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Department of
Transportation



Calculating Road User Cost for Specific Sections of Highway for Use in Alternative Contracting Project

Research Final Report from East Tennessee State University | K. Joseph Shrestha, Mohammad Moin Uddin, Jeremiah Adebiyi | September 26, 2021

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16. Abstract Road user costs (RUCs) quantify the inconveniences to road users resulting from ongoing construction projects. Although the concept of RUC has traditionally been associated with the life cycle cost analysis, its importance has increased in alternative contracting methods in recent years. Despite its importance, the Tennessee Department of Transportation (TDOT) currently lacks a systematic methodology to compute RUCs. With the increased use of alternative contracting such as A+B, TDOT can benefit significantly if a systematic methodology and a tool are developed to compute RUCs in-house. The main goal of this study is to develop a framework and accompanying tool to compute RUCs, which balances the ease of computing and accuracy of results. To achieve this goal, the study reviewed existing literature on the topic, conducted a nationwide survey, and identified the current best practices of calculating and utilizing RUCs. The study found that more than half of the state Departments of Transportation (DOTs) that responded to the questionnaire have developed their state-specific methodologies to compute RUCs. The delay costs and the vehicle operating costs are the two most common components computed by a majority of state DOTs. Based on the findings of the study, a framework to compute RUCs is developed to enable TDOT to quickly compute RUCs more efficiently. Subsequently, a spreadsheet based TDOT RUC Calculation Tool (TRCT) is developed to implement the framework. The tool can compute four components of the RUC: a) delay cost, b) vehicle operating cost, c) crash cost, and d) emission cost. Relevant standard datasets such as median household income and emission rates were collected and/or produced for the tool. The tool automatically accounts for the spatiotemporal variation in the RUCs using Consumer Price Index (CPI) and county-specific data. The computed RUCs can be used for A+B contracting, benefit-cost analysis, liquidated damage computation, and early-completion-incentive computation.			
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Executive Summary

Roadway construction projects often require a partial or full closure of the roadway. Partial closure of the road may result in a long queue while full closure will force road users to take longer detour routes to get to their destinations. If such impacts are likely to be significant, the Tennessee Department of Transportation (TDOT) needs to quantify the impact of the road closures while making project-management decisions. For instance, while traditional project delivery methods focus solely on the direct construction cost to the highway agency while evaluating the best bidder, alternative project delivery methods such as A+B include the Road User Cost (RUC) as an additional factor to select the best bidder. The RUC quantifies the inconveniences to road users resulting from ongoing construction projects. Despite its importance, TDOT lacked a systematic methodology to compute RUCs and had previously relied on consulting services to compute RUCs for its projects. With the increased use of alternative project delivery methods, TDOT can benefit significantly if a systematic methodology and a tool are developed to compute RUCs in-house.

The main goal of this study was to develop a framework and an accompanying tool to compute RUCs, which balances the ease of computing and accuracy of the results. Specific objectives to achieve this goal were: a) review existing methodologies to compute RUCs, b) conduct a nationwide survey to identify the best practices of calculating and utilizing RUCs, c) develop a framework to compute RUCs, and d) develop a tool to implement the framework.

The study reviewed relevant manuals, spreadsheets, and desktop- or web-based tools developed and used by various states such as Colorado, Michigan, Ohio, Oregon, and Texas. Based on the findings of the literature review, a nationwide survey was conducted to identify the best practices of calculating and utilizing RUCs. Based on the findings of the literature review and the nationwide survey, a theoretical framework was developed to compute the RUC. Subsequently, a spreadsheet-based tool was developed to implement this framework. A significant amount of standard data, such as median household income by county, was collected from various sources such as the Bureau of Labor Statistics (BLS) and the Federal Highway Administration (FHWA) to enable TDOT to compute RUCs more efficiently. Finally, a case study is conducted to demonstrate the use of the methodology and the tool.

Key Findings

The key findings of this study are:

- **Current Practices:** Most of the state Departments of Transportation (DOTs) have developed their state-specific methodologies.
- **Major Components of the RUC:** The major components of RUCs are a) delay cost, b) vehicle operating cost, c) crash cost, d) emission cost, and e) local impact cost. The delay cost and vehicle operating cost are the two most widely used components in RUC calculation.

Current Practices

Thirty-seven out of 50 state DOT representatives responded to the nationwide survey questionnaire developed to understand the current practices of calculating and utilizing RUCs.

Many state DOTs have developed their state-specific methodologies to compute RUCs for various purposes including incentives/disincentives determination, A+B contract evaluation, and lane rental cost determination. Most of them are based on theoretical foundations developed by FHWA and the American Association of State Highway and Transportation Officials (AASHTO). State DOTs calculate RUCs for select projects only – primarily depending on project duration and location. Most state DOTs have developed and preferred a spreadsheet-based tool in comparison to a web-based and desktop-based program.

Major Components of RUC

The RUC consists of five major components: a) delay cost, b) vehicle operating cost, c) crash cost, d) emission cost, and e) local impact cost. The delay cost accounts for the lost opportunity for the road users resulting from the additional travel time on the road. In other words, delay cost represents the dollar amount that the road users could have earned if they did not have to spend extra time on the road. The vehicle operating cost includes vehicle-related costs such as additional fuel cost, vehicle maintenance cost, and tire wear cost. The crash cost quantifies the increased likelihood of crashes because of the work zone. The emission cost quantifies the impact of additional pollution emitted as a result of the longer travel time. The local impact cost represents the costs associated with decreased business revenue in the surrounding area and increased congestion in the linked road network.

The inclusion of more components ensures accounting for broader impacts of the road closure. However, not all components are considered by state DOTs because of various practical limitations. Out of the five components, the delay cost and the vehicle operating cost are the two most common components computed by a majority of state DOTs. The delay cost is considered essential by about three-fourth of the respondents and 92% of the respondent stated including it as a part of the RUCs. The vehicle operating cost is considered essential by about half of the respondents and 73% of the respondents stated including it as a part of the RUCs. The availability of existing data and methodology appears to be the major reason for the wider use of the two components. Crash cost, emission cost, and local impact costs are considered required by 3% or fewer respondents. These are potentially perceived to be more challenging to compute and/or there is a lack of existing methodology to compute them. Specifically, the local impact cost is the most challenging component to realistically compute because of the nature of the data required. Future research should focus on developing a simplified method to compute the local impact cost with minimal user inputs.

Overall, the methodologies and spreadsheets developed and used by various state DOTs vary in complexity and accuracy. Many state DOTs use oversimplified methodologies that would result in less accurate RUC values that could impact various project management decisions. Most of the tools require manually updating various standard datasets as they do not properly account for the inflation for various RUC components. Thus, a more comprehensive framework and tool to compute RUC that can automatically account for inflation and county-specific values would aid TDOT in making more informed project management decisions.

Framework and Tool

Based on the findings of the study, a framework to compute RUCs is developed to enable TDOT to quickly compute RUCs more efficiently. A spreadsheet-based tool, entitled TDOT RUC

Calculation Tool (TRCT), was developed and is provided as a part of the deliverable. The tool eases the computation of the RUC that includes the delay cost, vehicle operating cost, crash cost, and emission cost. The local impact cost requires project- and location-specific data that are not easily accessible and/or available. As such, the local impact cost is not included in the computation. A set of standard data such as median wage for various counties is collected and provided in the tool. Such county-specific data enables TDOT to compute more accurate RUC values more efficiently. Further, each component of RUC values is adjusted automatically for inflation. As such, even if a standard dataset for the latest years is not available, RUCs are automatically adjusted using historical inflation indexes. The computed RUCs can be used for A+B contracting, lane rental, benefit-cost analysis, liquidated damage computation, and early-completion-incentive computation.

Key Recommendations

The key recommendations of the study are to:

- Implement and utilize the RUCs for relevant scenarios and
- Continuously improve RUC calculation methodology.

Implement and Utilize the RUCs for Relevant Scenarios

TDOT should implement and start to utilize the TRCT to compute RUCs for various purposes including A+B bidding, lane rental cost determination, liquidated damage determination, and early completion incentives calculation. TDOT should identify and document various internal sources of project-specific data, such as crash history, that are required to use the tool.

Continuously Improve RUC Calculation Methodology

The RUC calculation requires users to collect various standard external datasets such as median household income and wage rate. Such data changes over time because of the factors such as inflation. While the methodology automatically accounts for the effect of inflation using an inflation factor, such data should be updated regularly to ensure higher accuracy of the results. Similarly, other data such as Crash Modification Factors (CMFs) should be updated if newer values are available. Finally, future studies should focus on developing a methodology to quantify the local impact factor with limited and easily accessible data.

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Glossary of Key Terms and Acronyms

AAA	American Automobile Association
AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ATRI	American Transportation Research Institute
AVO	Average Vehicle Occupancy
BLS	Bureau of Labor Statistics
CPI	Consumer Price Index
CMF	Crash Modification Factor
ECI	Employment Cost Index
EPA	Environmental Protection Agency
DOT	Department of Transportation
EPDO	Equivalent Property Damage Only
FHWA	Federal Highway Administration
MOVES	Motor Vehicle Emission Simulator
MPG	Miles per Gallon
MPH	Miles per Hour
MVMT	Vehicle Miles Traveled
NCHRP	National Cooperative Highway Research Program
PDO	Property Damage Only
RUC	Road User Cost
TDOT	Tennessee Department of Transportation
TTI	Texas Transportation Institute
TRCT	TDOT RUC Calculation Tool
VMT	Vehicle Miles Traveled

Chapter 1 Introduction

Ongoing road construction projects cause inconvenience to road users as some or all lanes may be closed during construction, and the road users will need to slow down, take a detour, or wait in the queue to pass the construction work zones. However, such impacts are ignored while selecting the contractor for a construction project using the traditional contractor selection method – known as the apparent lowest bidder. In this method, the contractor providing the lowest bid amount is selected to execute the project without any consideration for the impact on the road users. To address this limitation, highway agencies have started using A+B contracting method that selects the contractor with the lowest sum of the bid amount (A) and the impact on the road users (B). The monetary quantification of this impact on the road users is commonly known as the Road Users Cost (RUC). The total RUC for a construction project can be computed as the product of the daily RUC and the number of days the road users will be impacted by the construction. The RUC depends on various factors such as the traffic volume and the work zone speed limit.

Many studies have been conducted to compute the RUC since as early as 1986 (Chui & McFarland, 1986; Mallela & Sadasivam, 2011; Qin & Cutler, 2013; Sun et al., 2013). Chui and McFarland (1986) categorized the RUC into vehicle operating costs, time costs, accident costs, traffic violation costs, and other non-quantifiable costs such as comfort and convenience. In 1985 dollar-value, the value of time was computed as \$8.00 per person-hour for drivers and \$10.40 per vehicle-hour for passenger cars based on survey data. The earlier studies focused on computing the RUC for benefit-cost analysis for new roadway projects. More recently, RUCs are increasingly being used to account for the impact of construction work zones on road users and to provide incentives or disincentives to the contractors.

