOT), vehicle operating cost (VOC), and accident cost (AC).

According to Ellis et al. (1997), RUC calculations generally include quantifiable and unquantifiable effects (*Figure 2-1*). Typically, most of the RUC calculations only consider quantifiable effects, which may include both monetary and non-monetary factors. An example of a non-monetary factor would be environmental impact. The monetary factor includes three cost components — VOT, VOC, and AC — each of which can be represented by several factors. For example, the VOT may be viewed as the savings from shorter travel times for drivers and passengers, and from quicker delivery of goods; the VOC may include vehicle operating and ownership costs; the AC typically includes costs related to fatalities and damage to properties. Depending on the availability of data and the purpose of RUC calculations, different combinations of these cost factors are included in RUC calculations.
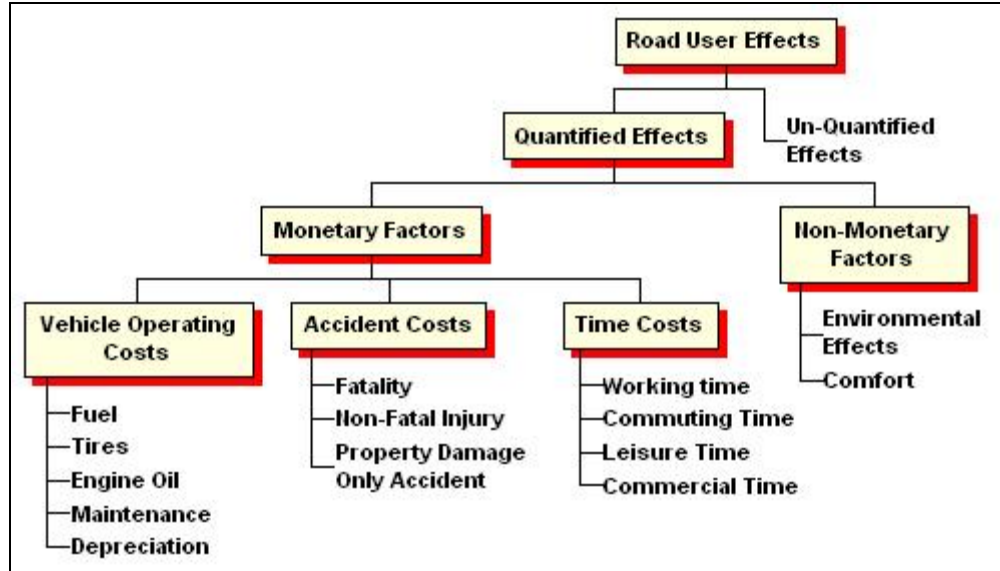
Figure 2-1 Road User Cost Components (Ellis et al. 1997)

2.2   An RUC Calculation Procedure

Daniels et al. (1999) suggested a procedure for estimating road user costs for the Texas DOT, as shown in *Figure 2-2*.

The procedure contains four steps:

1. Determine whether a project meets the criteria for performing an RUC calculation.

2. Select the appropriate analysis techniques for the project type.

3. Calculate travel time costs.

4. Adjust the RUC value appropriately for a particular application.

```
┌─────────────────┐
│ Does the project │
│                  │
│ meet the criteria │
└────────┬────────┘
         │
       ╭─────╮
       │ YES │
       ╰──┬──╯
          │
    ┌─────▼──────────┐
    │ Determine Project │
    │                   │
    │ Type and Analysis │
    └────────┬──────────┘
             │
       ┌─────▼────────────────────┐
       │ Calculate Travel Time Costs │
       │                            │
       │                            │
       └──────────────┬─────────────┘
                      │
                ┌─────▼──────────┐
                │ Adjust RUC as   │
                │                 │
                │ Appropriate     │
                └─────────────────┘
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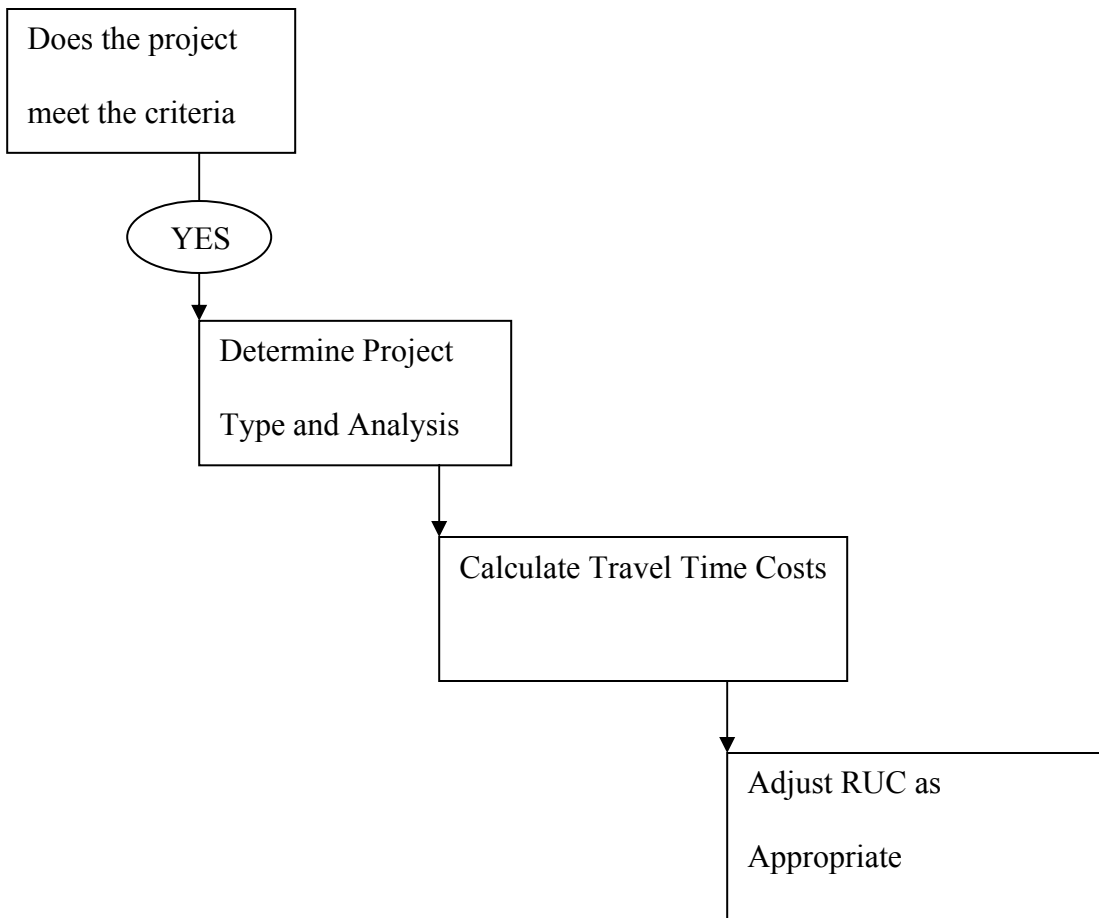
Figure 2-2   Procedures for Estimating Road User Costs (Daniels et al. 1999)

Typically, different state Departments of Transportation have their own rules for determining

which projects should go through an RUC calculation. For example, the following criteria are

proposed for the Texas DOT (Daniels et al., 1999):

- Projects that add capacity (may include grade separations),

- Projects where construction activities are expected to have an economic impact on

  local communities, and

- Rehabilitation projects in very high traffic volume areas.

There are mainly three types of analysis techniques that can be applied to work zone RUC calculations:

1. The phase-by-phase approach – This approach is mostly applicable to projects with severe capacity restrictions during construction, such that completion time of each phase is critical.

2. The before-versus-after approach – This approach compares road user costs associated with a highway facility before and after construction.

3. The during-versus-after approach – This approach compares road user costs associated with a highway facility during and after construction.

Daniel et al. (1999) further suggested dividing highway projects into four categories based on differences in analysis techniques:

1. Category I: high impact urban freeway construction or rehabilitation. The characteristics of such project include severe capacity reduction during construction, critical phase completion time, and interaction with other freeway or arterial projects.

2. Category II: urban arterial roadways, including signalized intersections and diamond interchanges.

3. Category III: Other capacity-adding projects, including highway widening projects and new facility construction.

4. Category IV: Rehabilitation and other non-capacity-adding projects, including paving projects, bridge replacements, and detour routing.

2.3 Existing RUC Analysis Methods

According to a survey of the Departments of Transportation in the United States, Canada, Hong Kong, and the Virgin Islands (Ellis et al. 1997), there are six general procedures that are applied to determine RUC, including (1) formulas, including calculation methods, which are simple combination of mathematical operations; (2) spreadsheets, including those developed either in-house or by consulting companies; (3) software, including the use of sophisticated software packages, usually of a commercial type; (4) AASHTO "Red Book"-based methods; (5) flat rates defined by legislators or national guidelines rather than recalculating for each project; (6) no formal methods.

Many studies of RUC calculations have been done at either the federal or state level (Wang and Goodrum 2005), e.g., MicroBENCOST (McFarland et al. 1993), Queue and User Cost Program of Work Zone (QUEWZ)(TTI 1998), Texas Transportation Institute Road Use Cost Tables (Daniels et al. 1999), West Virginia highway user benefit analysis system (Jaraiedi et al. 2000), QuickZone (Mitretek Systems 2005), Kentucky User Cost Program (KyUCP) (Rister and Graves 2002), Arizona RUC Model (ADOT 2002), and the AASHTO "Red Book" (AASHTO 2003). Many of those studies have also developed software tools for RUC calculations.

2.4 Methods Used by FDOT Districts

The methods currently used by FDOT districts for road user cost calculations can be categorized into four groups.

Group I: The ADOT Model.

The formula is as follows:

$$DailyValue = (AADT) \times (\Delta t) \times (w) \times (f) \times (d) \qquad \text{(2-1)}$$

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 issues such as safety, and

d = the weighted duration.

Work zone road user cost is calculated based on the during-versus-after construction approach.

Group II: Tables Developed by the Texas Transportation Institute

The road user costs of different types of projects in different settings (urban or rural) are derived by using the MicroBenCOST tool and listed in tables according to different truck percentages. The work zone road user costs are defined as the decrease in road user costs from the before-construction condition to the after-construction condition.

Group III: Self-Developed Formula

One formula that is used in three Districts (1, 3 and 7) is:

$$DailyCost = UserCost \times LengthofWorkZone \times ADT \div PostedSpeed \qquad \text{(2-2)}$$

The formula calculates the absolute road user cost associated with a work zone.

In addition, the following formula is used in District 3 to calculate the damage recovery:

$$HourlyUserCost = ADT \times \frac{NumberofLanesClosed}{NumberofTotalLanes} \times UserCost \div 24 \qquad (2\text{-}3)$$

The hourly user cost calculated by the formula refers to the total hourly wage associated with the vehicles impacted by a lane closure.

Another set of formulas is also used:

$$DailyValue = \frac{CEICost}{EstimatedTime} \qquad (2\text{-}4)$$

In calculations, the Incentive or Disincentive amount is calculated based on the CEI cost and 20% of the estimated contract time.

Group IV: No Formal Method

Some districts respond that they do not have any formal method for calculating road user costs.

As shown in **Table D-1** and **Figure D-4** in **Appendix D**, there are many differences with respect to RUC calculations among the districts, including the understanding of RUC, factors considered in the calculations, the calculation methods, and the use of calculation results. For example, some districts use absolute road user cost while others use additional cost. Some districts consider the value of time (VOT) only, while others consider additional factors such as vehicle operating cost (VOC) and accident cost (AC). Some districts compare road conditions before and after construction for deriving road user costs while others compare

road conditions during and after construction. There are even significant differences in the economic data used by the districts on the same project. Consequently, the results are quite different from district to district and are difficult to compare (***Figure D-4*** in ***Appendix D***).

However, there are some major commonalities among the various methods used by the districts. Firstly, the existing methods are simple. Secondly, cost factors such as the impact on the environment and on businesses are not considered. Thirdly, simple volume and speed models are assumed and queuing and detouring are usually not considered in detail.

2.5   Calculation of RUC Components

2.5.1   Value of Time

The value of time is the benefit that travelers gain from shorter travel time. Daniel et al. (1999) listed three types of time delay that are associated with the value of time:

- Detours and rerouting that add to travel time,

- Reduced roadway capacity, which reduces travel speed and increases travel time, and

- Delays in the opening of a new or improved facility that prevent users from gaining the benefits of shorter travel time.

