

Review of Road User Costs and Methods

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July 2013

Acknowledgements

This work was performed under the direction of the SD2011-05 Technical Panel:

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Funding for the work presented in this report was provided by the South Dakota Department of Transportation and the Mountain-Plains Consortium University Transportation Center

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TABLE OF CONTENTS

1. Executive Summary	1
1.1 Problem Description	1
1.2 Research Objectives.....	1
1.3 Findings and Conclusions	2
1.3.1 Literature Review	2
1.3.2 DOT Interviews	3
1.3.3 Proposed Methodology	4
1.3.4 Evaluation of Methodology	8
1.3.5 RUC Application	9
1.4 Summary and Recommendations	9
2. Problem Description.....	11
3. Research Objectives	13
3.1 Develop Road User Cost Methodology	13
3.2 Develop Road User Cost Worksheet	13
4. Task Descriptions.....	15
4.1 Project Scope Review	15
4.2 Literature Review.....	15
4.3 Survey	15
4.4 Sensitivity Analysis	15
4.5 Propose Methodology	16
4.6 Technical Memorandum	16
4.7 Revisions.....	16
4.8 Worksheet	16
4.9 User Manual.....	17
4.10 Final Report	17
4.11 Executive Presentation	17
5. Findings and Conclusions.....	19
5.1 Literature Review.....	19
5.1.1 Introduction.....	19
5.1.2 RUC Applications.....	20
5.1.3 Review of RUC Methods.....	27
5.1.4 Unit Cost.....	41
5.1.5 Summary	45
5.2 DOT Interview and Survey.....	46
5.2.1 SDDOT Interviews	46
5.2.2 Regional DOT Surveys	47
5.3 Current and Proposed Methodologies.....	48
5.3.1 Value of Road Users' Time (VOT)	48
5.3.2 Vehicle Operating Costs (VOC)	54
5.3.3 Accident Costs (AC).....	60
5.3.4 Other Impacts.....	63
5.4 Evaluation of Proposed Methodologies	64

5.4.1	Sensitivity Analysis	64
5.4.2	Case Study	74
5.4.3	Summary	82
5.5	SD RUC Application	85
5.5.1	Overview of the SD-RUC Application	85
5.5.2	RUC Modules	86
5.5.3	RUC Data Preparation	100
5.5.4	Default Values, Limitations and Updating Procedures.....	101
6.	Summary, Conclusions and Recommendations	107
6.1	Summary	107
6.2	Conclusions.....	108
6.2.1	Project Planning.....	108
6.2.2	Project Construction	108
6.3	Implementation and Recommendations.....	108
7.	Research Benefits	111
8.	References	113
	Appendix A: SDDOT Survey	117
	Appendix B: Regional DOT Survey	121