The National Cooperative Highway Research Program (NCHRP) synthesis 494 stated that the inclusion of the RUC is one of the great advances in public-sector infrastructure management and decision making (Flannery, Manns, and Venner 2016). The Federal Highway Administration (FHWA) encourages state Departments of Transportation (DOTs) to develop and implement policies and procedures to quantify the impact of construction on road users (Mallela and Sadasivam 2011). The FHWA report entitled *Work Zone Road User Costs: Concepts and Applications* details the available data and methodologies to compute various components of the RUC to help state DOTs to develop their state-specific methodologies. Many state DOTs such as Ohio, Texas, and Colorado DOTs have developed spreadsheet-based, desktop-based, or web-based tools to compute the RUC. However, the Tennessee Department of Transportation (TDOT) lacked a consistent methodology and a robust tool to compute RUCs and had heavily relied on consulting service providers. Developing a methodology and a tool to compute the RUC will enable TDOT to compute RUCs in-house quickly and consistently.

1.1 Research Objectives

The main goal of the study was to develop a TDOT-specific framework and accompanying tool to compute the RUC that balances the accuracy of the result and the effort required to compute it. Specific objectives of the study are a) review existing methodologies to compute the RUC, b) conduct a nationwide survey to identify the best practices of calculating and utilizing the RUC,

c) develop a framework to compute the RUC, and d) develop a tool to implement the framework.

1.2 Methodology

This study was completed in four phases a) Review Existing Studies, b) Conduct a Nationwide Survey, c) Develop a Framework to Compute the RUC, and d) Develop a TDOT RUC Calculation Tool (TRCT). A case study example is used to demonstrate the use of the TRCT.

1.3 Significance of Research

The RUC calculation methodology and an accompanying tool developed as a part of the study will enable TDOT to compute RUCs quickly and consistently for future projects. The RUC can be used for various purposes including:

- Selection of the best contractor for A+B contracting,
- Computation of daily lane rental costs for contractors,
- Computation of incentives and disincentives (liquidated damage), and
- Life cycle cost analysis for new roadway projects.

1.4 Organization of the Report

The remaining report is divided into six chapters. *Chapter 2 Literature Review* summarizes the findings from the literature review. *Chapter 3 Methodology* details the methodology used to complete the project. *Chapter 4 Nationwide Survey* presents the findings from the nationwide survey. *Chapter 5 Framework to Calculate RUCs* presents the framework to compute RUC. *Chapter 6 Spreadsheet-Based Tool and Case Study* provides an overview of the TDOT RUC Calculation Tool (TRCT) and a case study result. *Chapter 7 Results and Discussion* highlights the major findings from the study. And *Chapter 8 Conclusions and Recommendations* concludes the report with recommendations to TDOT to ensure that the outputs of the results are implemented and used properly. The Appendices include Standard Datasets and Nationwide Survey. The Standard Datasets tabulates relevant data from outside sources such as FHWA and AASHTO that are required to compute RUCs. The Nationwide Survey presents the questionnaire used for the nationwide survey.

Chapter 2 Literature Review

The Federal Highway Administration (FHWA) requires states to “implement a policy for the systematic consideration and management of work zone impacts on all Federal-aid highway projects ... throughout the various stages of the project development and implementation process” and “encourages states to implement such policy for non-Federal-aid projects as well (Federal Highway Administration (FHWA), 2004). The RUC quantifies such impact of construction work zones in monetary values. The RUC has traditionally been associated with the benefit-cost analysis of new construction projects (California Department of Transportation (Caltrans), 2013; Chui & McFarland, 1986; Flannery et al., 2016; Kimboko & Henion, 1981; Lee et al., 2018). NCHRP Synthesis 494, entitled *Life-Cycle Cost Analysis for Management of Highway Assets*, states that the inclusion of RUCs when comparing alternative projects is “one of the great advances in public-sector infrastructure management and decision making” (Flannery et al., 2016). Lee et al. (2018) argue that RUCs are essential components of life cycle cost analysis.

Over time, as the U.S. shifted its focus from the construction of new infrastructure to the improvement of existing infrastructure, the importance of RUC in construction management decision making is increasingly being realized (Daniels et al., 2000; Daniels & Ellis, 1999; Ellis et al., 1997; Huebschman et al., 2003; Jenkins & McAvoy, 2015; Mallela & Sadasivam, 2011; New Jersey Turnpike Authority, 2011; Sun et al., 2013; Sun Carlos et al., 2013). Overall, the RUC is used for multiple decision makings including the evaluation of bids in innovative contracting methods such as A+B, determining incentives and disincentives to contractors for early and late completion of construction, accelerating construction projects, determining the lane occupancy change for work-zone lane closure outside approved hours, and conducting life cycle cost analysis.

Despite the importance of the RUCs, prior studies have revealed that many state DOTs do not have well-developed methodologies for calculating RUCs, have outdated calculation methodologies, have relied mostly on engineering judgment, or have varied methodology within the same DOT (Qin & Cutler, 2013; Zhu et al., 2009). Prior to this study, TDOT also did not have a well-established methodology to compute RUCs. The remaining part of the chapter highlights major findings from the literature review that was used to develop a questionnaire survey and a framework to compute RUCs for TDOT.

2.1 Existing RUC Calculation Methodologies

FHWA and state DOTs have developed their state-specific methodologies to compute the RUCs. The FHWA report entitled *Work Zone Road User Costs: Concepts and Applications* is one of the most comprehensive resources on this topic (Mallela & Sadasivam, 2011). The report categorizes the RUCs into monetized and other impacts. Monetized impacts include a) travel delay cost, b) vehicle operating cost, c) crash cost, d) emission cost, and e) impacts of nearby projects. The first three components of monetized impacts have been included in most of the studies, some of which date back to as early as 1986 (Chui & McFarland, 1986; Jenkins & McAvoy, 2015; Sun et al., 2013). Other impacts include a) noise, b) business impacts, and c) inconvenience to the local community (Mallela & Sadasivam, 2011). These other impacts cannot be easily quantified. The various practices of computing monetized RUCs are described below.

Travel Delay Cost

The travel delay cost represents the cost associated with lost opportunity because the road users had to spend more time on the road. Although various methodologies compute travel delay costs differently, the fundamental equation used to calculate travel delay is presented in Equation (1).

$$\text{Travel Delay Cost} = \text{Delay Time in Hours} * \text{Hourly Dollar Value of Delay} \quad (1)$$

The delay time can be calculated for forced-flow (queued) traffic conditions or the free-flow traffic condition. For example, the Highway Capacity Manual considers various factors such as the number of open lanes, the intensity of construction activities, base capacity, and presence of on-ramps to analyze forced-flow traffic conditions to compute travel delay (Jenkins & McAvoy, 2015; Transportation Research Board (TRB), 2016). In an alternative scenario, the travel delay for the free-flow conditions can be computed based on the length of a work zone, speed limit without work zone, and work-zone speed limit. This travel delay for the vehicles is distributed for distinct types of vehicles such as passenger cars and trucks based on the historical vehicle composition data. This step to distribute the total delay across distinct types of vehicles is important as the hourly dollar values associated with delays can vary significantly based on the vehicle type. Further, depending on the vehicle occupancy, the purpose of travel (personal or business), and travel details (such as intercity or local), the hourly dollar value of delay can be different. However, none of the state DOTs currently use different hourly dollar values of delay for various locations within the state. The economic conditions within a state can vary widely depending on the location. This affects the construction costs and contractors' bids. As such, the effect of location on the hourly dollar value of delay should be considered for a more accurate representation of the RUCs.

Vehicle Operating Costs

The vehicle operating costs include the additional cost associated with the use of vehicles for longer periods because of the construction work zone. It includes various components such as fuel consumption, tire wear, engine oil consumption, repair and maintenance, and mileage-related depreciations (Ellis et al., 1997; Mallela & Sadasivam, 2011). Factors affecting the vehicle operating costs include detour length, speed, speed changes, and idling time. The fuel cost is the primary cost component of the vehicle operating costs. Several empirical formulas have been developed to link speed, terrain types, and distances with fuel consumption. Thus, depending on the location of the construction project, prior and current speed limits, and detour lengths, the increase in fuel consumption can be calculated as an additional vehicle operating cost. As detailed information of each vehicle cannot be obtained and used for all the vehicles traveling through construction zones, vehicle operating cost calculation methodology should emphasize accurate estimations of the vehicle operating costs based on the limited information that is easily accessible.

Crash Costs

In 2018, 755 fatalities occurred in construction work zones (American Road and Transportation Builders Association, 2020). Mishra et al. (2018) analyzed crashes in construction work zones to understand the various factors associated with crashes in construction work zones. The evaluation of crash costs in construction work zones is important as the likelihood of crashes

increases when there is a construction work zone (Huebschman et al., 2003). The direct and indirect costs associated with fatalities, injuries of various severity levels, and property damages are considered as components of the crash costs (Kasnatscheew et al., 2016; Mallela & Sadasivam, 2011). The crash costs are calculated based on the increase in the likelihood of crashes and crash severities resulting from the presence of work zones, and the monetary value of each crash. The likelihood of crashes can be calculated using crash modification factors presented in the AASHTO Highway Safety Manual (AASHTO 2010). Such crash modification factors need to be calibrated based on historical data (Sun et al., 2014). Most of the studies related to crash analysis are focused on crash frequency calculation rather than crash cost calculation. Thus, newer studies should focus on quantifying the monetary impact of crash costs.

Emission Costs

Compression ignition engine-powered vehicles produce emissions that include particulate matter (PM), NO_x, and CO that have an adverse effect on the climate and human health. Multiple factors, such as vehicle class and weight, driving cycle, fuel type, vehicle age, and terrain, affect emission (Clark et al., 2002; Franco et al., 2013; Mallela & Sadasivam, 2011). The increase in idling time, speed changes, and increased travel time are likely to increase emissions. The costs associated with such an increase in emission are included as emission costs. Accurate quantification of the increase in the quantity of emission as well as the unit cost of emission is challenging when a limited amount of data is available. The MOtor Vehicle Emission Simulator (MOVES) developed by the U.S. Environmental Protection Agency (EPA) can be used to estimate emissions based on project-level data (U.S Environmental Protection Agency (EPA), 2015). However, utilizing tools such as MOVES for each project requires a large amount of data may not be practical for the RUC calculation. To ease the emission calculations, some standard datasets can be produced from the MOVES based on locations and other standard conditions. These datasets can then be directly used to compute emission costs for a specific project without needing to use MOVES for every project.

Local Impacts

Ongoing construction projects can affect not only the road users of the same road but also road users of connected roads nearby (Mallela & Sadasivam, 2011). This is the most complicated component of the RUC and is generally not computed by state DOTs. The local business impact calculation requires additional research and surveys of businesses around the work zone to collect data such as the expected revenues for businesses when work zone was not set up and potential decrease in vehicular or foot traffic as a result of the work zone setup. Such data collection and/or estimation is challenging. Thus, utilizing the current methodologies to compute the local impact cost may require high investment of time and effort compared to the increase in the accuracy of total RUC. As such, more research effort should be invested in the future to enable computing the local impact with less effort.