Ellis et al. (1997) also concluded that the two main effects of work zone construction are the reduction in the operating speed and the reduction in the road capacity that will result in formation of queues. An example of these effects is when vehicles are forced to decelerate in advance of a work zone and keep stationary for some intervals while moving through the

queue. After reaching the front of the queue, the vehicles accelerate up to the speed at which they can travel through the work zone (Greenwood, Bennet & Rahman, 1995).

To account for the impact of time delays, the VOT needs to be evaluated. Normally the value of time depends upon the context of travel, the characteristics of travelers (especially the wage rates), and perhaps, the vehicle involved (AASHTO, 2003). According to the Red Book, the VOT is given by the following formula:

$$\Delta H_c = 100 M_c O_c \left[\frac{1}{S_0} - \frac{1}{S_1} \right] \tag{2-5}$$

where:

ΔH_c = the value of travel time savings enjoyed by user class c (in cents per vehicle mile),

M_c = the unit value of time for user class c (in dollars per hour),

O_c = the occupancy rate of vehicles of user class c, and

S_0, S_1 = the speeds without (S_0) and with (S_1) the improvement (in miles per hour).

2.5.2   Vehicle Operating Cost (VOC)

Ellis et al. (1997) noted the following components in the calculation of VOC:

- Fuel consumption,

- Tire wear,

- Oil consumption,

- Maintenance parts and labor, and

- Depreciation and Interest.

Although it is ideal to consider all types of operating and ownership costs when performing VOC analyses, the challenge is that data are not always available.

The AASHTO Red Book (2003) provides two procedures for calculating fuel consumption costs, i.e., as a function of speed or delay. The relationship between speed and fuel consumption is portrayed for both automobiles and trucks. Fuel costs are calculated as follows:

$$\Delta C(S)_{fuel} = (gal_{c,speed0} - gal_{c,speed1}) \times P_c \times L \qquad (2\text{-}6)$$

where:

$\Delta C(S)_{fuel}$ = Change in fuel costs as a function of speed for vehicle class c,

$gal_{c,speed0}$ = Gallons per mile for vehicle class c, during construction speed,

$gal_{c,speed1}$ = Gallons per mile for vehicle class c, after construction speed,

P_c = Fuel price per gallon for vehicle class c, and

L = The length of the work zone.

Fuel costs can also be calculated as a function of time delay:

$$\Delta C(D)_{fuel} = gal_{c,min} * \Delta T * P_c \qquad (2\text{-}7)$$

where:

$\Delta C(D)_{fuel}$ = Change in fuel costs as a function of speed for vehicle class c (cents),

$gal_{c,min}$ = Gallon per minute for vehicle class c,

ΔT = Time delay (minutes), and

P_c = Fuel price per gallon for vehicle class c (cents).

2.5.3   Accident Cost

Daniel et al. (1999) suggested including three different components in AC calculations, as shown in the following formula:

$$AC = FA + NFA + (PDO)x \qquad (2\text{-}8)$$

where,

FA = fatal accidents,

NFA = non-fatal injury accidents,

PDO = property damage-only accidents, and

x = adjustment factor for unreported PDO accidents.

Besides collecting data for the aforementioned components to be considered in AC calculations, another challenge is to estimate the increase in accident rates due to the presence of work zones. A wide range of estimates exist. For example, Graham et al. (1977) reported the pre-construction and during-construction crashes of 79 long-term construction projects. They indicated an average 7.5% increase 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 pre-construction period. Huebschman and Gracia (2003) found that the increase in crash rate during construction was 27.5%, based on 17 interstate projects.

In addition, the AASHTO Red Book (2003) provides a method for estimating the accident change, which is expressed as a function of the volume-capacity ratio, based on previous studies of urban freeway situations:

$$A_R = \frac{3.0234\left(\dfrac{V_1}{C_1}\right) - 1.11978\left(\dfrac{V_1}{C_1}\right)^2}{3.0234\left(\dfrac{V_0}{C_0}\right) - 1.11978\left(\dfrac{V_0}{C_0}\right)^2} - 1 \tag{2-9}$$

where,

A_R = Proportional change in accident rate,

$\left(\dfrac{V_0}{C_0}\right)$ = Volume-capacity ratio for urban freeway segment without improvement, and

$\left(\dfrac{V_1}{C_1}\right)$ = Volume-capacity ratio for urban freeway segment with improvement.

3 EVALUATION OF EXISTING TOOLS

This chapter reviews three existing RUC calculation methods: the Quick Zone, the QUEWZ, and the ADOTArizona DOT model.

3.1 The Quick Zone Model

The RUC calculation in the Quick Zone includes five components: travel time cost, vehicle operating cost, inventory cost (for freight), economic cost, and miscellaneous cost.

3.1.1 Travel Time Cost

Travel time cost (C_t) is calculated by the equation as follows:

$$C_t = w \times m \times \Delta t \times ADT \qquad (3\text{-}1)$$

where,

w = The unit value of time,

m = Average vehicle occupancy,

Δt = Delay per vehicle, and

ADT = Average Daily Traffic.

The value of w is shown in Table 3-1. For example, w is $24.19 per hour for business cars and $20.68 for trucks in local travel. The average vehicle occupancy may be obtained from the trip purpose from previous studies, e.g., 1.14 for business trips (FDOT 2005). In the Quick Zone model, the maximum average number of vehicles is calculated by a built-in deterministic queuing model, which quantifies corridor delay and queue length by considering

capacity reduction due to construction. The capacity is estimated based on the procedures in HCM 2000. The time delay is derived by using the procedure to compare the difference in travel time of the periods during and before construction. Comparisons during and after construction are not supported by the model.

Table 3-1 The Unit 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

3.1.2 Vehicle Operating Cost

The built-in equation for evaluating vehicle operating costs (C_v) is,

$$C_v = c \times d \times v \qquad (3\text{-}2)$$

Where,

c = Vehicle Operating Cost per mile,

d = Extra distance traveled on detour, and

v = Daily volume.

3.1.3 Inventory Cost

The formula for the Inventory Cost (C_i) is:

$$C_i = a \times p \times r \times t \times v \qquad \text{(3-3)}$$

Where,

a = Average payload,

p = Payload value per ton,

r = Hourly discount rate,

t = Delay per vehicle, and

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 $35,000 per ton, which is based on information from FHWA. Payload value per ton varies in each state. For example, in Wyoming, the value is $600 per ton or 30 cents per lb.

3.1.4 Economic Cost

Economic cost refers to the impact of construction on local businesses. It is evaluated by using the following formula.

$$EconomicCost = DailyIncome \times \%VolumeTakingDetour \qquad \text{(3-4)}$$

The formula is developed from a study of bypasses in Texas, which found that the loss in revenue is over 1% for each 1% of diverted volume. The formula assumes that local

businesses in the vicinity of a work zone will lose the same percentage of revenues as the result of detours.

3.1.5 Miscellaneous costs

In Quick Zone, there is a special component called miscellaneous cost, which considers project specific costs and may not be typically considered as part of road user costs. For the calculation of incentives and disincentives values, sometimes costs other than normal road user costs need to be considered. For example, in Virginia, one project includes a $500 daily cost for operating a temporary parking lot while a heavily used commuter lot was under construction.

3.2   The QUEWZ Model

Designed for analyzing limited access highway (or freeway) projects, the QUEWZ has two output options: the 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, are processed by four modules.

3.2.1 Capacity Estimation

In the estimation of the work zone capacity, there are two assumptions used by the QUEWZ-98 model. Firstly, the capacity of the normal situation is assumed to be 2000 vehicles per hour per lane (vphpl). Secondly, when the lane is closed for the work zone but the work activities have not yet started, the capacity is assumed to be 90% of the normal capacity, or 1800 vehicles per hour per lane. The assumptions are built into the QUEWZ software.

In a work zone with construction activities, QUEWZ uses the following formula to derive capacity.

$$C = (1600\,pcphpl - I - R) * H \qquad\qquad (3\text{-}5)$$

where,

C = per lane capacity (vphpl),

I = the adjustment factor for work type and intensity, in the range (-160, 160) pcphpl (passenger car per hour per lane),

R = the adjustment factor for the presence of ramps, in the range (0, 160) pcphpl,

E = the passenger car equivalent (veh/pc), and

$H = 100/[100 + P * (E - 1)]$.

A base work zone capacity, 1600 pcphpl, is built into the model. A user can adjust the value by adjusting the work type, the intensity, and the percentage of heavy vehicles (H). The value H is based on the actual percentage of heavy vehicles (P) and the passenger car equivalent for heavy vehicles (E). The default value for P and E are 8% and 1.7, respectively.

3.2.2   Speed –Volume Relationship

The data input for approaching traffic volume has two options: directional hourly volume and AADT (Annual Average Daily Traffic). If using the AADT option, the QUEWZ uses a directional, hourly distribution factor to convert AADT into directional hourly volumes. The directional, hourly distribution factors are calculated based on data collected from the ATR

(Automated Traffic Recorder) stations on the interstate highways in Texas for the month of October in 1985.
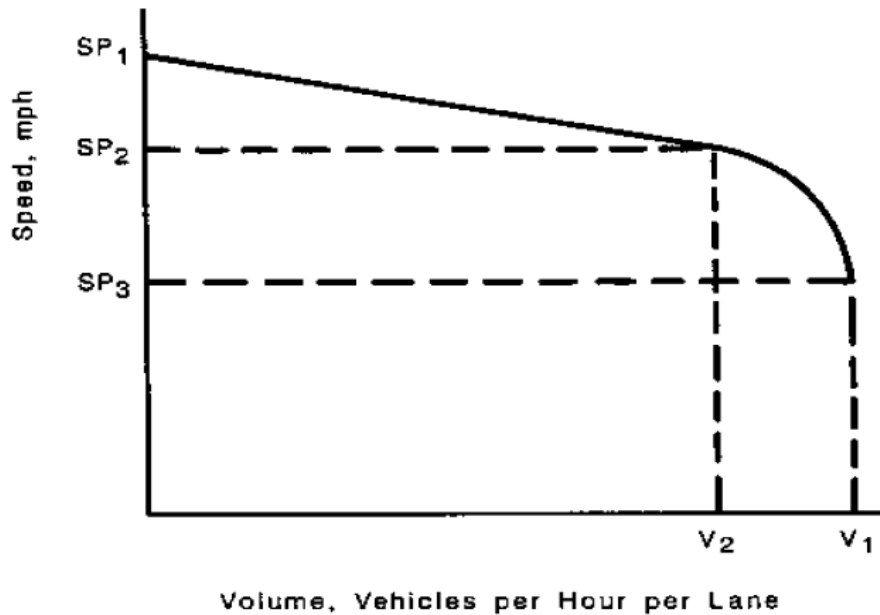
Figure 3-1 Speed -Volume Relationship in QUEWZ (Copeland, 1998)

In the QUEWZ model, the average speed in a work zone is calculated by using a built-in speed-volume relationship, which is developed based on an equation in HEEM (Highway Economic Evaluation Model). As shown in *Figure 3-1*, when the volume is equal or less than the service D/E breakpoint volume, the relationship between average speed and approaching volume is linear (Copeland, 1998). However, when the volume goes beyond the service D/E breakpoint volume, the speed-volume relationship becomes curvilinear. This speed-volume relationship is built into the QUEWZ software. The speed of trucks is assumed to be 90% of the speed of cars in the model.

3.2.3 Queuing and Diversion

The queue effect is calculated from the formula in the HCM 2000. To simplify the calculations, it is assumed that the approaching traffic volume remains unchanged after a queue is formed and that traffic is diverted only after the queue reaches an excessive value.

Excessive queuing is defined to be the volume of traffic that is diverted to other alternative roads. It is defined in two ways: the critical length of a 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 five ramps in the queue. The default maximum acceptable delay is 20 minutes. These numbers can be changed by users.

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

3.2.4 Components of RUC

The QUEWZ uses the following equation for the RUC calculations:

$$THC = CQUE + CDWZ + CDSC + CSPC + CSPQ + OC + OCQ \qquad (3\text{-}6)$$

where,

THC = Total Hourly Cost,

CQUE = Cost of delay due to queuing,

CDWZ = Cost of delay while going through work zones 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, and

OCQ = Vehicle running cost with a queue.