LIST OF FIGURES

Figure 1.1	Components of RUC.....	3
Figure 5.1	Typical Components of Road User Costs.....	20
Figure 5.2	Applications of Road User Costs.....	21
Figure 5.3	Value of User's Time Components.....	41
Figure 5.4	Vehicle Operating Cost Components.....	42
Figure 5.5	Detour Route (Work Zone) and Alternate Route(s) Due to Route Removal.....	48
Figure 5.6	Department of Energy Vehicle Occupancy Rates (2010).....	52
Figure 5.7	OVIDA Truck Operating Costs per Mile.....	56
Figure 5.8	Speed Change Cycle (2012, Autos).....	57
Figure 5.9	Speed Change Cycle (2012, Trucks).....	57
Figure 5.10	Relationship Between Methods.....	58
Figure 5.11(a)	RUC by Percent Truck*.....	68
Figure 5.11(b)	RUC Components (20 Percent Trucks)*.....	68
Figure 5.12(a)	RUC by VOF*.....	69
Figure 5.12(b)	RUC Components (VOF = 1.6).....	69
Figure 5.13(a)	RUC by K Value*.....	70
Figure 5.13(b)	RUC Components (K = 1.5).....	70
Figure 5.14(a)	RUC without Detour.....	71
Figure 5.14(b)	RUC Components without Detour.....	71
Figure 5.15(a)	RUC with Detour.....	72
Figure 5.15(b)	RUC Components with Detour.....	72
Figure 5.16	RUC by K Value.....	73
Figure 5.17(a)	Present Value for Alternative 1.....	75
Figure 5.17(b)	Net Present Value for Alternative 1.....	75
Figure 5.18(a)	Present Value for Alternative 2.....	76
Figure 5.18(b)	Net Present Value for Alternative 2.....	76
Figure 5.19(a)	Present Value Comparison.....	77
Figure 5.19(b)	Net Present Value Comparison.....	77
Figure 5.20(a)	PV of Proposed and Current Methodologies.....	79
Figure 5.20(b)	PV AC with SDDOT and FHWA Crash Severity Weights.....	79
Figure 5.21	Home Screen.....	87
Figure 5.22	Project Information Screen (Project Planning).....	88
Figure 5.23	Data Availability.....	89
Figure 5.24	Existing Conditions for Network Analysis.....	89
Figure 5.25	Alternative Conditions from Network model.....	90
Figure 5.26	Existing Conditions Screen.....	90
Figure 5.27	Alternative Selection Screen.....	91
Figure 5.28	Alternate Route Screen.....	92
Figure 5.29	Alternate Route Screen for Segments/Intersections.....	93
Figure 5.30	Project Planning Quick Report Alternatives Screen.....	94
Figure 5.31	Project Information Screen (Project).....	94
Figure 5.32	Phase Selection Screen.....	95

Figure 5.33	Phase Conditions Screen for Existing Conditions	95
Figure 5.34	Phase Conditions Screen for WZ Conditions	96
Figure 5.35	Phase Conditions Screen for Segments.....	96
Figure 5.36	Project Construction Quick Report Phase Selection Screen.....	97
Figure 5.37	Project Planning Input Screen.....	98
Figure 5.38	Project Construction Input Screen	99
Figure 5.39	Timeline of Update Source Availability	104

LIST OF TABLES

Table 5.1	Work Zone CMF for Temporary Lane Closures on Freeways (FHWA).....	25
Table 5.2	State Traffic Analysis Methods taken from FHWA	28
Table 5.3	Component Prices (1997 dollars) in HERS-ST	38
Table 5.4	Fuel Efficiency Adjustment Factor (2000)	38
Table 5.5	US Census Bureau State & County Quick Facts	42
Table 5.6	American Transportation Research Institute – Average Carrier Costs per Mile	43
Table 5.7	American Automobile Association – Average Cost per Vehicle.....	43
Table 5.8	Societal Crash Cost Estimates by Crash Severity	44
Table 5.9	Characteristics That Increase Vehicle Emission Rates	45
Table 5.10	South Dakota Occupational Wage Estimates (2010).....	49
Table 5.11	US Census Bureau State & County Quick Facts	51
Table 5.12	US Department of Labor - Wage and Hour Division for South Dakota (2011)	52
Table 5.13	LOS Criteria for Intersections*	53
Table 5.14	SD Fleet and Travel Rates (May 2012)	55
Table 5.15	American Automobile Association - Average Costs per Vehicle (2012).....	56
Table 5.16	Fuel Consumption by Operating Speed*	59
Table 5.17	Unit Crash Cost by Severity	61
Table 5.18	Work Zone CMF for Temporary Lane Closures on Freeways (FHWA, 2011).....	62
Table 5.19	State Highway System Weighted Accident Rates	63
Table 5.20	Controlled Variables	65
Table 5.21	Default Unit Costs	65
Table 5.22	Assumptions for Analysis	78
Table 5.23	Case Study 1	80
Table 5.24	Case Study 2	81
Table 5.25	Case Study 3	81
Table 5.26	Case Study 4	81
Table 5.27	Case Study 5	81
Table 5.28	Case Study 6	82
Table 5.29	Summary of Equations Applied For RUC Cost Components.....	83
Table 5.30	Summary of Resources Needed and Update Period	84
Table 5.31	Function and Display of each Worksheet	88
Table 5.32	Default Values	102
Table 5.33	Limitation of Values	103
Table 5.34	Update Sources and Availability	105