2.3 Limitations of Existing Methodologies Used by State DOTs

Various state DOTs developed their state-specific methodologies. In general, the methodologies developed by state DOTs tend to focus on minimizing the required data and oversimplifies the RUC calculation process by sacrificing the accuracy of the result. Other limitations of existing methodologies include:

- Most state DOTs only include two of the five components of the RUC.
- Existing methodologies typically ignore the variation in RUC across the state despite differences in the economic conditions and road construction costs.
- Many state DOT spreadsheets typically cannot address the temporal effect on the RUC automatically.
- The lack of a comprehensive yet easy-to-use methodology and an accompanying tool to compute emission costs.

Chapter 3 Methodology

The study was completed in four phases: a) Review Existing Studies, b) Conduct a Nationwide Survey, c) Develop a Framework to Compute the RUC, and d) Develop an RUC Calculation Tool.

3.1 Review Existing Studies

This study conducted an extensive review of existing literature on the RUC published by FHWA, state DOTs, and university researchers.

3.2 Conduct a Nationwide Survey to Identify Best Practices

Based on the findings from the review, a survey questionnaire was developed to understand the current practices of calculating and utilizing the RUCs. A pilot study of the survey was conducted with TDOT engineers. Subsequently, the questionnaire was updated to accommodate the feedback from the TDOT representatives. Most of the questions were in the form of multi-select, multiple-choice, or Likert scale questions. The survey questionnaire used for the study is attached in the Appendix (see Nationwide Survey).

The contact information of all 50 state DOT engineers related to the RUC was collected by visiting corresponding state DOT websites and/or other relevant websites. The updated questionnaire was distributed to the state DOT engineers via REDCap®, a web-based surveying tool. Finally, the results from the survey were analyzed descriptively and the findings were presented visually in bar charts.

3.3 Develop a Framework to Compute the RUC

The findings from the literature review and nationwide survey were used to identify the best practices of calculating and utilizing RUCs. These findings were further used to develop a framework to compute RUCs.

3.4 Develop a Tool to Implement the Framework

A spreadsheet-based tool was developed to implement the framework. A number of historical and calculated datasets were collected while developing the tool. This includes data such as:

- Median household incomes for various counties in Tennessee,
- Hourly wage rates,
- Historical Consumer Price Indexes (CPI),
- Fuel consumption per mile at various speeds,
- Vehicle operating costs per mile,
- The monetary value of crashes of various severity,
- Crash Modification Factors (CMF) for work zones,
- Emissions per mile at various speeds, and
- Unit costs of distinct types of emissions.

A sample roadway project was selected to evaluate the system. A case study was conducted using the data for a specific project.

authorized time. About half of the respondents are utilizing the RUCs to evaluate construction phasing options (such as nighttime or weekend construction), to conduct benefit-cost analysis, and to accelerate construction contracts. This result on benefit-cost analysis aligns with the finding from a previous study conducted for South Carolina DOT, which found that 60% (19 out of 32) of responding state DOTs did not include the RUCs in life cycle cost analysis (Rangaraju et al., 2008).

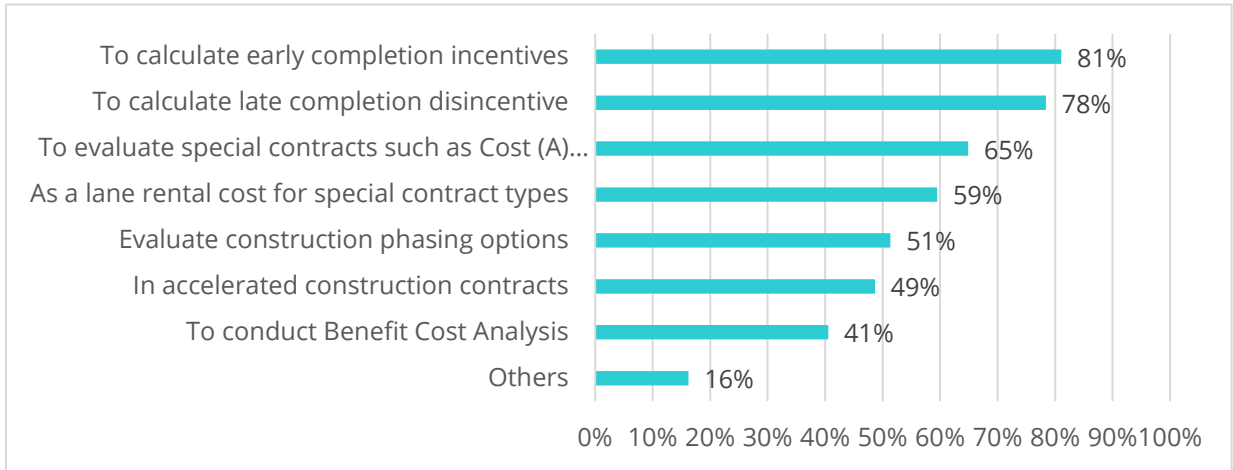


Figure 4.2 RUC application stage.

The TDOT does not calculate the RUCs for all the projects. As such, to understand the DOT practices of determining if RUCs should be calculated and included on contracts, respondents were asked to select the criteria for such a decision. The duration, location, and complexity of the project were the top three factors in determining the inclusion of the RUCs (Figure 4.3). Although the dollar value of the project might appear to be the primary factor in such determination, it is not considered as important as the duration, location, and complexity of the project. State DOTs are more likely to calculate the RUCs for projects in urban areas with higher traffic volumes and projects that need to be completed in a short amount of time to minimize the impacts on road users.

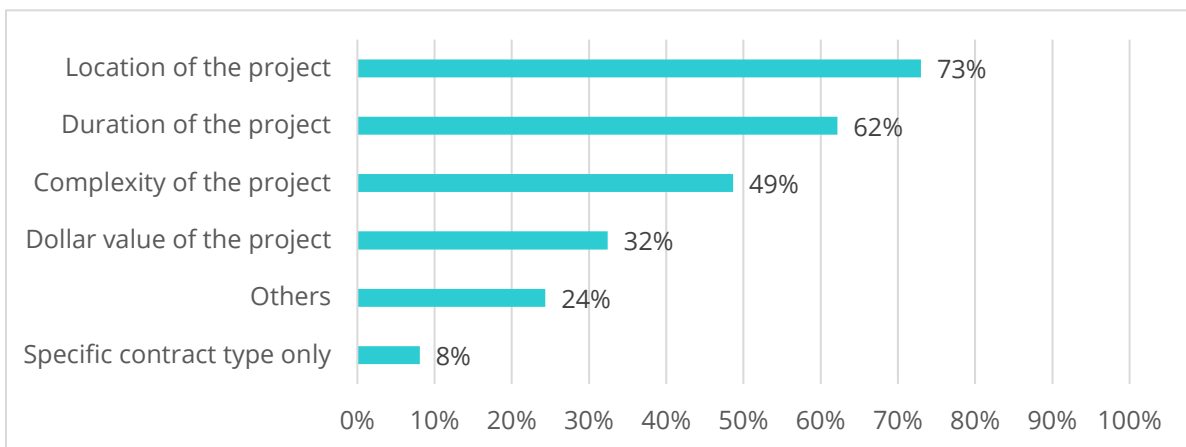


Figure 4.3 Criteria to determine if RUC should be calculated.

4.2 RUC Calculation Methodology

The RUCs calculation methodologies vary by state. Sixty-two percent of the respondents have their state-specific methods (Figure 4.4). However, a part or whole of the methodologies for most state DOTs is based on other standard methodologies. For example, the delay time for a work zone is generally calculated using the methodology from the Highway Capacity Manual (Transportation Research Board 2010). The delay time calculation presented in the FHWA methodology published in the *Work Zone Road User Costs: Concepts and Applications*, is also based on the Highway Capacity Manual (Mallela & Sadasivam 2011).

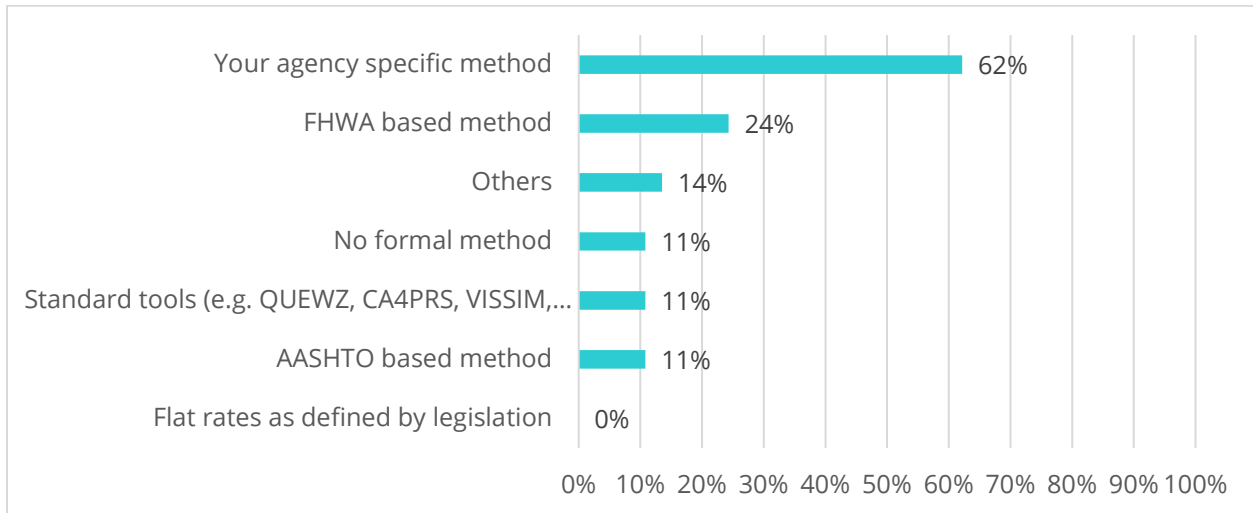


Figure 4.4 RUC calculation methodologies.

Figure 4.5 compares the currently used and preferred tool types to compute RUCs in various state DOTs. The responses indicate that majority of state DOTs prefer and use a spreadsheet-based tool. However, a spreadsheet-based tool is used by more respondents than preferred while a web-based tool is used by fewer respondents than preferred. None of the respondents preferred a desktop-based tool, probably because state DOTs are utilizing desktop-based tools developed a long-time ago. Such tools often tend to look outdated and cannot be accessed from multiple computers without installing them on each computer. This trend towards web-based tools is also apparent in other construction tools used by state DOTs such as AASHTOWare Project (AASHTO 2020) that has slowly migrated from being a desktop tool to a web-based tool over several years. AASHTOWare products are widely used by state DOTs for various purposes including daily work report data collection from construction sites (Shrestha et al., 2019).