3.3　　The ADOT Arizona DOT Model

The ADOT Arizona DOT model is an Excel spreadsheet-based tool for calculating the daily value of time delay due to the existence of work zones.

3.3.1　The Calculation Formula

The ADOT Arizona DOT model uses the following formula:

$$DailyValue = AADT \times \Delta t \times w \times f \times d \tag{3-7}$$

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 the impacts to issues such as detours and safety, and

d = the weighted duration.

In this formula, the analysis of road user costs only considers the time delay and the impact on the environment. Vehicle operation cost (VOC) and accident cost (AC) are not included (ADOT 2002). The model uses an impact factor to account for the impact of highway construction on detours and safety.

3.3.2   Time delay

In the model, Δt (time delay) is determined by two variables: the traffic volume per lane and the posted speed. There are two main assumptions associated with the determination of time delay: the time-volume relationship and time-velocity relationship.
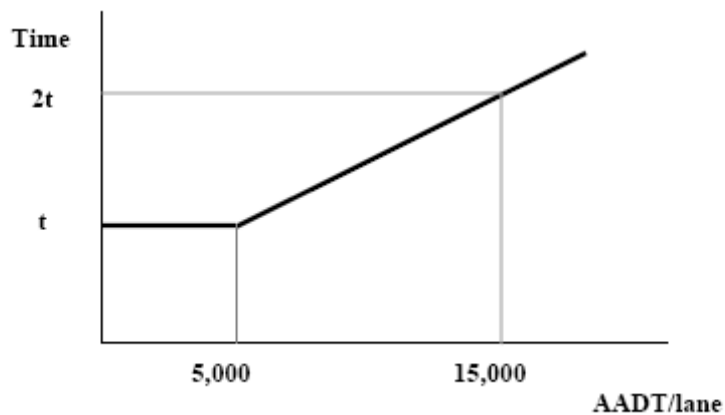
Figure 3-2 Volume-Time Relationship in the ADOT (Arizona DOT) Model (ADOT 2000)

As shown in *Figure 3-2*, it is assumed that the time to travel from A to B does not change when the ADT per lane is less than 5,000. When the ADT per lane is over 5,000, t increases linearly with a slope of t/10,000. Thus, when the ADT per lane is 15,000, the time required to

travel through is doubled. The ADOT (Arizona DOT) model compares the user costs during and after construction to derive the RUC due to construction.

The ADOT (Arizona DOT) model simply assumes that the time required to travel through the work zone is equal to the quotient of distance and velocity. In the model, the distance is supplied as the length of a work zone under traffic control. The velocity is represented by the posted speed limit, which is different from the average speed in the QUEWZ model.

3.3.3 Wage Calculations and the Impact Factor

The average hourly wage is calculated as the weighted hourly wage of commercial and noncommercial drivers.

$$w = c \times \$18.50 + (1-c) \times \$10.50 \tag{3-8}$$

where c is the percentage of commercial drivers, which is often referred to as truck drivers.

In addition, it is suggested to use 1.2 for the impact factor in the following situations, although the number is subjective:

- There is a uncommon concentration of traffic volumes due to the presence of local businesses;
- There is a history of a high number of traffic accidents;
- There is heavy pedestrian traffic in the vicinity.

3.4 Comparisons of the Three Models

In order to have a better understanding of the three models, three sample projects have been collected and analyzed. Basic information on the three projects is presented in Appendix D. The analysis is focused on 1) the data input for each method, and 2) reported limitations of each method.

3.4.1 Data Input Analysis

QUEWZ

The QUEWZ requires four categories of data input:

1. Lane closure configuration,

2. The schedule of work activities,

3. The traffic volume approaching the highway segment under study, and

4. Alternatives to the default values set by QUEWZ.

Data input describing the lane closure configuration includes the number of directional roadways in which lanes are closed; the total number of lanes in each direction; the number of open lanes through the work zone in each direction; the length of the lane closure, and the capacity of the work zone.

The schedule of work activities is defined by the hours when the lane closure begins and ends and the hours when work activity begins and ends. The traffic control plan provides general information about the schedule of construction activities, such as the non-peak hours, but the

detailed information of the start and end time of the activities needs to be obtained from other sources.

The QUEWZ allows the approaching traffic volume to be supplied either as the directional hourly volumes or the AADT of the highway under study. If the AADT is input, it will be transformed into a distribution of hourly volumes based on a default traffic pattern built in the QUEWZ. The built-in traffic pattern is computed by using the October 1985 data from automatic traffic recorder stations on the interstate highways in Texas.

Some variables have default values set by the QUEWZ. Although user alternatives are allowed to replace the default values, when user alternatives are not provided for the variables, the QUEWZ will turn to the default values collected in Texas. These variables include:

- The percentage of heavy vehicles and the cost factor,

- Variables used to define the speed-volume relationship curve, including the free flow speed, LOS D/E breakpoint speed, speed at capacity, LOS D/E breakpoint capacity, and volume at capacity,

- Variables used for the diversion algorithm, including the critical length of a queue and maximum acceptable delay, and

- Variables for the work zone capacity calculation, including the inbound directional capacity and the outbound directional capacity.

During the analysis, it was found that about half of the required input data are not easily available.

Quick Zone

In order to perform an RUC evaluation by using the Quick Zone, the following data are required:

- Nodes and Links – Components of a highway network. Nodes and links represent intersections and highways, respectively.

- Demand – The hourly volume of cars or trucks using a highway facility during a given time period.

- Demand Patterns - Distribution of demand over a 24- hour period.

- Work Zone Plan – Information such as the start and end date of construction activities, highway segments affected by construction, capacity decrease of each affected highway, and days of a week that the construction can take place.

- User and Economic Data - The impact of construction on pedestrians, residents, and travelers.

The Quick Zone takes two steps for RUC analysis. In the first step, users are required to describe the highway network surrounding a work zone, including work zone links, mainline links, and detour links. The network will be defined by the X-Y coordinates of the nodes and the properties of the links, including the number of lanes, capacity, length, free flow speed, direction (inbound or outbound), jam density, type, and position. Network building is a labor-intensive process. Among the properties of each link, the capacity, the jam density, and the free flow speed will involve additional calculations.

In the second step, users are required to provide the hourly, daily, and monthly distribution of traffic volumes. In addition, a very detailed work zone plan must be input, even though this information may not be easily available to the district engineers. Finally, the user and economic costs require information about travel behavior, e.g., the mode shifting change (%), cancelled trips (%), and the miscellaneous costs, which are also difficult to obtain.

ADOT Model

Compared with the QUEWZ and Quick Zone models, the ADOT model simplifies data input. It involves only:

- Lane closure configurations,

- Traffic volumes, and

- State-estimated project durations and contract amount.

The lane closure configurations are described in a simpler way, involving the number of lanes during and after construction, the traffic control during construction, and the posted speed limit during and after construction. Traffic volumes are represented by ADT (Average Daily Traffic) without considering an hourly volume distribution. All these data are available in construction drawings. The state estimated project durations and contract amounts may be subjective values.

3.4.2 Characteristics of the Three Models

QUEWZ

Major characteristics of the QUEWZ include:

- It is designed for analysis of work zones on freeways or limited access highways. For example, the built-in formula for calculating work zone capacity is for freeways.

- It can only be applied to highway facilities with two or more lanes in each direction.

- The default hourly volume distribution is based on field data collected from the interstate highways in Texas.

- The model uses an assumed speed-volume curve. The speed of trucks is assumed to be 90 percent of car speed.

- The software tool associated with the QUEWZ model is DOS-based.

Quick Zone

The Quick Zone is characterized by the following factors:

- It compares conditions during and before construction for RUC calculations. In some cases, other types of comparisons may be more desirable.

- It is very difficult to develop network models with intersections in urban street scenarios.

- Many types of data, such as the hourly volume distribution for each link of a highway network, are difficult to obtain.

The ADOT Model

The major characteristics of the ADOT model include:

- The model only includes the calculation of VOT. The VOT and AC are not taken into consideration.

- The entire AADT is applied in calculations, without considering the fact that part of it may not be affected by construction activities.

- The time delay Δt is calculated based on an assumption that when traffic counts per lane are less than 5000 AADT/lane, the travel time t is constant. When traffic counts per lane are more than 5000 AADT/lane, the time increases in a linear fashion and the acceleration is t/10000 hr-ln/AADT. This model is built-in and fixed.

- The tool associated with the model is spreadsheet-based.

4   THE PROPOSED PROCEDURE AND SOFTWARE

This chapter describes the development of an RUC calculation procedure that requires a limited number of data inputs. The software tool based on the procedure is also introduced. However, details regarding the use of the software are presented in a separate document, "The FDOT RUC Software User Manual."

4.1   Types of Facilities

According to the HCM (Highway Capacity Manual) 2000, the proposed procedure classifies highway facilities into four types to facilitate RUC calculations:

1. Limited Access Highways (Freeways): A limited access highway, sometimes called freeway, is defined as a multilane divided highway with a minimum of two lanes for the exclusive use of the traffic in each direction and full control over access without traffic interruption.

2. Two-lane Highways: A two-lane highway is a highway with a two-lane cross section, one lane for each direction of flow, on which passing maneuvers must be made in the opposing lane.

3. Multilane Highways: A multilane highway refers to a highway with at least two lanes for the exclusive use of traffic in each direction, with no control or partial control of access. It may have periodic interruptions to flow at signalized intersections no closer than 2 miles.

4. Urban Streets: Urban streets refer to urban arterials and collectors, including those in downtown areas. Signalized intersections of urban streets are less than 2 miles apart.

In addition, projects are classified by urban or rural setting. The differences are reflected in many factors such as different AADTs and PHFs (Peak Hour Factors) used in speed calculations.

4.2   Cost Components of RUC Calculations

Three main components are included in RUC calculations. The daily road user cost (RUC) associated with a construction condition is the sum of several components, as follows:

$$RUC = GIF \times (VOT + VOC + AC) \qquad (4\text{-}1)$$

where,

VOT = Value of Time,

VOC = Vehicle Operating Cost,

AC = Accident Cost, and

GIF = General Impact Factor.

The analysis of VOT is related to the time delay caused by the reduced speed of vehicles traveling through a work zone, which is discussed in detail in Section 4.5. The VOC, mainly including additional fuel cost, is discussed in Section 4.7. The calculations of accident costs are discussed in Section 4.8. The GIF reflects the impact of detours, lane closures, and work zones on aspects other than road users, such as limited access to pedestrians. This factor is similar to the impact factor of the ADOT (Arizona DOT) model. A default value of 1 is

typically assigned to GIF. There is no specific data to support the determination of GIF. Usually, the rule-of-thumb in the ADOT model can be followed:

- Uncommon concentration of traffic volumes: adding 20%;

- History of high number of traffic accidents: adding 20%;

- Heavy pedestrian usage or school in vicinity: adding 20%;

4.3 Analysis Techniques

Although there are several analysis techniques that have been proposed by previous studies (Daniels et al. 1999), this study uses a during-versus-after approach because this approach represents the worst case.

4.4 Traffic Distribution

Normally, the traffic data that are available to Districts are in the form of AADT (Annual Average Daily Traffic). However, when the VOT is calculated, hourly traffic volumes are needed to reflect the traffic that is actually affected by construction. Thus, it is necessary to break AADT into hourly traffic volumes. To do so, a series of distribution factors have been developed in this study (*Figure 4-1*). A distribution factor is the average percentage of traffic volume in a particular hour of a 24 hour period. There are seven types of distribution factors to support the calculations of this study.

The distribution factors are computed based on the traffic volume data in the database of Florida Traffic Information 2005 (FTI), which records hourly traffic information 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-hour traffic counts were retrieved from the database and analyzed. The default distribution factors have been calculated as the average percentage of traffic volume in both directions.

4.5 Average Travel Speed

The estimation of average speed for different types of facilities is based on the procedures in the HCM 2000. Due to the complexity of traffic analysis in various highway conditions, the procedures typically require many data inputs. In order to simplify the calculations, default values of some variables are assigned to establish the conditions of a base model. Adjustments can then be made to the base model to reflect project-specific observations by users.

4.5.1 Estimating Average Travel Speed in Urban Street Scenarios

The estimate of average travel speed in urban street scenarios is based on the HCM 2000 procedures:

$$S_A = \frac{3600L}{T_R + d} \qquad\qquad (4\text{-}2)$$

where,

S_A = Average travel speed of vehicles in a highway segment (miles/hr),

L = Segment length (miles),

T_R = Running time on the segment, and

d = Control delay for through movements at the signalized intersection(s).

The running time is the time that vehicles take to travel through a highway segment under free flow conditions. A project may be divided into several segments. The running time in each segment may be calculated using formula 4-1. The total running time of the project is the sum of the running times of the segments. The control delay is estimated by using procedures from the HCM 2000, including,

$$d = d_1(PF) + d_2 + d_3 \qquad (4\text{-}3)$$

$$d_1 = \frac{0.5C\left(1 - \frac{g}{C}\right)^2}{1 - \left[\min(1, x)\frac{g}{C}\right]} \qquad (4\text{-}4)$$

$$d_2 = 900T\left[(X - 1) + \sqrt{(X - 1)^2 + \frac{8kIX}{cT}}\right] \qquad (4\text{-}5)$$

Traffic Distribution Pattern by Facility Type

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Rural Freeway	2%	1%	1%	1%	1%	1%	3%	4%	5%	5%	6%	7%	7%	7%	7%	7%	7%	7%	6%	5%	4%	3%	2%	1%
Rural Two Lane	1%	1%	0%	1%	1%	4%	6%	5%	5%	5%	6%	6%	6%	6%	6%	8%	8%	8%	6%	4%	3%	2%	2%	1%
Rural Multilane	1%	1%	0%	1%	1%	2%	5%	7%	7%	6%	7%	7%	7%	8%	8%	8%	7%	7%	4%	2%	2%	1%	1%	1%
Urban Freeway	2%	1%	1%	1%	1%	1%	1%	2%	3%	5%	6%	7%	8%	8%	7%	7%	7%	7%	7%	6%	5%	4%	3%	2%
Urban Two Lane	1%	1%	0%	0%	0%	1%	3%	5%	5%	5%	6%	6%	7%	7%	7%	7%	8%	8%	7%	5%	4%	3%	2%	1%
Urban Multilane	1%	1%	0%	0%	1%	1%	3%	5%	6%	5%	6%	6%	7%	7%	7%	7%	8%	8%	6%	5%	4%	3%	2%	2%
Urban Street	1%	1%	1%	1%	1%	1%	3%	5%	6%	5%	6%	6%	7%	7%	7%	7%	7%	7%	6%	5%	4%	3%	2%	2%

Figure 4-1 Distribution Factors and Traffic Pattern by Facility Type

where,

d = Control delay (seconds/veh),

d_1 = Uniform delay (seconds/veh);

d_3 = Initial queue delay (seconds/veh), not considered,

PF = Progression adjustment factor, default 1,

X = Volume to capacity (v/c) ratio for the lane group,

C = Cycle length (second), default 90s,

c = Capacity of lane group (veh/hr),

g = Effective green time for lane group(s), default g/C ratio 0.45,

T = Duration of analysis period (hour), default 1 hour;

k = Incremental delay adjustment for the actuated control, default 0.5, and

I = Incremental delay adjustment for the filtering or metering by upstream signals, default 1.

The capacity C is either given, or estimated by using the procedures discussed in Appendix A. However, there is a lack of research on the impact of work zones on highway capacity. In this study, an assumption of 10% capacity reduction is applied.

The average hourly volume per lane is estimated by dividing AADT:

$$V = \frac{AADT}{N \times 24} \tag{4-6}$$

Where,

V = Average hourly volume,

$AADT$ = Average Annual Daily Traffic counts,

N = The total number of lanes for two directions.

The default values and the assumption of capacity reduction reflect the configurations of the base model, which helps to simply data input.

4.5.2 Estimating Average Travel Speed in Two-Lane Highway Scenarios

Analyses of two-lane highways in urban settings with traffic lights spacing at 2 miles or less can use the methods discussed in section 4.5.1. Otherwise, the following formulas are used:

$$S_A = FFS - 0.00776V_P - f_{np} \qquad (4\text{-}7)$$

Where,

S_A = Average travel speed (miles/hr),

f_{np} = Adjustment for percentage of no-passing zones, default 0, and

V_P = Passenger-car equivalent flow rate for peak 15-min period (pc/hr).

The FFS is determined by using the formulas in Appendix B. V_P is estimated by using the following formula,

$$V_P = \frac{V}{PHF * f_G * f_{HV}} \qquad (4\text{-}8)$$

Where,

V_P = Passenger-car equivalent flow rate for peak 15-min period (pc/hr),

V = Demand volume for the full peak hour (veh/hr), which is estimated using the average hourly volume (formula 4-6),

PHF = Peak Hour Factor, 0.92 for urban settings and 0.88 for rural settings,

f_G = Grade adjustment factor, default 1, and

f_{HV} = Heavy-vehicle adjustment factor.

The f_{HV} is estimated by the following formula:

$$f_{HV} = \frac{1}{1 + HV(E_T - 1)}$$ (4-9)

Where,

HV = Percentage of heavy vehicles, and

E_T = Passenger car equivalent, default 2.

Similarly, this base model is obtained using the default values and assumption. In addition, this study uses average hourly volume to estimate the peak hour volume.

4.5.3   Estimating Average Travel Speed in Multilane Highway Scenarios

The following formulas are used for estimating the average travel speed of vehicles traveling on multilane highways.

For flow rate (V_P), $V_P > 1400$ and $55 < FFS \leq 60$:

$$S_A = FFS - \left[\left(\frac{3}{10}FFS - 13\right)\left(\frac{V_P - 1400}{28FFS - 880}\right)^{1.31}\right]$$ (4-10)

For $V_P > 1{,}400$ and $50 < FFS \leq 55$:

$$S_A = FFS - \left[\left(\frac{34}{205}FFS - \frac{219}{41}\right)\left(\frac{V_P - 1400}{\frac{171}{5}FFS - 1181}\right)^{1.31}\right]$$ (4-11)

For $V_P > 1400$ and $45 < FFS \leq 50$:

$$S_A = FFS - \left[\left(\frac{10}{43}FFS - \frac{350}{43}\right)\left(\frac{V_P - 1400}{33FFS - 1050}\right)^{1.31}\right]$$ (4-12)

For $V_P > 1400$, and $FFS = 45$:

$$S_A = FFS - \left[\left(\frac{1}{5}FFS - \frac{56}{9}\right)\left(\frac{V_P - 1400}{36FFS - 1120}\right)^{1.31}\right]$$ (4-13)

For $V_P \leq 1400$:

$$S_A = FFS$$ (4-14)

44

where,

S_A = Average travel speed (miles/hr),

FFS = Free Flow Speed, determined by using formulas in Appendix B,

V_P = 15 min passenger-car equivalent flow rate (pc/hr/ln), determined by using formulas (4-15):

$$V_P = \frac{V}{PHF * N * f_{HV} * f_P}$$ (4-15)

where,

V = Hourly volume (veh/h), estimated by using formula 4-6,

PHF = Peak hour factor,

N = Number of lanes,

f_{HV} = Heavy-vehicle adjustment factor, and

f_P = Driver population factor.

The f_{HV} is determined by:

$$f_{HV} = \frac{1}{1 + HV(E_T - 1)}$$ (4-16)

where,

HV = Percentage of heavy vehicles, and

E_T = Passenger car equivalent, default 2.

The hourly volume is estimated by using the average traffic volume (formula 4-6). The peak hour factor, PHF, can be obtained by using the table in Appendix C. The default value for the driver population factor, f_P, is set to 1, which reflects weekday commuter traffic. These conditions reflect the characteristics of the base model.

4.5.4   Estimating Average Travel Speed in Limited Access Highway Scenarios

The average travel speed of vehicles traveling on limited access highways is estimated by using the following formulas.

For 70< FFS ≤ 75 and (3400-30FFS) < V_P ≤ 2400:

$$S_A = FFS - \left[\left(FFS - \frac{160}{3}\right)\left(\frac{V_P + 30FFS - 3400}{30FFS - 1000}\right)^{2.6}\right] \qquad (4\text{-}17)$$

For 55 ≤ FFS ≤ 70 and for flow rate (V_p), (3400-30FFS)< V_p ≤ (1700+10FFS):

$$S_A = FFS - \left[\frac{1}{9}(7FFS - 340)\left(\frac{V_P + 30FFS - 3400}{40FFS - 1700}\right)^{2.6}\right] \qquad (4\text{-}18)$$

For $55 \le FFS \le 75$ and $V_p \le (3400 - 30FFS)$:

$$S_A = FFS \tag{4-19}$$

where,

S_A = Average travel speed (miles/hr),

FFS = Free Flow Speed, determined from Appendix B,

V_P = 15 min passenger-car equivalent flow rate (pc/hr/ln),

V_P can be determined by using the following formula:

$$V_P = \frac{V}{PHF * N * f_{HV} * f_P} \tag{4-20}$$

Where,

V_P = 15-min passenger-car equivalent flow rate (pc/hr/ln),

V = Hourly volume (veh/hr), estimated by using formula 4-6,

PHF = Peak Hour Factor,

N = Number of lanes,

f_{HV} = Heavy-vehicle adjustment factor, and

f_P = driver population factor.

The f_{HV} is estimated as:

$$f_{HV} = \frac{1}{1 + HV(E_T - 1)} \tag{4-21}$$

where,

HV – Percentage of heavy vehicles

E_T – Passenger car equivalent, default 2

As discussed previously, the hourly volume can be estimated as the average traffic volume. The peak hour factor, PHF, can be obtained by using the table in Appendix C. The default value for the driver population factor, f_P, is set to 1, which reflects weekday commuter traffic. These are the conditions of the base model for calculating travel speed in limited access highway scenarios.

4.6 Value of Time

According to the AASHTO Red Book, the value of time per vehicle is calculated as:

$$\Delta H_c = M_c \times O_c \times \Delta T \tag{4-22}$$

where,

ΔH_c = The value of travel time savings enjoyed by user class c (in dollars per vehicle),

M_c = The unit value of time for user class c (in dollars per hour),

O_c = The occupancy rate of vehicles of user class c and

ΔT = The time delay due to construction, (in hours).

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.

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 past decade, it is estimated that the average occupancy rate in the year 2007 is 1.41, which is used in the calculations of the sample projects.

The calculation of VOT is based on the estimate of time delay, average wage of the drivers, and the percentage of trucks and passenger cars:

$$VOT = V * (PC * AWCD + PT * AWTD) * \Delta T * O_c \quad\quad (4\text{-}23)$$

where,

VOT = Value of time in dollars,

V = Daily traffic affected by construction activities,

PC = Percentage of passenger cars,

$AWCD$ = Average Wage of Passenger Car Drivers,

PT = Percentage of trucks,

$AWTD$ = Average Wage of Truck Drivers,

ΔT = Time delay,

O_c = Occupancy rate.

The estimate of ΔT is performed based on the following formula:

$$\Delta T = l * \left(\frac{1}{S_A'} - \frac{1}{S_A} \right) + \Delta T' \qquad (4\text{-}24)$$

Where,

ΔT = Time delay,

l = Length of a work zone,

S_A', S_A = Average travel speed during and after construction, respectively, and

$\Delta T'$ = Estimated additional delay time.

The estimate of speed in work zones and after construction can be determined by the type of facility, as discussed in Section 4.5.

The ΔT can be adjusted by users, i.e., using $\Delta T'$, according to some simple rules to account for the impact of simplification (e.g., different default values) on the speed calculation process. The speed calculations for different situations are simplified to reduce the complexity that is inherent in traffic analyses and to satisfy the objectives of this study. The simplification in some cases may lead to unsatisfactory results. In addition, in typical cases, the initial speed data available to district engineers are the posted speed

limits, which do not reflect the actual travel speeds during and after construction. On the other hand, the speed calculation procedures in HCM 2000 are not specifically designed to consider the impact of work zones. Thus, it is necessary to allow users to adjust the ΔT.

It was recommended by a district scheduling engineer to use the following rule-of -thumb for determining the $\Delta T'$:

- Work zones are classified into three types according to the characteristics of construction, i.e., light construction, moderate construction, and heavy construction. Light construction refers to situations in which only minor construction activities take place and temporary construction barriers, such as cones, are used. Moderate construction involves the use of permanent construction barriers but without the presence of heavy construction equipment and activities such as those for earthwork or foundations. Heavy construction makes use of permanent construction barriers and heavy construction equipment and activities.