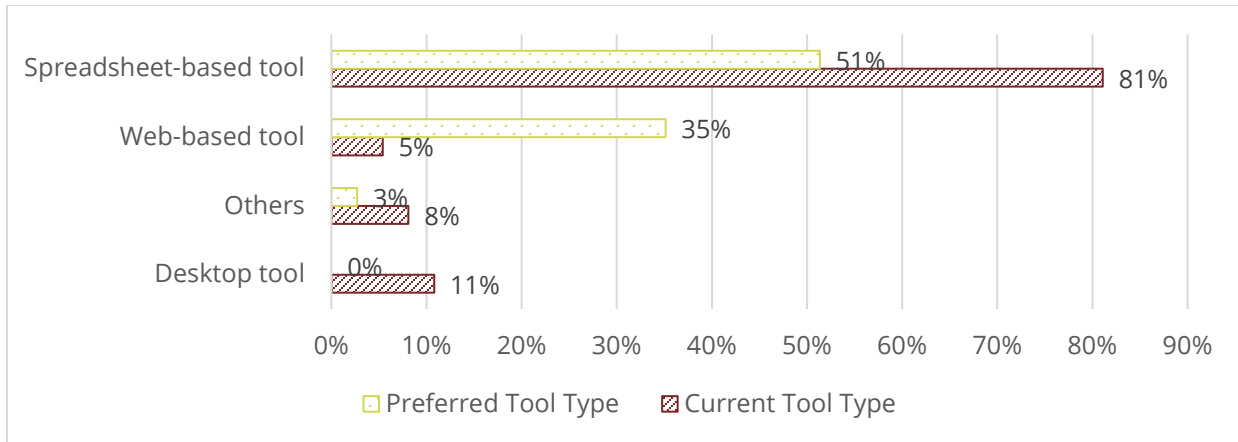


Figure 4.5 Preferred and currently used RUC calculation tools type.

The RUC consists of five major components: a) delay cost, b) vehicle operating cost, c) emission cost, d) crash cost, and e) local impact costs (Figure 4.6). Table 4.1 shows various components included in RUC calculation by various state DOTs. Most respondents indicated that the delay cost and vehicle operating costs are currently included in their RUC calculation methodology. These two components are also considered essential by more than half of the respondents. While other RUCs such as local impacts, emission costs, and crash costs are considered somewhat important by many respondents, less than a quarter of respondents included such components in their road user calculation methodologies. This is most likely because of the lack of well-established methodologies and/or required data to quantify such costs.

The survey found that none of the state DOTs included all five components of the RUCs in their methodologies. The Florida DOT is the only state DOT that included four of the five components in its methodology. Seven state DOTs included three of the five components. Eleven DOT included two components. Similarly, six state DOTs included only one component. Finally, three states do not calculate RUCs for their construction projects. Louisiana, Kansas, and Washington DOT stated that they do not calculate RUCs. However, it is possible that the respondents of the questionnaire are not aware of the RUC calculation methodology used by their state and hence stated that they do not calculate RUC.

TABLE 4.1
RUC COMPONENTS INCLUDED IN VARIOUS STATE DOT METHODOLOGIES

State	Delay Cost	Vehicle	Crash Cost	Emission Cost	Local Impact
Alabama	X	X	-	-	-
Arizona	X	X	-	-	X
Arkansas	X	X	X	-	-
Colorado	X	-	-	-	X
Delaware	X	X	-	-	-
Florida	X	X	X	-	X
Georgia	X	X	-	-	-
Hawaii	X	X	-	-	-
Idaho	X	-	-	-	-
Indiana	X	X	-	-	-
Iowa	X	X	X	-	-
Kansas	-	-	-	-	-
Kentucky	X	X	-	-	-
Louisiana	-	-	-	-	-
Maine	X	X	X	-	-
Maryland	X	X	-	-	-
Michigan	X	X	-	-	-
Minnesota	X	X	-	X	-
Mississippi	X	-	-	-	-
Missouri	X	X	-	-	-
Montana	X	X	-	-	-
New Hampshire	X	X	-	X	-
New Jersey	X	X	-	-	-
North Dakota	X	X	-	-	-
Ohio	X	X	-	-	-
Oregon	X	X	-	-	-
Pennsylvania	X	-	-	-	-
Rhode Island	X	X	-	-	-
South Carolina	X	-	-	-	-
South Dakota	X	X	-	-	-
Tennessee	X	X	-	-	-
Utah	X	-	-	-	-
Vermont	X	-	-	-	-
Virginia	X	X	-	-	-
Washington	-	-	-	-	-
Wisconsin	X	X	-	X	-
Wyoming	X	X	-	-	-

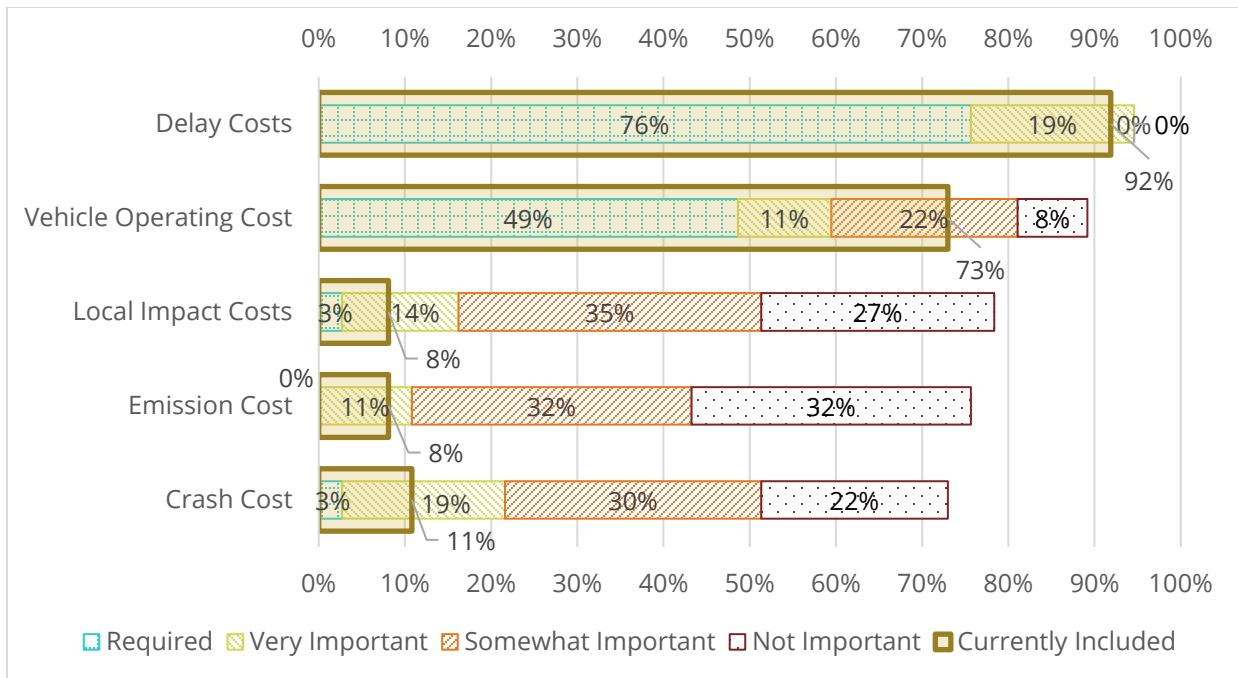


Figure 4.6 Inclusion and importance of RUC components.

The vehicle operating cost can be further divided into costs associated with fuel consumption, maintenance and repair, tire wear, oil consumption, and depreciation. The importance of these components as per the respondents is shown in Figure 4.7. Fuel cost and maintenance and repair costs are considered as required by more respondents than the remaining components.

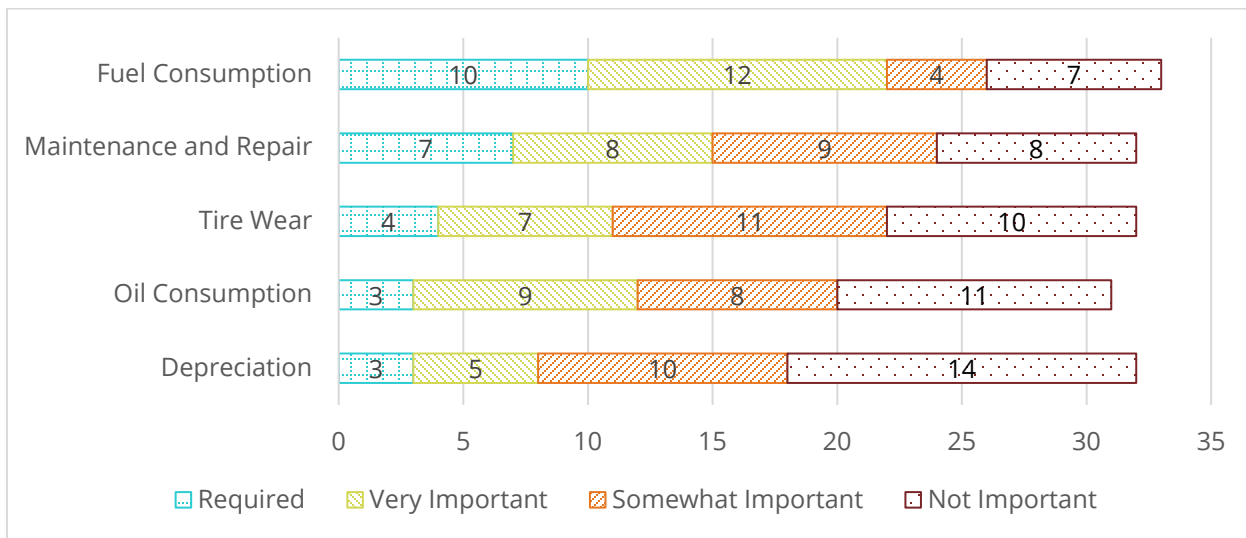


Figure 4.7 Importance of various components of vehicle operating costs.

4.3 Discussions

While existing road user calculation methodologies might have been serving well for state DOTs, several improvements can be made. First, different values of the hourly time value of money can be considered for various locations in the state. This ensures that both the

construction costs as represented by the bid amounts and the RUCs account for the regional economic conditions while evaluating the bids. Second, a consistent methodology and easy-to-use tool should be developed to ease the use of the RUCs in more projects and reduce subjective biases. Third, the rates such as the value of time and fuel costs should be updated regularly to ensure that the values represent the current market conditions. Fourth, the use of more components will ensure accounting for the broader impact of the road closures. Finally, the RUC calculation methodology and tool should balance the effort required to compute RUC and the accuracy of the RUC value.

4.4 Conclusions

Many state DOTs have developed their state-specific methodologies to compute RUCs for various purposes including incentives/disincentives determination, A+B contract evaluation, and lane rental cost determination. Some state DOTs lack any systematic RUCs calculation methodologies while others had varied methodologies within the same state DOT. Even if the road user calculation methodology is developed for a state DOT, the RUCs are not calculated for all projects. The decision on whether to calculate the RUCs primarily depends on the duration and location of the projects. Most state DOTs prefer a spreadsheet-based or web-based tool to automate the RUC calculation. The delay cost and vehicle operating costs are the two most widely used components of the RUCs.

The findings of the study represent the most comprehensive comparison of the current practices of calculating and utilizing the RUCs in various state DOTs in the U.S. The findings are expected to aid state DOTs in developing a new RUC calculation methodology or improving the existing one.

Chapter 5 Framework to Calculate RUCs

This chapter develops a framework to compute RUCs for roadway projects. The framework is developed based on the findings from the literature review and nationwide survey questionnaire. The framework is implemented as a spreadsheet-based tool to ease the computation of the RUC. The framework can be divided into two components: a) data collection and processing and b) RUC calculation. The framework is implemented as a spreadsheet-based tool that is briefly discussed at the end of this chapter.

5.1 Data Collection

The RUC calculation requires project-specific and standard datasets. Major project-specific data attributes include:

- Average Annual Daily Traffic (AADT),
- Location (e.g., county),
- Project Year (e.g., 2020),
- Speed limits (e.g., posted, work zone, and detour speed limits),
- Length of the work zone, detour, etc., and
- Crash statistics (such as count and severity of crashes).

These data attributes can be obtained from various existing tools that TDOT uses. Major standard datasets from outside sources include:

- Median household income,
- Hourly wage rates,
- Consumer Price Index (CPI),
- Average Vehicle Occupancy (AVO) factors,
- Fuel consumption rates (gal/mile),
- The unit price of fuel,
- Vehicle operating costs per mile (\$/mile),
- Comprehensive crash costs,
- Crash Modification Factors (CMF),
- Emission rates (grams/mile), and
- The unit cost of emission (\$/ton).

These attributes need to be collected from other sources such as FHWA, Bureau of Labor Statistics (BLS), AASHTO, American Automobile Association (AAA), and American Transportation Research Institute (ATRI).

Some of the data needs to be processed for further use in the RUC calculation. For example, the framework may need the number of crashes by severity. However, existing tools at TDOT may provide details for each crash. Once all required datasets are collected and processed, they can be used to compute the RUC.

5.2 RUC Calculation

The RUC consists of five sub-components a) delay cost, b) vehicle operating cost, c) crash cost, d) emission cost, and e) local impact cost. Initially, the daily cost associated with each sub-

component is calculated. For a multi-day project, this daily cost is multiplied by the number of days the roads are closed to get the total RUC.

Delay Cost

The delay cost represents the additional cost incurred by the road users because of the extra time taken while driving through a work zone or taking a detour. The total delay cost can be calculated as the sum of delay costs experienced by distinct types of vehicles that may drive through the work zone or take a detour:

$$\text{Delay Cost} = \sum(\text{Hourly VOT per Vehicle} * \text{Number of Vehicles} * \text{Delay Per Vehicle}) \quad (2)$$

The hourly Value of Time (VOT) varies by the type of vehicle (auto or truck) and trip purposes (personal or business). The hourly VOT also should either be based on the project year data or need to be adjusted to account for inflation if previous year data are used. For example, if annual inflation is $i\%$ and data from n years ago was used, then the adjusted hourly VOT can be calculated as:

$$\text{Adjusted Hourly VOT} = \text{Hourly VOT} * (1 + i)^n \quad (3)$$

Delay per vehicle depends on factors such as whether the specific vehicle took a detour, various speed limits, and the length of the work zone. Formulas to compute relevant components of the delay costs are presented below. The first three formulas are used to compute VOT for various scenarios and the latter two are used to compute delays per vehicle.

Hourly VOT for Auto – Personal Trip

The VOT for auto for a personal trip can be calculated based on the median household income, hourly multiplier, and Average Vehicle Occupancy (AVO) as follows:

$$\text{Hourly VOT for Auto} = (\text{Median Household Income} / 2080) * \text{Hourly Multiplier} * \text{AVO} \quad (4)$$

First, the median household income is converted to hourly equivalent by dividing it by 2080. Then, the hourly multiplier adjusts the hourly value to per person instead of per household. Finally, the AVO accounts for the multiple occupants in the vehicle.

Hourly VOT for Auto – Business Trip

The VOT for auto for a business trip uses hourly wage instead of household income as shown in the equation below.

$$\text{Hourly VOT for Auto} = \text{Average Hourly Wage and Benefit} * \text{Hourly Multiplier} * \text{AVO} \quad (5)$$

The hourly multiplier and AVO varies by trip mode and trip purpose.

Hourly VOT for Truck

The VOT for a truck can be calculated based on the average hourly wage and benefit for truck drivers, AVO, and hourly multiplier. FHWA recommends the hourly multiplier for a truck as 100% for trucks which indicates that 100% of the hourly wages should be considered for VOT calculation. FHWA recommends an AVO value of 1.0 for trucks which indicates that usually, only one person drives a truck without any additional person.

$$\text{Hourly VOT for Truck} = \text{Average Hourly Wage and Benefit} * \text{Hourly Multiplier} * \text{AVO} \quad (6)$$

Delay Time – Not Taking Detour

For vehicles that are not taking a detour, the delay time can be calculated as the difference between the time required to travel at the work zone speed limit and the time required to travel at the posted speed.

$$\text{Delay Time (Not Taking Detour)} = \frac{\text{Work Zone Length}}{\text{Work Zone Speed Limit}} - \frac{\text{Work Zone Length}}{\text{Posted Speed Limit}} \quad (7)$$

Delay Time – Taking Detour

For vehicles that are taking a detour, the delay time can be calculated as the difference between the time required to travel along the detour at the detour speed limit and the time required to travel along the original route at the posted speed limit.

$$\text{Delay Time (Taking Detour)} = \frac{\text{Length Along the Detour Route}}{\text{Detour Speed Limit}} - \frac{\text{Length Along the Original Route}}{\text{Posted Speed Limit}} \quad (8)$$

Note that the above delay time calculations are based on free-flow traffic scenarios. If a forced-flow scenario is to be considered for higher accuracy, more detailed calculations and data inputs will be required.

Vehicle Operating Cost

The vehicle operating cost is the additional cost associated with increased vehicle usage (distance or duration). It mainly consists of costs associated with fuel, maintenance and repair, tire wear, oil consumption, and depreciation. These costs can vary widely based on factors such as vehicle types, vehicle make and model, and road conditions. The total vehicle operating cost can be computed as:

$$\begin{aligned} \text{Vehicle Operating Cost} & \quad (9) \\ & = \sum (\text{Unit Cost per Mile} * \text{Distance Travelled per Vehicle} * \text{Number of Vehicles}) \end{aligned}$$

However, the RUC should include only the additional vehicle operating costs compared to the original scenario without road closure. Thus, first, the expected vehicle operating cost should be calculated using the original distance and original unit cost per mile. Then, the new expected vehicle operating cost should be calculated with the actual distances and unit costs per mile. The new expected vehicle operating cost should be calculated for two scenarios: a) vehicle not taking a detour and b) vehicle taking a detour.

When a vehicle is not taking a detour, the distance traveled per vehicle does not change for the actual condition (work zone) compared to the base condition (no-work zone). However, the unit cost per mile may vary based on the operating speed depending on the data source used. As such, even if total distance does not change, the unit cost per mile can change which may result in an increased or even reduced vehicle operating cost.

When a vehicle is taking a detour, the new distance will be the distance of the detour, and the unit cost per mile will depend on the detour speed. In general, detours are longer than the original route. As such, the total vehicle operating cost would tend to increase while taking a detour.

Unit Cost Per Mile

The unit cost per mile can be calculated for various vehicle types using vehicle characteristics and roadway characteristics. However, such a process requires an extensive amount of data.

Thus, data produced from other sources such as AASHTO, AAA, and ATRI can be used. The AAA, for example, is an organization that publishes the actual cost of owning and driving an auto in the United States, and it is updated annually (AAA, 2019). Similarly, ATRI publishes survey-based operating costs for trucks and is published annually as well (Murray & Glidewell, 2019).

AASHTO provides fuel consumption per mile which varies by the operating speed. However, AASHTO does not provide costs for non-fuel components. AAA and ATRI provide data for both fuel and non-fuel costs. However, it provides a single unit cost per mile irrespective of the operating speed. Thus, if road users are not taking a detour, the vehicle operating cost will not change from that method since the unit cost per mile and distance traveled per vehicle will remain the same in the base condition as well as work zone condition. Using AASHTO values also enables utilizing the local fuel cost for the state or county while AAA and ATRI values are nationwide values that require further adjustment if a localized value is desired.

As AASHTO does not provide non-fuel costs, a ratio of the total cost to fuel cost is generated from AAA and ATRI data. This ratio is then used to adjust the cost calculated from AASHTO to include non-fuel costs. Further, to account for the strengths of both data sources, an average of the additional vehicle operating cost calculated from the two datasets can also be used.

AASHTO provides fuel consumption (gallon/mile) data for various autos and trucks which can be multiplied with the current fuel price (\$/gallon) to get the unit cost per mile.

$$\text{Cost per mile} = \text{Fuel Consumption per mile} * \text{Unit Cost of Fuel} \quad (10)$$

Alternately, if more extensive vehicle operating cost is desired, data from AAA and ATRI can be used which includes non-fuel costs. For example, the data provided by AAA for autos includes the following costs:

- Fuel
- Maintenance, Repair, Tire
- Insurance
- License, Registration, Taxes
- Depreciation
- Finance Charges

Out of those the insurance, licenses, registration, and taxes are not expected to increase because of the additional distance traveled. As such, these components can be excluded while calculating the unit cost per mile. Similarly, the data provided by ATRI for trucks include the following costs:

- Fuel
- Truck/Trailer Lease or Purchase Payment
- Repair and Maintenance
- Truck Insurance Premiums
- Permits and Licenses
- Tires
- Tolls

From this list, the truck insurance premiums, permits and licenses, and tolls can be excluded while calculating the unit cost per mile.

While TDOT engineers should be able to provide the latest fuel cost per gallon from various sources, the data from AAA and ATRI may be outdated over time. As such, the data from AAA, ATRI, and Texas Transportation Institute (TTI) should be adjusted for inflation to the project year using the same method used to adjust Hourly VOT for delay cost.

Crash Cost

The crash cost quantifies the increased likelihood of crashes because of the presence of work zones. The crash cost can be calculated as the sum of crash costs for vehicles taking a detour and vehicles not taking a detour.

$$\begin{aligned} \text{Crash Cost for Vehicles Not Taking Detour} & \quad (11) \\ & = \sum (\text{Unit Crash Cost} * \text{Expected Increase in Crash Rate} * \text{Vehicle Miles}) \end{aligned}$$

$$\begin{aligned} \text{Crash Cost for Vehicles Taking Detour} & \quad (12) \\ & = \sum (\text{Unit Crash Cost} * \text{Crash Rate} * \text{Additional Vehicle Miles}) \end{aligned}$$

For vehicles not taking a detour, the total vehicle mile does not increase but the crash rate increases because of the work zone. For vehicles taking a detour, the crash rate is assumed to be constant, but vehicles will travel additional distances which will increase the likelihood of crashes.

Unit Crash Cost

The unit crash cost varies depending on the severity of the crash. The crashes are generally classified into five severity levels as shown in the table below.