- The additional travel time $\Delta T'$ is calculated as:

$$\Delta T' = \frac{3600 \times (V_p - V_c)}{V_p \times V_c}$$
(4-25)

Where,

V_p - Posted speed limit during construction, and

V_c - Estimated travel speed during construction.

- In light construction situations, the default value for $V_p - V_c$ is 5 miles/hour. Users may choose to use other values according to specific project conditions.

- In moderate construction situations, if the posted speed limit is less than 30 miles/hr, the default value for $V_p - V_c$ is 5 miles/hour; otherwise, the default is 10 miles/hour. These values are also changeable by users based on their judgment of specific project conditions.

- In heavy construction situations, if the posted speed limit is above 70 miles/hr, the default value for $V_p - V_c$ is 20 miles/hour; otherwise, the default is 10 miles/hour. Users can use different values according to specific project conditions.

The system planning office of the FDOT recommended average wage costs for passenger car and truck drivers to be \$12.89 and \$27.00 in the Life Cycle Cost Analysis Handbook, which was in 1996 dollars. These numbers are used as base values, which are adjusted using CPI (Consumer Price Index) when used in RUC calculations.

4.7   Vehicle Operation Cost

Due to the lack of data, this study only considers fuel consumption costs in VOC calculations. Other types of costs can be added when data are available.

Since travel speed during and after construction are estimated (Section 4.5) for every project, it is reasonable to use the formula that calculates fuel costs as a function of speed (Section 2.5.2).

Based on the average travel speed during and after construction, the fuel consumption of the two situations, $gal_{c,speed1}$ and $gal_{c,speed2}$, can be looked up in Table 4-1, which is obtained from the AASHTO "Red Book". The average travel speed is calculated based on previous discussions (Section 4.5). Florida-specific fuel costs can be obtained from the website of AAA (www.fuelgaugereport.com).

Thus, VOC can be estimated as:

$$VOC = V \times (gal_{c,speed1} - gal_{c,speed2}) \times P_c \times L \tag{4-26}$$

Where,

VOC = Vehicle operation cost in dollars,

V = Daily traffic volume affected by construction activities,

$gal_{c,speed0}$ − Gallons per mile for vehicle class c, during construction speed,

$gal_{c,speed1}$ − Gallons per mile for vehicle class c, after construction speed,

P_c − Fuel price per gallon for vehicle class c, and

L - The length of the work zone.

Table 4-1 Fuel Consumption for Autos and Trucks, by Average Speed (AASHTO "Red Book" 2003)

Gallons per Mile		
Speed(mph)	Autos	Trucks
5	0.117	0.503
10	0.075	0.316
15	0.061	0.254
20	0.054	0.222
25	0.050	0.204
30	0.047	0.191
35	0.045	0.182
40	0.044	0.176
45	0.042	0.170
50	0.041	0.166
55	0.041	0.163
60	0.040	0.160
65	0.039	0.158

4.8 Accident Cost

Although previous studies have suggested some procedures for calculating accident costs, this study has developed a customized approach due to the lack of data, especially when it comes to the increase in accident rates due to construction. The customized procedure is shown as follows:

$$AC = \frac{A \times R_{wa} \times V \times L}{1000000} \times C \qquad (4\text{-}27)$$

where,

AC = The additional accident costs due to the presence of work zones,

A = Crash rate per million vehicle miles,

R_{wz} = Percentage change of the accident rate in a work zone,

L = The length of a work zone (miles),

V = Total hourly volume during construction per day, and

C = The average crash dollar value per accident.

Table 4-2 Average Accident Costs and Crash Rates by District and Project Setting

District	Accident Cost		Accident Rate	
	Urban	Rural	Urban	Rural
1	$77,861	$115,227	2.569	1.112
2	$76,286	$117,087	2.68	6.83
3	$64,990	$139,696	2.722	0.92
4	$74,482	$138,072	2.277	0.73
5	$73,501	$165,004	1.91	1.386
6	$49,665	$165,252	5.434	3.568
7	$57,458	$108,973	3.418	1.83
Turnpike	$52,674	$66,733	1.64	0.44

Due to a variety of findings as discussed in the literature review and the difficulty in

deriving the increase in accident rates in Florida, a range of 7.5% to 27.5% is assumed in

this study, following the previous studies. To calculate *A* and *C*, a table has been developed based on crash reports collected from the safety office of the FDOT. There are two types of data, crash rates and average crash dollar values, which are categorized by district (Table 4-2). *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. The hourly volumes can be estimated as the average hourly volume, using formula 4-6.

4.9   The RUC Software

An RUC calculation tool is developed as part of this project, based on the Microsoft .NET Framework. For details of using the software, please refer to

Major features of the tool are:

- Simple data input: The new tool requires only a limited number of data inputs (seventeen types of project-specific data and nine types of default data), including facility data, traffic data, work zone schedule data, and economic and project data, which can be easily obtained by district engineers.

- Comparable calculation results: The new tool can produce RUC calculations according to different types of facilities in different project settings (e.g., urban streets and rural limited-access highways), detours, and construction schedules, which is more practical than some existing tools. The results are comparable to those obtained by using the ADOT model and the QUEWZ model.

- User friendly interfaces: The software takes ease of use as a top priority. For example, the software dynamically updates the displayed RUC when a user makes changes to data input; and presents 24 checkboxes for users to define a construction schedule.

- Realistic modeling of calculation scenarios: The new tool is developed based on the strategy of using recognized methods (e.g., the Highway Capacity Manual and the AASHTO Red Book) to develop a base model and adjusting the base model according to user's judgment of specific project conditions. Such a strategy helps to simplify the data input requirements, while maintaining the capability to produce comparable results.

- Easy management of data: By using the window-based technology, data needed for calculations are consistently maintained within the standalone software environment.

5 VALIDATION

The proposed new procedure is validated by a comparative study, a correlation analysis, and a data input analysis. Projects are collected from FDOT district 6 for the purpose of validation.

5.1 Sample Projects and Calculations

The data of seven sample projects are shown in Appendix E: Sample Projects for Validations. RUC calculations of the sample projects are performed by using the new procedure, the ADOT model, and the QUEWZ model. The results of the calculations are also presented in Appendix F.

5.2 Comparative Study

The RUC calculation results using the three different methods, as well as the actual incentives, are shown in Table 5-1.

Table 5-1 Comparisons of RUC Calculation Results

Sample Project	New Procedure	ADOT	QUEWZ	Actual I/D
Ex1	$3,151	$5,975	$115	$1,800
Ex2	$19,762	$17,289		$20,000
Ex3	$3,195	$52,600	$241	$2,400
Ex4	$5,311	$24,338	$559	$4,000
Ex5	$56,650	$306,714		$25,000
Ex6	$72,426	$21,688	$16,630	$20,000
Ex7	$14,559	$3,257		$20,000
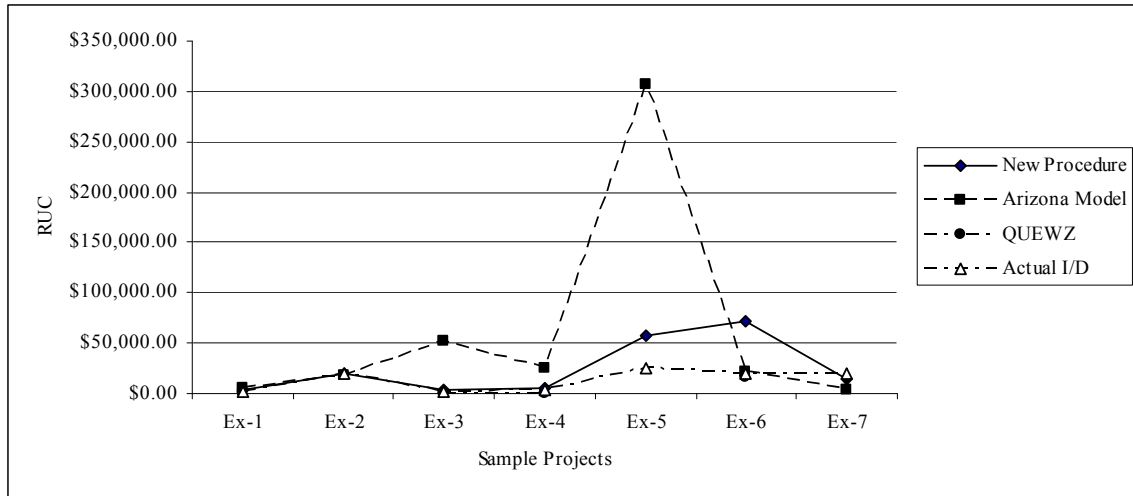
Figure 5-1 Comparisons of Calculation Results

A visual observation of ***Figure 5-1*** reveals that the results of the ADOT model can be too large and that those of the QUEWZ model can be too small. The ADOT model may produce higher values than the other two models. This is due to the time-speed relationship built into the ADOT model, which assumes that travel time increases linearly as the AADT per lane increases over 5,000 vpd (Vehicle Per Day) and that the travel time is doubled when the AADT (Annual Average Daily Traffic) reaches 15,000 vpd. Given this assumption, the additional travel time calculated from the ADOT model can be much higher than that from the new model and the QUEWZ model, resulting in a higher RUC. In addition, the ADOT model uses AADT in calculations without differentiating volumes affected by construction from those that are not, which may also contribute to a large RUC value.

The RUC calculated from the QUEWZ model shows abrupt changes from example to example. In the QUEWZ model, the road user costs of Exs. 1 and 4 are extremely low: $115.00 and $241.00, respectively. This is because the two projects are of urban arterials,

while 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 usually much higher than the capacity and volume of typical urban streets.

The result of sample project 6 using the new procedure shows an exception. This is because the volume capacity (V/C) ratio during construction exceeds one, meaning that the capacity of the highway facility cannot satisfy the demand. In reality, traffic may divert from the highway under study. To reflect such a reality, users may choose a discounted AADT for the construction period.

5.3   Correlation Analysis

In the correlation analysis, the study includes comparisons of the results derived from the new procedure, the ADOT model, and the QUEWZ model with actual incentive data. The incentive data were assigned to the sample 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 indicate a more practical method, closer to what has been practiced. Thus, two measures are used 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. If a method can generate results that better resemble the pattern of the actual incentives and are more similar in dollar values with the actual incentives, that method is regarded as more accurate.

The Pearson correlation coefficient, ρ_{XY}, between two arrays of variables, i.e., the RUC calculated using one of the three methods and the actual incentives, is defined as:

$$\rho_{XY} = \frac{\text{cov}(X,Y)}{\sigma_X \sigma_Y} = \frac{E((X - \mu_X)(Y - \mu_Y))}{\sigma_X \sigma_Y} \tag{5-1}$$

where "E" is the expected value operator and "cov" means covariance.

Since the QUEWS model can only be applied to four projects, two separate analyses are performed, i.e., comparing all three models based on Ex 1, Ex 3, Ex 4, and Ex 7; and comparing the new model and the ADOT model based on all projects. The results of the comparisons are shown in Table 5-2.

Table 5-2 Results of Correlation Analysis

	The New Model	**The ADOT Model**	**The QUEWZ Model**
All Models	0.9968	-0.1371	0.9964
Two Models	0.7396	0.4538	

According to Table 5-2, the correlation analysis of the three models based on the four projects shows that the new model and the QUEWZ model both match well the pattern of the actual incentives. However, the QUEWZ model generates very low RUCs. The analysis of the two models based on all projects reveals that the new procedure has a slight advantage over the ADOT model in terms of correlation analysis. In addition, the ADOT model may produce excessively high values, as discussed in the previous section.

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5.4   Data Input Analysis

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

1. Facility data – Describing the facility type, the number of lanes and the length of work zones.

2. Traffic data- Including the AADT and the posted speed limit during and after construction.

3. Work zone schedule data – The starting and ending time of the work zone activities.

4. Economic and project data – The average wage rates of drivers, fuel cost data, accident costs, accident rates, impact factors, and so on.

These types of data are easily accessible to district engineers. The ADOT model also uses data that can be easily obtained. However, the QUEWZ model uses some data that can be difficult to get. Some examples are shown in Table 5-3.

5.5   Summary

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.