TABLE 5.1
KABCO CRASH SEVERITY RATING

Code	Severity	Description
K	Fatal	An injury that results in death within 30 days of crash occurrence
A	Incapacitating	Any injury other than a fatal injury that prevents the injured person from walking, driving, or normally continuing the activities the person was capable of performing before the injury occurred (e.g., severe lacerations, broken limbs, damaged skull)
B	Injury Evident	Any injury other than a fatal injury or an incapacitating injury that is evident to observers at the scene of the crash in which the injury occurred (e.g., abrasions, bruises, minor cuts)
C	Injury Possible	Any injury reported that is not a fatal, incapacitating, or non-incapacitating evident injury (e.g., pain, nausea, hysteria)
O	Property Damage Only (PDO)	Property damage to property that reduces the monetary value of that property

(Source: FHWA)

Standard unit crash costs can be obtained from reports such as *Crash Costs for Highway Safety Analysis* (FHWA, 2018). This national-level data can be adjusted for a specific state using the per capita income ratio.

$$\begin{aligned} \text{Unit Crash Cost for a Specific State} & \qquad \qquad \qquad (13) \\ & = \text{National Unit Cost of Crash} * \frac{\text{Per Capita Income for the State}}{\text{Per Capita Income for the U.S.}} \end{aligned}$$

If the unit crash cost is not available for various severity levels, the concept of Equivalent Property Damage (EPDO) can be used along with the weights for crashes of various severities.

$$\begin{aligned} \text{Unit Crash Cost of Desired Crash Severity} & \qquad \qquad \qquad (14) \\ & = \text{Unit Crash Cost of a PDO crash} * \text{Weight for Desired Crash Severity} \end{aligned}$$

Standard values of the weights are available and are calculated based on historical crash costs for various crash severities.

Crash Rate

The historical crash rate (crashes per mile traveled) from the past several years can be calculated as:

$$\text{Historical Crash Rate} = \frac{\text{Total Number of Crashes}}{\text{Total Vehicle Miles Travelled}} \qquad \qquad \qquad (15)$$

The historical number of crashes around the work zone area can be obtained from TDOT systems that store crash data. This data should cover several years of crashes (e.g., 5 years) if available. Also, the data should represent crashes from the work zone and a few miles beyond the work zones in both directions of the roadway. This will ensure that the crash rates are generalized rather than over-localized. For example, if the crash data is collected only from the work zone length, any previous crash that might have occurred just a few feet from the work zone would be excluded from the data while calculating the historical crash rate. Similarly, if there was only one crash in 20 miles distance and it occurred within the work zone, the crash rate would be significantly higher when only the work zone length is used to compute the historical crash rate. Thus, historical crash data from a wider length should be selected to get a more reliable historical crash rate.

If EPDO is to be used, the total number of crashes can be replaced with the number of EPDO crashes which can be obtained as:

$$\begin{aligned} \text{Total Number of Crash} & \qquad \qquad \qquad (16) \\ & = \sum(\text{Number of Crash of Specific Severity} \\ & \quad * \text{Weight for the Crash Severity Compared to PDO}) \end{aligned}$$

The total vehicle miles traveled can be calculated as:

$$\begin{aligned} \text{Total Vehicle Miles Travelled} & \qquad \qquad \qquad (17) \\ & = \text{Length of Study Section} * \text{Average AADT} \\ & \quad * \text{Number of Years of Crash Data} * 365 \end{aligned}$$

For vehicles not taking a detour, the expected crash rate will increase. This increased crash rate can be computed using Crash Modification Factors (CMFs). A CMF represents the expected ratio of crashes in the new scenario compared to the base scenario. In this case, the new scenario is

the presence of a work zone, and the base scenario is the no-work zone condition. The CMFs are calculated from historical data, and standard data are available from CMF Clearinghouse.

Using the standard CMF for work zone, the expected crash rate when work zone is present can be calculated based on the historical crash data:

$$\text{Expected Crash Rate} = \text{Historical Crash Rate} * \text{CMF} \quad (18)$$

Now, the expected increase in the number of crashes per mile can be calculated as:

$$\begin{aligned} \text{Expected Increase in Crash Rate} & \quad (19) \\ &= \text{Expected Crash Rate With Workzone} - \text{Historical Crash Rate Without Work Zone} \\ &= \text{Historical Crashes Rate} * (\text{CMF} - 1) \end{aligned}$$

Vehicle Miles

The total miles represent the total miles traveled by all vehicles. For vehicles not taking a detour, it can be obtained as the product of the distance traveled by each vehicle along the original route and the number of vehicles not taking a detour.

$$\begin{aligned} \text{Vehicle Miles} &= \text{Distance Travelled by Each Vehicle} \quad (20) \\ &* \text{Number of Vehicles Not Taking Detour} \end{aligned}$$

For vehicles taking a detour, the additional vehicle miles can be calculated as:

$$\text{Additional Vehicle Miles} = (\text{Detour Distance} - \text{Original Distance}) * \text{Number of Vehicles Taking Detour} \quad (21)$$

Emission Cost

The pollutants emitted from vehicles have an adverse effect on human health and the environment. The emission cost quantifies this impact of additional emission resulting from the additional driving because of the work zones. The emission cost generally represents a smaller percentage of the RUC. The major pollutants that are generally considered for emission costs are Carbon Monoxide (CO), Nitrogen Oxides (NO_x), Sulfur Oxides (SO_x), Volatile organic compounds (VOCs), and Particulate Matter (PM 2.5). The emission cost can be calculated as:

$$\begin{aligned} \text{Total Emission Cost} & \quad (22) \\ &= \sum (\text{Unit Cost of Emission} * \text{Emission per Mile} \\ &* \text{Total Vehicle Miles Travelled}) \end{aligned}$$

However, the emission cost for RUC should only include an increase in emission resulting from the work zone. Thus, the total emissions can be computed for the base scenario without the work zone and the new scenario with the work zone. For the new scenario, the total emission can be calculated as the sum of emissions from vehicles not taking a detour and emissions from vehicles taking a detour. For the vehicles taking a detour, the total vehicle miles traveled will increase and emissions per mile can change depending on the speed limits. For the vehicles not taking a detour, the total vehicle miles will not change, but the speed for the work zone will change which will affect the emissions per mile.

Unit Cost of Emission

Standard values of unit costs of emissions are published in HERS-ST. These values should be adjusted to the current year as other costs discussed before. These values are generally provided in dollars per ton.

Emission per Mile

Various models are available to compute emissions per mile. The MOtor Vehicle Emission Simulator (MOVES) developed by Environmental Protection Agency (EPA) is a powerful tool that can be used to estimate emissions per mile. The emission per mile generated by MOVES varies by several factors such as the area type (urban or rural) and vehicle operating speed.

Total Vehicle Miles Traveled

The total vehicle miles traveled can be computed using the number of vehicles and the distance traveled by each vehicle.

Local Impact Cost

The local impact cost includes various costs such as the reduced revenue in the nearby businesses and the impact on the road users in the connected road network. To quantifying these impacts, a detailed analysis of the network using a significant amount of additional information will be needed. Thus, the local impact cost is the most challenging cost to accurately quantify and is generally neglected by state DOTs while computing RUCs. The local impact cost calculation is not considered in this framework and the accompanying tool either. However, this is an area that should be considered for future research.

Chapter 6 Spreadsheet-Based Tool and Case Study

This chapter gives a brief overview of the tool and a sample case study result.

6.1 Tool to Implement the Framework

Many research projects produce theoretical frameworks without any tangible tool to implement the framework. When such implementations are not provided as the deliverables of the project, the results of the study are often not used for practical applications. To avoid such a scenario, this study developed a tool to implement the framework and ease the calculation of the RUC.

Three major options were available to implement a framework: a) spreadsheet-based tool, b) web-based tool, and c) desktop-based tool. A spreadsheet-based tool is generally easy to learn, easy to use, and does not require any installation. However, all the relevant data needs to be entered manually. Also, systematic collection and analysis of historical RUC data would require additional effort when a spreadsheet-based tool is used. A web-based tool resides in the server and does not need to be installed on any computer. As such, web-based tools are easier to update and maintain compared to the desktop-based tools that need to be installed on each computer. Both web-based and desktop-based tools can easily be connected to a systematic database to retrieve relevant data from existing databases and save the results. This would allow for easier retrieval and analysis of historical RUC data in the future. A web-based tool was initially proposed to TDOT. However, because of administrative and other reasons, TDOT chose a spreadsheet-based tool. This section gives a brief overview of the TDOT RUC Calculation Tool (TRCT).

The TRCT consists of several sheets including a) Instructions, b) Main Sheet, c) Value of Time, d) VOT Data, e) Delay Cost, f) Vehicle Operating Cost, g) VOC Data, h) Crash Cost, i) CC Data, j) Emission Cost, k) EC Data, l) Options, and m) Inflation Indexes. The spreadsheet follows the principle of Separation of Concerns (SoC) that is widely used in computer programming. In SoC, the code (or calculations in this context) are separated into multiple components (or sheets in this context) – each of them serving a specific purpose. Thus, it enables users to compute and test a specific subset of calculations when desired.

The sheet titles and the input fields in the spreadsheet tool are color coded to ease its use (Figure 6.1).

Color Codes
Inputs: Main Inputs: Enter a value manually or select a value from the dropdown.
Calculations: Calculate values - no need to enter anything.
Outputs: Outputs from the calculations.
Standard Data Input: Standard data that should be updated regularly when newer data are available.

Figure 6.1 Color coding for TRCT.

The sheets are protected to disable unintended accidental changes. Only the input fields can be edited by default. The cells for standard data inputs are also enabled by default. If users need to edit any protected field, they can go to Review -> Unprotect Sheet to enable editing anything in the sheet as shown in the Figure. To protect the sheet from editing afterwards, users can go to Review -> Protect Sheet -> OK. If it asks for password, use "ETSU" without the quotes.

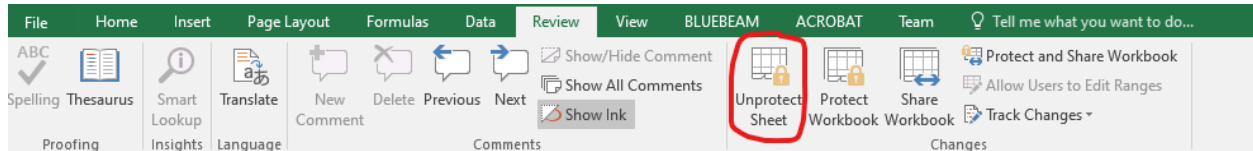



Figure 6.2 Unprotecting TRCT sheet for editing.


A brief description of each sheet in the TRCT tool is provided below.

Instructions

The *Instructions* sheet contains some important points and steps to use the tool. A screenshot of a portion of the sheet is shown in Figure 6.4.



Welcome to Tennessee Department of Transportation (TDOT) Road User Cost (RUC) Calculation Tool (TRCT)



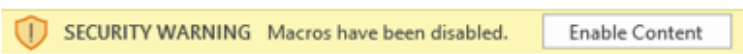
Developed by

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The TRCT implements the findings of the TDOT funded research project #RES#2020-21 Calculating Road User Cost for Specific Sections of Highway for Use in Alternative Contracting Project. This tool can be used to compute RUC with minimal effort.

Important Points

- If a security warning about Macros shows up, please click Enable Content. All the calculations will work without enabling the Macros, but the buttons below will not work.