Table 5-3 Difficult Input Data of the QUEWZ Model

Speed-Volume Relationship	LOS D/E Breakpoint Speed (mph)
	Speed at capacity (mph)
	LOS D/E Breakpoint Volume (vphpl)
	Volume at capacity (vphpl)
Diversion Algorithm	Critical length of queue (miles)
	Maximum acceptable delay (minutes)
	Critical length of queue
Wok Zone Capacity	Inbound direction (vphpl)
	Outbound direction (vphpl)
	I = adjustment for the type and intensity of work activity
	(-160 to 160 pcphpl) (Inbound/Outbound)
	R = adjustment for the presence of ramps(0-160 pcphpl)
Emission Rate	HC Idle Car, CO Idle Truck, CO Idle Car, CO Idle Truck, Nox Idle Car, Nox Idle Truck

Although different models have their strengths, the new procedure can generate RUC estimates that are consistent and comparable with those generated with the ADOT and QUEWZ models. In addition, the new procedure uses reasonable amounts of input data to perform the calculations.

6 CONCLUSIONS

In this study, a work zone RUC calculation tool has been developed for FDOT. The tool can help the engineers to estimate RUC for determining incentives/disincentives. The development of such a tool is motivated by the fact that there is not a standard tool used

by the FDOT for RUC calculations, which may result in many differences among FDOT districts. These differences are reflected by observations such as varying interpretations of the concept of RUC, different sets of cost factors included in calculations, and the application of different economic data in calculations. In addition, existing RUC calculation tools cannot satisfy the need of district engineers, mainly due to the lack of user friendly tools or excessive requirements for data input.

A review of the three existing RUC models, the ADOT model, the QUEWZ, and the Quick Zone reveals that each model has its strengths and weaknesses. The QUEWZ is applicable only for analyses of freeways or limited access highways. In addition, the traffic and economic data built-into the model are based on data from Texas, which may not be applicable in other states. The Quick Zone requires specification of a network of the subject highway facility and its adjacent highways. In addition, the Quick Zone needs the monthly, daily, and hourly traffic distributions and the project phase information. Such high-labor intensive analyses are not what district engineers are looking for. A case study also reveals that many types of data for building the network are not easily available to district engineers. Although the ADOT model requires very simple data inputs, it has many obvious limitations, e.g., it only estimates time delay costs; it does not consider the impact of construction schedules; and it uses a built-in time-volume relationship for estimating travel time. The limitations of the existing models further emphasize the need to develop a new procedure for the FDOT.

The RUC is a unique type of cost to motorists in that there is no actual cost against which the estimated RUC can be validated. Such a calculation process should strike a balance between practicality and the desired level of accuracy. Therefore, it is important that the calculation process be based on recognized methods and procedures, and the results of calculations be used as references. The new RUC procedure has been developed based on the calculation procedures in the HCM 2000 and the concepts and algorithms of the 2003 AASHTO Red Book.

One of the key issues in RUC calculations is the estimation of travel speed in both during and after construction. This study has applied a strategy to balance the simplification of the data input requirements with the accuracy of the results. For each facility type in a particular setting, a base model is first developed for speed calculations and then users are allowed to adjust the speed based on their judgment and experience according to specific project conditions. The speed adjustment may account for additional travel time that may not be considered due to the simplification process. For example, due to the difficulty in estimating capacity reduction in work zones, a 10% reduction due to construction is assumed for all types of projects by default. The capacity reduction will be reflected in a speed reduction. Therefore, in addition to the 10% reduction, users may use the speed adjustment to account for additional impacts on speed due to capacity reduction.

This strategy is shown to be effective based on the analysis of seven sample projects, including a comparative study, a correlation analysis, and a data input analysis on the

new procedure, the ADOT model, and the QUEWZ model. The new procedure has demonstrated its capability to produce reasonable RUC estimates and to use limited amounts of input data to perform the RUC calculations.

Based on the new procedure, a software tool has been developed using the Microsoft .NET Framework. The software tool is designed to provide a user-friendly environment for RUC calculations.

Further study is needed in the following areas:

- There is lack of empirical data for calculating the increase in accident rates in work zones. Although the crash data from the Safety Office of the FDOT are used in the project, they can only provide information on average accident costs and average accident rates for the purpose of this study. There is still a need for the data to support the estimation of the increase in accident rates in work zones. Currently, the study uses a range of 7.5% to 27% to estimate the increase in accident rates based on existing literature. More research is needed to develop an effective method for estimating the increase in accident rates in work zones.

- The estimate of VOC only includes fuel consumption costs. Further studies are needed to include other types of cost components in VOC calculations, such as vehicle maintenance cost and depreciation.

- Currently, AADT is used for estimating traffic volumes in various calculations. However, since AADT is bi-directional, it is difficult to obtain

directional hourly volumes from AADT. It would be ideal to use directional volumes in some situations such as diversion or detour calculations. The challenge is to collect sufficient representative sample data of Florida highways by district and facility types.

- More studies are needed to look into a simpler method for estimating the impact of detours and diversions. Currently, the software tool uses a subjective estimate of detour time to consider the impact of detours when needed.

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Appendix A: Procedures for Estimating Highway Capacities

The capacity of highway facilities is calculated based on the procedures published in the Highway Performance Monitoring Systems (HPMS) by the Federal Highway Administration (FHWA).

A-1 Urban Streets

The capacity of urban streets is estimated as:

$$C = 1900 * f_w * f_{HV} * PHF * g / C \qquad \text{(A- 1)}$$

where,

C = Street capacity (pcphpl),

f_w = Adjustment factor for lane width,

f_{HV} = Adjustment factor for heavy vehicles,

PHF = Peak Hour Factor, 0.88 for rural conditions, 0.92 for urban conditions,

g/C = Effective green time-to-cycle length ratio, 0.55 for principal arterials, 0.45 for minor arterials, 0.40 for collectors.

The adjustment factor for lane width is calculated as:

$$f_w = 1 + \frac{(w - 12)}{30} \qquad \text{(A- 2)}$$

where,

w - Lane width, minimum 8, maximum 16, default 12.

The adjustment factor for heavy vehicles is calculated as,

$$f_{HV} = \frac{100}{100 + HV(E_T - 1)} \qquad \text{(A- 3)}$$

where,

HV – Percentage of heavy vehicles,

E_T – Passenger car equivalent, default 2.

A-2 Two-Lane Highways

For projects in rural settings, the recommended procedure is as follows:

$$C = 3200 * PHF * f_G * f_{HV} - V_{NP} \qquad \text{(A- 4)}$$

where,

PHF = Peak Hour Factor, 0.88 for rural conditions, 0.92 for urban conditions,

f_G = Adjustment factor for grades,

f_{HV} = Adjustment factor for heavy vehicles in traffic stream, calculated by using (A-3),

V_{NP} = Volume adjustment for no-passing zone.

When use A-3 for estimating f_{HV}, the following Table A-1 can be used to determine E_T.

Table A-1 Value for Different Terrain

Two-Way Flow Rate (pch)	Type of Terrain		
	Level	Rolling	Mountainous
0 – 600	1.7	2.5	7.2
600 – 1200	1.2	1.9	7.2
> 1200	1.1	1.5	7.2

The calculation of V_{NP} is based on the following procedure,

$$V_{NP} = \frac{f_{NP}}{0.00776}$$

(A- 5)

where,

f_{NP} = Adjustment for percentage of no-passing zones, Exhibit 20-11, HCM 2000.

For projects in urban settings, the recommended procedure is as follows,

$$C = s_0 * f_w * f_{HV} * f_p * f_a * PHF \qquad\qquad (A\text{-}6)$$

where,

s_0 = Base saturation flow rate per lane (pcphpl), default 1,900 pcphpl,

f_w = Adjustment factor for lane width, calculated by using (A-2),

f_{HV} = Adjustment factor for heavy vehicles in traffic stream, calculated by using (A-3),

f_p = Adjustment factor for existence of parking activity, default 1,

f_a = Adjustment factor for area type, default 0.991,

PHF = Peak Hour Factor, 0.88 for rural conditions, 0.92 for urban conditions.

A-3 Multi-Lane Highways

The base capacity is calculated as:

$$C_b = 1000 + 20 * FFS \qquad for\ FFS \leq 60 \qquad\qquad (A\text{-}7)$$

$$C_b = 2200 \qquad for\ FFS > 60 \qquad\qquad (A\text{-}8)$$

where,

C_b = Base capacity,

FFS = Free Flow Speed,

If peak capacity is needed, it is calculated as:

$$C_p = C_b * PHF * f_{HV} * f_p \qquad \text{(A- 9)}$$

where,

C_p = Peak capacity,

PHF = Peak Hour Factor, see Appendix C,

f_{HV} = Adjustment factor for heavy vehicles in traffic stream, calculated by using (A-3) and applying a factor of 1.5 (level terrain), or 2.5 (rolling terrain), or 4.5 (mountainous terrain) for E_T,

f_p – Adjustment factor for driver population, default 1.

A-4 Freeways

The base capacity is calculated as,

$$C_b = 1700 + 10 * FFS \qquad for\ FFS \le 70 \qquad \text{(A- 10)}$$

$$C_b = 2400 \qquad for\ FFS > 70 \qquad \text{(A- 11)}$$

where,

C_b = Base capacity,

FFS = Free Flow Speed,

The peak capacity, if needed, is calculated as:

$$C_p = C_b * PHF * f_{HV} * f_p \qquad\qquad (A\text{-}12)$$

where,

C_p = Peak capacity,

PHF = Peak Hour Factor, see Appendix C,

f_{HV} = Adjustment factor for heavy vehicles in traffic stream, calculated by using (A-3) and applying 1.5 for E_T,

f_p = Adjustment factor for driver population, default 1.

A-5 Freeway Work Zone Capacity

Chapter 22 of the HCM 2000 provides a method for calculating work zone capacity. According to the HCM 2000, work zones are divided into two types, short-term work zones and long-term work zones, in freeway settings. The two types of work zones are differentiated by the types of barriers they use. Long-term work zones usually use portable concrete barriers; whereas short-term work zones use standard channeling devices (e.g., traffic cones).

Although this study does not use the methods discussed in the following sections because they are only applicable to freeways, it is worthwhile to include the discussion of the methods in the report so that future studies may use the discussion as a reference.

Short-Term Work Zones

The reduced capacity can be calculated by the following formula:

$$C_a = (1600 + I - R) * f_{HV}$$

(A- 13)

where,

C_a = Adjusted mainline capacity (veh/h),

f_{HV} = Adjustment for heavy vehicles,

I = Adjustment factor for type, intensity, and location of the work activity, and

R = Adjustment for ramps.

$$f_{HV} = \frac{1}{1 + P_T (E_T - 1)}$$

(A- 14)

where,

f_{HV} = Heavy-vehicle adjustment factor,

P_T = Proportion of heavy vehicles, and

E_T = Passenger-car equivalent for heavy vehicles, default 1.5.

The estimate of I is based on the intensity of work activities. The following rules may be used to simplify the calculation:

- Normal conditions, I is 0,

- More intensive than normal conditions, I is 1.1*1600 = 1760 pcphpl,

- Less intensive than normal conditions, I is 0.9*1600 = 1440 pcphpl.

Adjustments for ramps are not considered.

Long-Term Construction Zones

The Exhibit 22-4 of the HCM 2000 presents some useful information for estimating long-term work zone capacity (Table A-2). It is obvious that the information may not be sufficient to cover different scenarios, e.g., 4 normal lanes.

Table A-2 Summary of Capacity Values for Long Term Construction Zones

No. of Normal Lanes	Lanes Open	Number of Studies	Range of Values (veh/h/ln)	Average per lane (veh/h/ln)
3	2	7	1780-2060	1860
2	1	3	-	1550

(Source: Exhibit 22-4 in HCM 2000)

Appendix B: The Procedure for Calculating Free Flow Speed

Although the HCM 2000 presents different procedures for estimating Free Flow Speed (FFS), a simplified approach suggested by an NCHRP study is applied in this study. The simplified approach ignores the difference between different types of highway facilities.