- If another security warning shows up asking if you want to make this file a Trusted Document, click "Yes" but **DO NOT** check the "Do not ask me again for network files" checkbox.

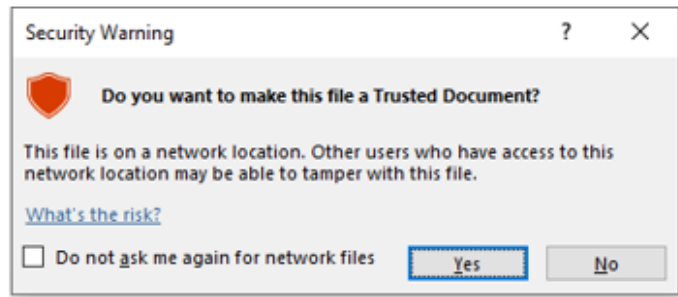


Figure 6.3 Screenshot of the Instructions Sheet of TRCT.

Main Sheet

All the project-specific data should be entered in the *Main* sheet. The values entered here will be referenced in other sheets, as necessary and relevant. The final outputs such as the daily RUC are also presented in the same sheet. This would allow users to easily update the input and see the changes reflected directly in the same sheet. If the user is not interested in the

details of the calculation, this sheet contains everything. A screenshot of a portion of the sheet is shown in Figure 6.4.

Inputs

General Information

Project Number	SampleSullivan	
Project Location Detail	SampleSullivan	
Project Description	This project is used in the report.	

Project Information

County	Sullivan	
Project Year	2021	
Area Type	Rural	

General Traffic Data

AADT	33,276	
Supplied AADT Type	AADT for Affected Direction(s)	(Either one way traffic is affected and one way AADT is provided) OR (Two way traffic is affected and two way AADT is provided)
AADT to be Used	33,276	
Percentage of Car	69%	%
Trip Mode	All Trip Mode	

Work Zone Configurations

Posted Speed Limit	65	mph	
Work Zone Speed Limit	55	mph	(If complete closure, use same speed as detour speed limit)
Detour Speed Limit	55	mph	(If detour is not provided, use same speed as work zone speed limit.)
Construction Duration	120	days	
Length of Work Zone (Reduced Speed Limit)	0.75	miles	(If complete closure, use same length as the original route)
Length of Original Route	5.37	miles	
Length of Detour Route	8.45	miles	(If detour is not provided, use same length as the original route)
Likelihood of Taking Detour	Some Will Take Detour		
Percentage of Vehicles Taking Detour	25%	%	

Figure 6.4 Screenshot of the Main Sheet of TRCT.

Value of Time

The *Value of Time* sheet computes the hourly value for auto and truck. The computed values are referenced in the *Delay Cost* sheet.

VOT Data

The VOT Data sheet contains standard data for Value of Time Calculation.

Delay Cost

The *Delay Cost* sheet calculates the delay cost component of the RUC for vehicles taking a detour and not taking a detour. It utilizes the hourly value of time computed in the *Value of Time* sheet.

Vehicle Operating Cost

The *Vehicle Operating Cost* sheet computes the vehicle operating costs using AASHTO, AAA, and ATRI data.

VOC Data

The *VOC Data* sheet includes standard data for vehicle operating cost calculation.

Crash Cost

The *Crash Cost* sheet computes crash cost using crash rates and the crash modification factors for various crash severities.

CC Data

The *CC Data* contains standard data relevant for crash cost calculation.

Emission Cost

The *Emission Cost* sheet computes the total dollar equivalent of the additional emission resulting from the road closure.

EC Data

The *EC Data* sheet contains data relevant for emission cost calculation. Most of the data are produced using EPA's MOVES tool.

Options

Options Data sheet stores distinct options that are shown as a drop-down list in the Main Sheet. It also provides a brief description of those options.

Inflation Indexes

The *Inflation Indexes* stores historical CPI data and computes annual CPI that is used throughout the sheet to adjust various costs to the current dollar values.

6.2 Sample Case Study

A case study was conducted using the tool developed in the previous chapter. Mr. Jamie Fitzpatrick identified a sample project and provided relevant information for the project. The most important project-specific data attributes used for the case study are listed in the table below.

TABLE 6.1
PROJECT SPECIFIC DATA INPUT FOR THE CASE STUDY

Variable	Value
Project Information	
County	Sullivan
Project Year	2021
Area Type	Rural
General Traffic Data	
AADT	33,276
Supplied AADT Type	AADT for Affected Direction(s)
Percentage of Car	69%
Trip Mode	All Trip Mode
Work Zone Configurations	
Posted Speed Limit	65 mph
Work Zone Speed Limit	55 mph
Detour Speed Limit	55 mph
Construction Duration	120 days
Length of Work Zone (Reduced Speed Limit)	0.75 miles
Length of Original Route	5.37 miles
Length of Detour Route	8.45 miles
Likelihood of Taking Detour	Some Will Take Detour
Work Zone Configuration	
Number of Years of Crash Data	4
Length of Section Corresponding to Crash Data	0.60
Average AADT from the Historical Data	36,296
Total Number of Crashes from the Historical Data	
K - Fatal Injury	1
A - Incapacitating Injury	0
B - Non-Incapacitating	5
C - Possible Injury	0
O - Property damages only	16
Miscellaneous	
Operating Cost Calculation	Average
Average Gasoline Price	\$2.26/gallon

Variable	Value
Average Diesel Price	\$2.30/gallon

Based on these inputs and other standard datasets, the computed RUCs are tabulated below.

TABLE 6.2
RUC OUTPUTS

Item	Value
Delay Cost	\$17,556.47
Vehicle Operating Cost	\$16,938.71
Crash Cost	\$15,578.30
Emission Cost	\$88.78
Total RUC Per Day	\$50,162.27

If three contractors bid on the project with the various hypothetical amounts and number of days to complete the project as tabulated below, we can evaluate the best contract using A+B.

TABLE 6.3
HYPOTHETICAL BIDS FROM CONTRACTOR

Bidder	Bid Amount	Number of Days
Bidder 1	\$2,500,000	120
Bidder 2	\$2,400,000	130
Bidder 3	\$2,750,000	115
Bidder 4	\$2,550,000	118

The A+B values for each contractor can be calculated as:

$$A + B = \text{Bid Amount} + \text{Daily RUC} * \text{Number of Days}$$

Thus, for Bidder 1, $A+B = \$2,500,000 + \$50,162.27 * 120 = \$8,519,472.40$

For Bidder 2, $A+B = \$2,400,000 + \$50,162.27 * 130 = \$8,921,095.10$

For Bidder 3, $A+B = \$2,750,000 + \$50,162.27 * 115 = \$8,518,661.05$

For Bidder 4, $A+B = \$2,550,000 + \$50,162.27 * 118 = \$8,469,147.86$

Although the apparent lowest bidder was Bidder 2 with \$2,400,000, the bidder expects to complete the project with 130 days which is the highest duration of all. Bidder 3 expects to complete the project in the lowest number of days (115). However, neither of them has the lowest A+B value. Bidder 4 which expects to complete the project in 118 days for \$2,550,000 has the lowest A+B and should be selected as the best bidder for the project. Bidder 4's proposal will optimize the use of agency funds and the road users' inconvenience.

Chapter 7 Results and Discussions

Despite the importance of the RUC, TDOT currently lacks a systematic methodology to compute RUCs. This study reviewed existing studies on the topic and conducted a nationwide survey to identify the best practices of computing and utilizing RUCs. Subsequently, a TDOT-specific methodology and an accompanying tool were developed to compute RUC. The major findings and recommendations are briefly discussed below.

7.1 Current Practices of Calculating and Utilizing RUCs

The concept of the RUC existed as early as 1986. Traditionally, RUCs were computed primarily for the benefit-cost analysis and life-cycle-cost analysis for roadway and bridge projects. Nowadays, the RUC is also used:

- As a factor to select the best bidder for A+B contracting,
- To determine daily lane rental costs, and
- A major factor to determine early completion incentives and liquidated damages.

Most of the state DOTs reported calculating RUCs. The majority of state DOTs stated that they have developed their state-specific methodology to compute the RUC. In general, these methodologies rely on the foundations developed by FHWA and AASHTO.

Over 80% of the state DOTs are utilizing spreadsheet-based tools and the majority of the respondents prefer a spreadsheet-based tool over a web-based or desktop-based tool. A web-based tool is the second most preferred tool type that is preferred by 35% of the states. A spreadsheet-based tool is easy to learn, easy to use, and does not require any installation. However, all the relevant data needs to be entered manually. Also, systematic collection and analysis of historical RUC data would require additional effort when a spreadsheet-based tool is used. A web-based tool resides on a server and does not need to be installed on any computer. As such, a web-based tool is generally easier to update and maintain compared to a desktop-based tool that needs to be installed on each computer. Both web-based and desktop-based tools can easily be connected to a systematic database to retrieve relevant data from existing databases and save the results. This would allow for easier retrieval and analysis of historical RUC data in the future.

7.2 Framework and Tool to Compute RUC

A framework and an accompanying TDOT-specific tool were developed to ease calculating RUCs in-house. The spreadsheet-based tool attempts to minimize the effort required to compute the RUC while maximizing the accuracy by accounting for the majority of the RUC component and considering the effect of inflation wherever relevant to adjust historical standard datasets. All the calculations in the tool are automated and users can observe detailed calculations for each RUC component. Local impact cost calculation was not implemented in the tool as it requires a significant amount of additional project-specific data. Such data are not easily available and generating such data would take a considerable time and effort for each project.

The tool is also developed with potential future data update in mind. For example, if a user obtains newer data for median salary for various counties in the state, they can update the

data in VOT and the Data Year field. Such standard data are included in separate sheets to ease the data updating process.

7.3 Discussions

This study presents the most recent and comprehensive results from the nationwide survey of current practices of calculating and utilizing RUCs. The framework and the accompanying tool developed from the findings of the study enable TDOT to compute a comprehensive RUC that includes a) delay cost, b) vehicle operating cost, c) crash cost, and d) emission cost. The easy-to-use tool is expected to enable TDOT to compute RUCs without relying on outside consultants. The tool provides an opportunity to update relevant data such as median wages. At the same time, to ensure that values are relevant even if TDOT does not update such standard data, inflation is accounted for all calculations based on historical CPIs. Proper use of this tool to compute RUCs and decisions based on RUCs will ensure that road users' inconvenience is minimized to optimize the overall project cost.

Deliverables

The major deliverables of the project are the quarterly reports, final report, tool to compute RUC, on-site training, and online training module. Quarterly reports have been regularly submitted to TDOT. TDOT RUC Calculation Tool (TRCT) has been developed and is being finalized. The final version of the tool is submitted to TDOT along with this final report. Due to COVID-19, the researchers have been meeting virtually with TDOT representatives, and a representative has been trained online.

Chapter 8 Conclusions and Recommendations

This study reviewed existing literature, conducted a nationwide survey, and developed a framework and an accompanying tool to compute RUC. The tool is expected to aid TDOT engineers in quickly and accurately computing the RUC. The recommendations, significance of the study, and limitations of the study are presented below.

8.1 Recommendations

The following recommendations will ensure better use of the tool for future projects:

- TDOT should identify and properly document various internal sources of project-specific data required for the RUC tool.
- TDOT should conduct some pilot studies at the beginning. Multiple members from TDOT should review the results and make any adjustments to the tool if necessary.
- TDOT should assign one or more staff members as default personnel to compute RUCs for relevant future projects.
- TDOT should continue to collect RUC data systematically and potentially share RUC data to the public and contractors to communicate the importance of balancing the direct TDOT cost and indirect RUC that affect the contractor selection process.

Additionally, the following recommendations are provided for potential future research projects:

- TDOT should consider updating this framework and tool to account for additional delays resulting from queues and address the varying delays experienced by road users throughout the day.
- TDOT should consider updating this framework and tool to enable lane rental cost calculation.
- TDOT should consider developing a web-based tool in the future so that the data from previous projects are easily accessible when required.
- TDOT should consider developing a methodology to compute the local impact cost for mega projects.
- TDOT should consider expanding this framework and tool for its use in more complicated projects such as intersection and ramps that involves multiple routes.

8.2 Significance of the Study

The framework and tool developed in this study are expected to aid TDOT in computing and utilizing the RUC for future projects. The RUC can be used for various purposes including the evaluation of A+B contracts, lane rental cost, incentives, and liquidated damages. Proper use of RUC will ensure that TDOT will minimize the overall project cost by not only looking at the direct agency cost but also the indirect costs incurred by road users.

8.2 Limitations of the Study

This framework and methodology developed in this tool do not include the local impact cost component of the RUC.

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Appendices

Standard Datasets

TABLE A.1

DISTRIBUTION OF VEHICLE MILES BY TRIP PURPOSE

Travel Type	Recommended Values	
	Personal	Business
Local Travel	95.4%	4.6%
Intercity Travel	78.6%	21.4%

(Source: Revised Departmental Guidance on Valuation of Travel Time in Economic Analysis (*Revised Value of Travel Time Guidance.Pdf*, 2015.))

TABLE A.2

RECOMMENDED PERCENTAGE VALUE OF TIME AS THE HOURLY MULTIPLIER BASED ON TRIP MODE AND PURPOSE

Transportation Mode and Trip Purpose	Recommended Value of Time
Auto	
Personal (local)	50% of the wage rate
Personal (intercity)	70% of the wage rate
Business	100% of the wage rate
Truck	
In-Vehicle Business	100% of total compensation
Excess (waiting time) Business	100% of total compensation

(Source: U.S. Department of Transportation. 1997)

TABLE A.3

AVERAGE VEHICLE OCCUPANCY FACTOR FOR TRAVEL TIME RELIABILITY MEASURE BY FHWA

Vehicle Type	Average Vehicle Occupancy Factor
Auto	1.7
Trucks	1.0

(Source: [FHWA National Household Travel Survey \(2018\)](#))

TABLE A.4
FUEL CONSUMPTION (GALLON PER MILES)

Operating Speed (mph)	Auto	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

(Source: AASHTO (2010))

TABLE A.5
RUC PASSENGER VEHICLE OPERATING COST PER MILE (2019)

Cost Element	Weighted Average
Fuel	\$0.12
Maintenance, Repair, Tire	\$0.09
Insurance	\$0.10
License, Registration, Taxes	\$0.07
Depreciation	\$0.29
Finance Charges	\$0.08

Source: AAA and TTI (*RUC Memo, 2020*)

TABLE A.6
ESTIMATE OF TRUCK COSTS PER MILE: 2019 DATA ESTIMATED BY TTI

Estimated Cost Per Mile	2019
Fuel	\$0.39
Truck/Trailer Lease or Purchase Payment	\$0.27
Repair and Maintenance	\$0.18
Truck Insurance Premiums	\$0.09
Permits and Licenses	\$0.03
Tires	\$0.04
Tolls	\$0.03

Source: ATRI and TTI (*RUC Memo, 2020*)

TABLE A.7
ADDITIONAL DATA SOURCES

Data	Source	Update Frequency
Median household income Auto	U.S. Census Bureau -State and County Quick Facts Per capita money income in the past 12 months.	Annual
Wages and Benefits for Truck Drivers	U.S Bureau of labor statistics for occupational employment and wages.	Annual

TABLE A.8
2001 CRASH COST FOR HIGHWAY SAFETY ANALYSIS (2018)

Crash Type	Crash Cost
Fatal (K)	\$11,295,400
Disabling Injury (A)	\$655,000
Evident Injury (B)	\$198,500
Possible Injury (C)	\$125,600
PDO (O)	\$11,900

TABLE A.9

UNIT COST CRASH BY CRASH SEVERITY CORRESPONDING TO THE EQUIVALENT PROPERTY DAMAGE ONLY (EPDO)

Crash Type	Comprehensive Crash cost	Weight Compared to PDO
Fatal (K)	\$6,229,446.05	567.05
Disabling Injury (A)	\$330,101.17	30.05
Evident Injury (B)	\$120,586.72	10.98
Possible Injury (C)	\$67,962.11	6.19
PDO (O)	\$10,985.72	1.00

TABLE A.10

WORK ZONE CMF FOR TEMPORARY LANE CLOSURE ON FREEWAY (FHWA, 2011)

Crash Severity	CMF
All	1.77
Property Damages Only (PDO)	1.90
Serious Injury, Minor Injury	1.60

TABLE A.11

HERS-ST UNIT COST OF EMISSION (2000 DOLLAR VALUES)

Pollutant	Damage Cost (\$/ton)	Adjustment Factors	
		Urban	Rural
Carbon Monoxide	\$100	1	0.5
Volatile Organic Compounds	\$2,750	1.5	1
Nitrogen Oxides	\$3,625	1.5	1
Sulfur Dioxide	\$8,400	1.5	1
Fine Particulate Matter (PM 2.5)	\$4,825	1	0.5

Nationwide Survey

Survey on Road User Cost Calculation Methodology

Dear Highway Agency Representative,

Thank you for participating in this survey on road user cost calculation methodologies! This survey is a part of a research project funded by the Tennessee Department of Transportation (TDOT).

Construction activities impact the mobility of road users, which is quantified as the road users' cost. The goal of this survey is to understand the current practices of calculating road user costs in various highway agencies.

The results of the survey will be used to develop an improved road user cost calculation methodology and automation tool for TDOT. The survey should take about 15 minutes. If any questions are not relevant, you can skip the question. You can save the survey anytime and resume it via the original link. If you have any questions, you may contact K. Joseph Shrestha (shresthak@etsu.edu, 702-518-1175).

Thank you!

K. Joseph Shrestha

Assistant Professor

East Tennessee State University

Survey Questionnaire

General Information

Job Title

State

- Alabama
- Alaska
- Arizona
- Arkansas
- California
- Colorado
- Connecticut
- Delaware
- Florida
- Georgia
- Hawaii
- Idaho
- Illinois
- Indiana,
- Iowa
- Kansas
- Kentucky
- Louisiana
- Maine
- Maryland
- Massachusetts
- Michigan
- Minnesota
- Mississippi
- Missouri
- Montana
- Nebraska
- Nevada
- New Hampshire
- New Jersey
- New Mexico
- New York
- North Carolina
- North Dakota

- Ohio
- Oklahoma
- Oregon
- Pennsylvania
- Rhode Island
- South Carolina
- South Dakota
- Tennessee
- Texas
- Utah
- Vermont
- Virginia
- Washington
- West Virginia
- Wisconsin
- Wyoming

Applications of Road User Cost

Does your DOT calculate road user costs for roadway projects?

- Yes
- No

At which stage do you use the road user cost?

- Planning and Environmental
- Bidding and Contracting
- Roadway Construction

What are the current uses of road user cost in your DOT?

- To calculate early completion incentives (such as
- liquidated savings)
- To calculate late completion disincentives (such as liquidated damages)
- In accelerated construction contracts (such as no excuse bonus or locked incentives)
- As a lane rental cost for special contract types
- To evaluate special contracts such as Cost (A) + Time (B)
- To conduct Benefit-Cost Analysis
- Evaluate construction phasing options (such as nighttime construction)
- Others

If Others, please list

What are the criteria your DOT uses when determining whether road user cost needs to be included in the contract?

- Dollar value of the project
- Location of the project
- Duration of the project
- Complexity of the project
- Specific contract type only
- Others

If Others, please list

Road User Cost Calculation Methodologies

What method does your DOT use to calculate road user cost?

- AASHTO based method.
- FHWA based method.
- Your agency-specific method
- Flat rates as defined by legislation.
- Standard tools (e.g., QUEWZ, CA4PRS, VISSIM, etc.)
- No formal method
- Others

If Others, please list

How would you classify your current road user calculation method/tool?

- Spreadsheet-based tool
- Desktop tool
- Web-based tool
- Others

If Others, please list

What type of road user cost calculation tool would you prefer the most?

- Spreadsheet-based tool
- Desktop tool
- Web-based tool
- Others

Please provide a web link, if available, about your DOT's road user cost calculation method.

Please upload the user manual, document, information about your DOT's road user cost method, if available.

Please upload the road user cost calculation spreadsheet that your DOT uses, if available.

Which of the following components are included in road user cost calculation in your DOT?

- Delay Cost
- Vehicle Operation Cost
- Crash Cost
- Emission Cost
- Local Impact Cost
- Others

If Others, please list

Please mark the importance of the following components of road user costs.

	Required	Very Important	Somewhat important	Not Important
Delay Cost	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Vehicle Operating Cost	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Crash Cost	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Emission Cost	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Local Impact Cost	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Please mark the importance of the following components of road user costs.

Yes	No	I do not know
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Please mark the importance of the following components of Vehicle Operating Costs

	Required	Very Important	Somewhat important	Not Important
Fuel Consumption	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Oil Consumption	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Tire wear	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Maintenance and Repair	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Depreciation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Data Requirements for Road User Costs

What traffic data do you use for road user cost calculation?

- Hourly demand data
- Peak hour demand data
- Average daily traffic data
- Annual average daily traffic data
- Others

If Others, please list

What vehicle types do you use for traffic composition?

- Motorcycle
- Passenger car
- Passenger truck
- Light commercial truck
- Bus
- Single unit truck
- Combination truck
- Others

If Others, please list

What would like to change to improve the current practice of calculating and utilizing road user cost, if any?

What are the work zone configuration inputs for road user cost estimation?

- Number of lanes in each direction
- Number of open lanes through the work zone in each direction
- Length of the lane closure
- Lane width
- Lateral clearance restrictions
- Turn restrictions.
- Availability and traffic characteristics of alternative routes
- Hours of lane closure (begin and end time)
- Hours of work activity (begin and end time)
- Signalization
- Type of work zone
- passenger cars per hour per lane (pcphpl)
- vehicles per hour per lane (vphpl)
- Highway Capacity Manual (HCM)
- recommendation
- Work zone capacity model
- Your agency-specific estimating method
- Others

What is the input for work zone capacity?

Which of the following method is used for the estimate of work zone capacity?

If Others, please list

Please provide any additional comments about road user costs.

What are the inputs for travel speeds?

- Free-flow speed
- Work zone speed