The free flow speed, *FFS*, can be estimated by the following methods,

$$FFS = 0.88 * PST + 14 \quad if \ PST \succ 50mph \quad \text{(B- 1)}$$

$$FFS = 0.79 * PST + 12 \quad if \ PST \leq 50mph \quad \text{(B- 2)}$$

where,

PST – Posted Speed Limit

Appendix C: Peak Hour Factor

This study will estimate PHF for multilane and limited access highways based on a procedure published by HPMS (Highway Performance Monitoring Systems). Major steps of the procedure are as follows,

1. Set PHF = 1

2. Use A-9 or A-12 to calculate peak capacity for multi-lane and limited access highways, respectively;

3. Determine initial volume-to-capacity ratio (*V/C*);

4. Assign PHF using ***Table C-1***

Table C-1 PHF Value Calculation

Type	*V/C* Ratio	PHF
Rural	< 0.7744	0.88
	$0.7744 \leq V/C \leq 0.9025$	Equation (D-1)
	>0.9025	0.95
Urban	<0.8100	0.90
	$0.8100 \leq V/C \leq 0.9025$	Equation (D-1)
	>0.9025	0.95

$$PHF = \frac{0.9025 \times (V/C)^{0.5}}{0.95} \qquad \text{(C-1)}$$

Appendix D: Sample Projects for the Second Survey and the Comparison Study

D-1 Sample Projects for the Second Survey and the Comparisons of Existing Models

Sample project 1 is a resurfacing project provided by District 6. The project is located on State Road No. 916 in Miami-Dade County, in the city of Opa-Locka. SR 916 is located between the Palmetto Expressway (826) and I-95. SR 916 is a two-directional urban arterial where each direction has three lanes. The work zone extends from the intersection with NW 27th Ave to the intersection with NW 7th Ave. The highway network is shown in *Figure D-1*.
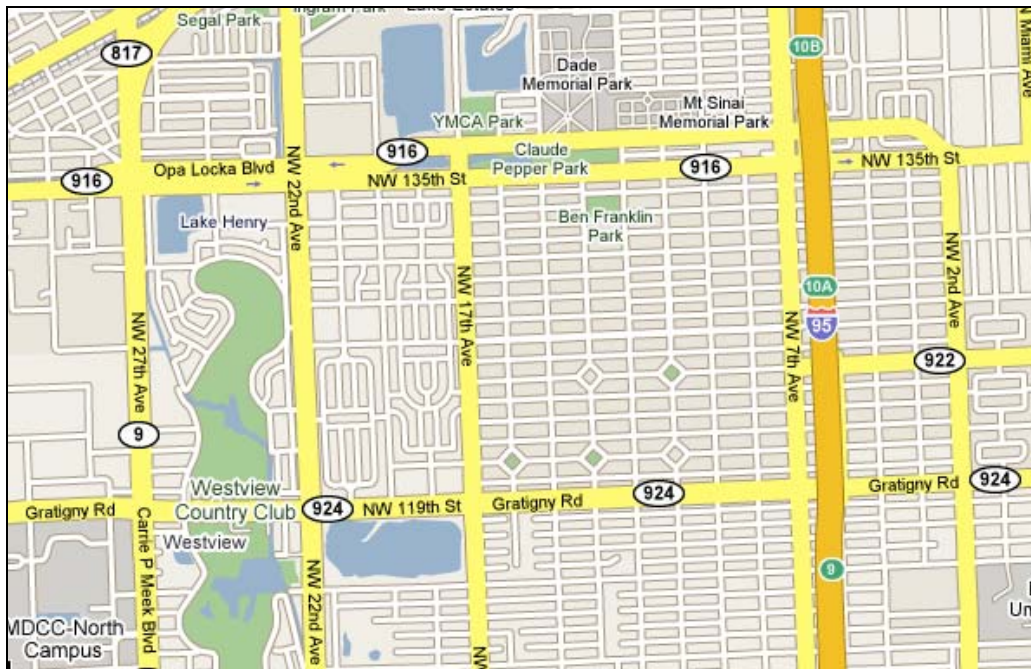
Figure D-1 The Highway Network of Sample Project 1

Sample project 2 is also provided by District 6. The project is located on State Road No. 916 (Opa Locka Boulevard). The work zone extends from N.W. 67th Ave. to N.W. 57th Ave, as shown in *Figure D-2*. The road is an urban arterial with two directions and one lane per direction. The project type is a widening project. The length of the project is 1.052 miles.

Figure D-2 Highway Network of Sample Project 2

Sample project 3 is a capacity-adding project provided by District 5. The project is located on State Road No.25. The work zone extends from the intersection of SR 27 and SR 50 to Minneola, as shown in *Figure D-3*. The contract duration is 980 calendar days.

Figure D-3 Highway Network of Sample Project 3

Facility and traffic data of the three projects are listed in *Table D-1*.

Table D-1 Facility and Traffic Data of the Sample Projects

	Sample Project 1	Sample Project 2	Sample Project 3
Type	Urban Street	Urban Street	Urban Multilane
AADT	15385	19297	33300
Truck %	7%	6%	26.20%
# of lanes (During)	4	2	4
# of Lanes (After)	6	4	6
Posted Speed (During)	35	30	45
Posted Speed (After)	35	30	50
Length (miles)	2.002	1.052	2.778
Lane Closure Schedule*	9:00am to 3:30pm	24 hours per day	9:00am to 3:30pm

RUC Calculations of the Second Survey

Sample project 3 is used by all FDOT districts to determine if there are any differences among the RUC calculation methods currently used by the districts. *Figure D-4* shows the RUC results from different districts. *Table D-2* is a summary of the methods used by the districts.
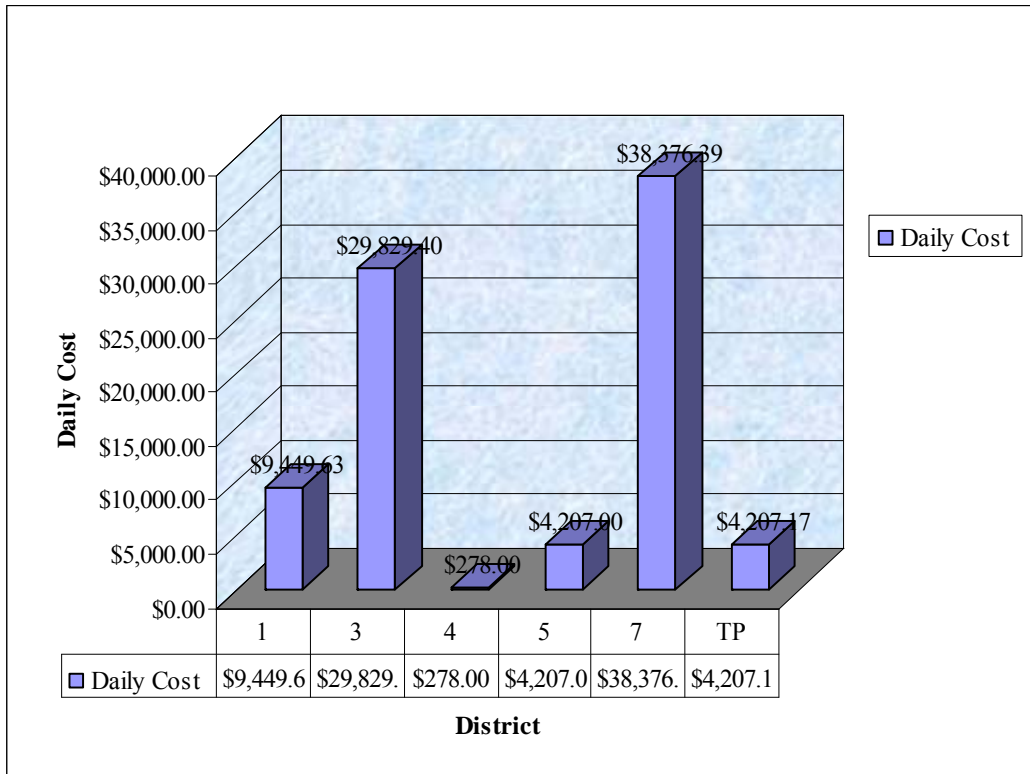
Figure D-4 RUC Calculations by FDOT Districts Using Sample Project 3

Table D-2 A Summary of Current RUC Calculation Methods by FDOT Districts

Category	Method	District	Analysis	Factor
I	ADOT Model	5,Turnpike	During vs. After	VOT
II	TTI Look Up Table (MicroBENCOST)	4	Before vs. After	VOT VOC AC
III	Customized formula	1,3,7	N/A	VOT VOC
IV	Not using any specific method	2,6	N/A	N/A
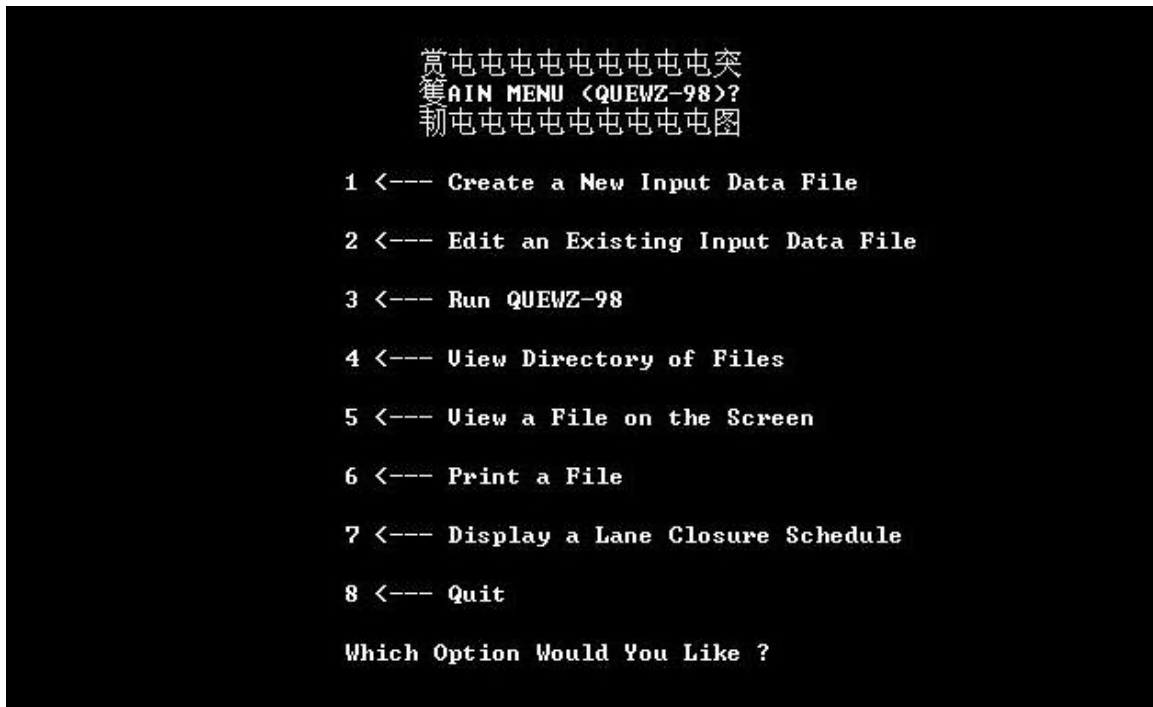
Notes: VOT – value of time, VOC – vehicle operation cost, AC – accident cost

D-2 Sample Project Calculations for Comparisons of the Three Models

The QUEWZ Model

The QUEWZ 98 is a DOS-based program that can be used to perform RUC calculations. The operation menu is shown in *Figure D-5*.

Figure D-5 Input Menu of QUEWZ

In the case studies, the road user cost output option is selected. The required data input includes:

- ▪ The traffic volume approaching a work zone: There are two options to input the traffic volume data, the AADT option and the directional hourly volume option. In the case studies, the AADT option is selected because the hourly volume is not available. The input AADT is converted into the directional hourly volume based on the default hourly distribution in the QUEWZ Model.

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The estimated directional hourly volume reflects the average distribution of the traffic volume on urban and rural interstate highways in Texas.

- The lane closure configuration: In the case studies, in order to simplify the data input, it is assumed that one lane is closed for each direction during construction. For sample project 2, there is only one lane for each direction. QUEWZ is not applicable for this situation because in the lane number input menu, the smallest selectable lane number is two.

- The schedule of construction activity: In the case studies, the schedule of construction is determined according to the definition of non-peak hours in the traffic control plan.

- Default values of project and economic data: Some default values need to be set before performing calculations, including wage adjustments, the truck percentage, the speed-volume parameters, the diversion algorithm, the work zone capacity, and the emission rate. In the case studies, the wages are adjusted by a Consumer Price Index factor of 1.24. Default values are used for the speed-volume relationship parameters, the diversion algorithm, work zone capacity, and the emission rate.

QUEWZ analyzes the additional user cost on an hourly basis. The results of sample projects 1 and 3 are shown in *Figures E-6* and *E-7* (since sample project 2 is a two-lane facility, QUEWZ cannot be applied).

```
Ex1.dat                                                    QUEWZ-98
-----------------------------------------------------------------------
                      ADDITIONAL ROAD USER COSTS ($)
     HOUR             INBOUND              OUTBOUND             TOTAL
-----------------------------------------------------------------------


     0- 1
     1- 2
     2- 3
     3- 4
     4- 5
     5- 6
     6- 7
     7- 8
     8- 9
     9-10                 8.                   6.                 14.
    10-11                 7.                   7.                 14.
    11-12                 8.                   8.                 15.
    12-13                 8.                   8.                 15.
    13-14                 8.                   8.                 16.
    14-15                 8.                   9.                 17.
    15-16                10.                  13.                 23.
    16-17
    17-18
    18-19
    19-20
    20-21
    21-22
    22-23
    23-24
-----------------------------------------------------------------------
    TOTAL                57.                  59.                115.
-----------------------------------------------------------------------
```

Figure D-6 QUEWZ RUC Output of Sample project 1

```
the study of Ex3                                           QUEWZ-98
-----------------------------------------------------------------------
                      ADDITIONAL ROAD USER COSTS ($)
     HOUR             INBOUND              OUTBOUND             TOTAL
-----------------------------------------------------------------------


     0- 1
     1- 2
     2- 3
     3- 4
     4- 5
     5- 6
     6- 7
     7- 8
     8- 9
     9-10                41.                  27.                 68.
    10-11                34.                  31.                 65.
    11-12                36.                  36.                 73.
    12-13                38.                  38.                 76.
    13-14                39.                  39.                 79.
    14-15                42.                  47.                 89.
    15-16                53.                  84.                137.
    16-17
    17-18
    18-19
    19-20
    20-21
    21-22
    22-23
    23-24
-----------------------------------------------------------------------
    TOTAL               284.                 303.                587.
-----------------------------------------------------------------------
```

Figure D-7 QUEWZ RUC Output of Sample Project 3

The Quick Zone Model

The data input of the Quick Zone model mainly includes four components: the highway network, the traffic demand, the construction phase information, and the economic parameters. These are divided into nine sub-modules. In the network design, each link of the network, representing a highway, is defined by nine parameters: the node numbers, capacity of the link per lane, number of lanes, length of the link, free flow speed, jam density, direction (I/O) of the link, type, and position. The demand module requires traffic volume data such as the AADT, as well as the monthly, daily, and hourly AADT pattern for both directions of each link. The data required by the construction phase information module is shown in *Figure D-8*. The user cost parameters module includes four types of data: delay costs, vehicle operating costs, the inventory costs, and the economic costs, as shown in *Figure D-9*.

In the case studies, a major challenge is to obtain the data required by the Quick Zone. Highway networks are designed based on the network information provided by the database of Florida Traffic Information (FTI), which contains traffic counts at many locations in the Florida highway network. However, difficulties are still experienced in obtaining traffic volume data for our local networks. The Quick Zone model requires more AADT data than is typically available to the district engineers. In the case studies, the daily and hourly distributions are the default values provided by the Quick Zone; while the monthly distribution is assumed to be constant. In addition, the free flow speed is assumed to be 50 mph and the jam density is assumed to be 190.

Figure D-8 Input Module of the Construction Phase Module

Figure D-9 The User Cost Parameters Module

The results on the three sample projects are shown in *Table D-3*.

Table D-3 RUC Calculation Results of Sample Projects by Quick Zone

	Delay Cost			Inventory Cost		Total Costs
	Mainline Cost		Detour Costs	Mainline	Detour	
	Car (Dollars)	Trucks (Dollars)	Car + Trucks (Dollars)	(Dollars)	(Dollars)	(Dollars)
Project 1	$15,151,860	$1,094,611	$0	$0	$0	$16,246
Project 2	$62,612,750	$4,523,312	$0	$7,590	$0	$67,143,650
Project 3	$8,156,757	$589,266	$16,679	$5,079	$582	$8,768,363

The ADOT Model

The ADOT model only estimates the cost of time delay. The required data is composed of two parts: the work zone data (including the AADT, truck percentage, posted speed, and work zone length) and the economic data. State estimated project contract amounts and durations are also needed. The work zone data can be obtained from drawings, and the state estimated contract amount and duration of a project can be acquired from the project contract.

The calculation of time delay is expressed using the following formula:

1) When volume < 5000,

$$t = t_c - t_f = (l_c / s_c) - (l_f / s_f)$$

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2) When volume >5000,

$$t = t_c - t_f$$

$$t_c = l_c / s_c \left[1 + (A_c - 5000)/10000\right]$$

$$t_f = l_f / s_f \left[1 + (A_f - 5000)/10000\right]$$

where, t_c and t_f are the travel time of during and after construction, respectively. A_c and

A_f stand for the AADT during and after construction, respectively.

The total daily value allowed is the lesser of the maximum daily value and the daily value. The estimated daily value is calculated as,

$$DailyValue = ADT \times AdditionalTime \times AverageWag\,e \times IF \times \frac{Duration\,of\,TrafficCon\,trol}{\Pr ojectDurat\,ion}$$

The Maximum daily value is estimated as,

$$MaximumDailyValue = 0.2 \times \frac{EstimatedConstructionCost}{Estimated\,\Pr ojectDuration}$$

The calculation results for the three sample projects are listed in *Table D-4*.

Table D-4 RUC Calculations by the ADOT Model

PROJECT DATA	Unit	Sample 1	Sample 2	Sample 3
STATE ESTIMATED DURATION=	Days	360	540	980
STATE $ ESTIMATE=	$	$1,200,000.00	$2,000,000.00	$20,615,130.00
ADT=	Veh	15138	18900	33300
TRUCKS=	%	6.99%	6.17%	26.20%
AVG USER WAGE=	$/Hr.	$11.06	$10.99	$12.60
TOTAL # OF LANES OPEN (CONSTR)=	ea.	4	2	4
DURATION OF T.C. CONDITION=	Days	300	450	980
SPEED LIMIT (CONSTR)=	mph	35	30	45
LENGTH (CONSTR)=	Miles	2.001	1.052	2.778
TOTAL # OF LANES OPEN (NEW)=	ea.	6	2	6
SPEED LIMIT (NEW)=	mph	40	40	50
LENGTH (NEW)=	Miles	2.001	1.052	2.778
CONSIDER OTHER IMPACTS (YES/NO)=		No	No	No
ONE DIRECTIONAL TRAFFIC (YES/NO)=		No	No	No
MAXIMUM DAILY VALUE=		$666.67	$740.74	$4,207.17
ADD'L TIME TO TRAVEL THRU=	Hrs.	0.01	0.01	0.02
DAILY VALUE=		$974.75	$2,193.43	$9,917.34
SUM=		$974.75	$2,193.43	$9,917.34
TOTAL DAILY VALUE ALLOWED=		**$666.67**	**$740.74**	**$4,207.17**
TRAVEL TIME:				
DURING CONSTRUCTION	Hrs.	0.057	0.051	0.082
AADT/# <= 5,000		0.057	0.035	0.062
AADT/# > 5,000		0.043	0.051	0.082
AFTER CONSTRUCTION	Hrs.	0.050	0.038	0.059
AADT/# <= 5,000		0.050	0.026	0.056
AADT/# > 5,000		0.037	0.038	0.059

Appendix E: Sample Projects for Validations

Seven projects from District 6 have been used in the validation. The project information

is presented in *Table E-1*.

Table E-1 Project Data

Variable	Ex1	Ex2	Ex3	Ex4	Ex5	Ex6	Ex7
Type	Urban Street	Urban Street	Urban Street	Urban Street	Rural Multilane	Urban Street	Urban Street
AADT-2007	15385	19297	52145	30951	42367	40498	9787
Truck %	7%	6%	8.50%	7.53%	16.60%	3.70%	13.49%
# of lanes (During)	4	2	4	4	2	2	2
# of Lanes (After)	6	4	6	6	4	4	4
Posted Speed (During)	35	30	35	40	40	55	30
Posted Speed (After)	35	30	35	40	55	55	30
Length (miles)	2.002	1.052	1.534	2.308	3.927	1.648	1.887
Lane Closure Schedule*	9:00am to 3:30pm	24 hours per day	Midnight to 5:30am and 10:00pm to Midnight	9:00am to 3:30pm	24 hours per day	9:00am to 3:30pm	24 hours per day
Average Wage of Car Drivers ($/hr)**	$17.11	$17.11	$17.11	$17.11	$17.11	$17.11	$17.11
Average Wage of Truck Drivers ($/hr)**	$35.84	$35.84	$35.84	$35.84	$35.84	$35.84	$35.84
Fuel Cost (Gal/hr)+	$2.79	$2.79	$2.79	$2.79	$2.79	$2.79	$2.79
Average Accident Cost ($/per accident)++	$49,665	$49,665	$49,665	$49,665	$49,665	$49,665	$49,665
Average Accident Rate (# of accident per million vehicle miles)++	5.434	5.434	5.434	5.434	5.434	5.434	5.434

Notes: * the RUC software cannot take half-hours into consideration, so the calculation of volume during lane closure uses the hourly volume of the entire hour, even though only half of the hour is used for lane closure.
** Average wages for car and truck drivers are 2007 data.
+ Fuel cost is based on 2007 fuel cost data.
++ Average accident cost and average accident rate are district-specific and based on the crash reports from the Safety Office of the FDOT.

The calculation results using the new model are as follows (*Table E-2*).

Table E-2 Calculation Results of Sample Projects by Using the New Model

	Ex 1	Ex 2	Ex 3	Ex 4	Ex 5	Ex 6	Ex 7
VOT ($)	2,350	17,432	2,537	3,781	45,565	64,184	9,281
VOC ($)	490	1,919	455	807	3,760	7,567	4,904
AC ($)	312	4,11	202	723	7,324	675	374
Impact Factor	1.0	1.0	1.0	1.0	1.0	1.0	1.0
RUC ($)	3,151	19,762	3,195	5,311	56,650	72,426	14,559
Additional Speed Adjustment (Miles/Hour)	10	15	10	10	5	5	15
Detour Time (Minutes)	0	0	0	0	0	0	0

The calculation results using the ADOT model are as follows (*Table E-3*). The

spreadsheet prepared by the ADOT DOT is used. The RUC calculations are discussed in

Appendix D.

Since the estimated construction cost, project duration, and traffic control plan of the

sample projects are not available, the Daily Value is used as the RUC of the projects for

the comparative analysis.

Table E-3 Calculation Results of Sample Projects using the ADOT Model

	Unit	EX 1	EX 2	EX 3	EX 4	EX 5	EX 6	EX 7
AVERAGE DAILY TRAFFIC	Veh	15385	19297	52147	30915	42000	40498	9235
TRUCKS	%	7%	6%	9%	8%	17%	4%	13%
AVG USER WAGE	$/Hr.	26.48	26.48	26.48	26.48	26.48	26.48	26.48
TOTAL # OF LANES OPEN (CONSTR)	ea.	2	1	2	2	1	2	1
SPEED LIMIT (CONSTR)	mph	35	30	35	40	40	55	30
LENGTH (CONSTR)	Miles	2.002	1.052	1.534	2.308	3.927	1.648	1.887
TOTAL # OF LANES OPEN (NEW)	ea.	3	2	3	3	2	3	2
SPEED LIMIT (NEW)	mph	35	30	35	40	55	55	30
LENGTH (NEW)	Miles	2.00	1.05	1.53	2.31	3.93	1.65	1.9435
CONSIDER OTHER IMPACTS (YES/NO)		No	No	No	No	No	No	No
ONE DIRECTIONAL TRAFFIC (YES/NO)		No	No	No	No	No	No	No
ADD'L TIME TO TRAVEL THRU	Hrs.	0.01	0.03	0.04	0.03	0.28	0.02	0.01
DAILY VALUE	$	**5,975**	**17,289**	**52,600**	**24,338**	**306,714**	**21,688**	**3,257**

The calculation results by using the QUEWZ model are as follows (*Table E-4*).

Table E-4 Calculation Results of Sample Projects using the QUEWZ Model

	Ex 1	**Ex 2**	**Ex 3**	**Ex 4**	**Ex 5**	**Ex 6**	**Ex 7**
RUC ($)	115	N/A*	214	559	16,630	N/A*	N/A*

Notes: *QUEWZ cannot be applied to the analysis of two lane facilities.