LIST OF ACRONYMS

AAA	American Automobile Association
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AC	Accident Costs
ADT	Average Daily Traffic
AIS	Abbreviated Injury Scale
AR	Accident Rate
ATRI	American Transportation Research Institute
AWSC	All-way Stop Controlled
BCA	Benefit Cost Analysis
CA4PRS	Construction Analysis for Pavement Rehabilitation Strategies
CMF	Crash Modification Factor
CPC	Costs per Cycle
CPI	Consumer Price Index
CR	Crash Rate
CRUC	Calculated Road User Cost
DOE	Department of Energy
DOL	Department of Labor
DOT	Department of Transportation
EPDO	Equivalent Property Damage Only
EPI	Employment Cost Index
FHWA	Federal Highway Administration
GUI	Graphic User Interface
HCM	Highway Capacity Manual
HCS+	Highway Capacity Software
HERS-ST	Highway Economic Requirement System-State Version
HSM	Highway Safety Manual
IHSDM	Interactive Highway Safety Design Module
LCCA	Life Cycle Cost Analysis
MOT	Maintenance of Traffic
MPO	Metropolitan Planning Organization
MVMT	Million Vehicle Miles of Travel
NCHRP	National Cooperative Highway Research Program
NHTS	National Household Transportation Survey
NPTS	Nationwide Personal Transportation Survey
OODA	Owner-Operator Independent Drivers Association
PCC	Portland Cement Concrete
PDO	Property Damage Only

PPI	Producer Price Index
PSR	Present Serviceability Rating
QUEWZ	Queue and User Cost Evaluation of Work Zones
RUC	Road User Costs
SDDOT	South Dakota Department of Transportation
SSI	Social Security Income
TAT	Traffic Analysis Toolbox
TMP	Traffic Management Plan
TRB	Transportation Research Board
TRDF	Texas Research and Development Foundation
TTC	Temporary Traffic Control
TTI	Texas Transportation Institute
TWSC	Two-way Stop Controlled
USCB	United States Census Bureau
VBA	Visual Basic for Applications
VMT	Vehicle Miles Traveled
VOC	Vehicle Operating Costs
VOF	Vehicle Occupancy Factor
VOT	Value of User's Time
WZ	Work Zone

1. EXECUTIVE SUMMARY

1.1 Problem Description

The South Dakota Department of Transportation (SDDOT) uses road user costs (RUC) to calculate incentive or disincentive compensation for contractors, quantify project-specific liquidated damages, select the ideal sequencing of a project, and forecast the long-term effects new construction will have on the traveling public. The current RUC calculations were initially set in 1996 by research project SD1995-07 *Criteria and Guidelines for Innovative Contracting*; they have undergone little updating aside from unit cost values. Since the last research project, the two offices (Project Development and Operations Support) that depend on RUC have updated these values to keep up with inflation, but have done so independently. Currently, they use different worksheets with similar fields, but the values used to calculate RUC are substantially different.

Maintaining the most up-to-date RUC is extremely important to SDDOT, as underestimation of RUC results in increased costs to the traveling public, while overestimation results in the SDDOT overpaying on incentives for early completion of construction projects. Obtaining proper RUC also helps to justify the deployment of new technologies that can accelerate the construction process for pavement and bridges and strengthen the economic competitiveness of SD in the region. Calculated RUC in South Dakota are currently much lower than those of surrounding states, in part due to infrequent updates. As a result, South Dakota construction projects may be given a lower priority compared with projects managed by the same contractor in surrounding states that have greater incentive/disincentive values. The subsequent impacts to South Dakota road users include extended construction periods, prolonged traveler delays, compromised safety, and inconvenience.

1.2 Research Objectives

The study covered in this report was undertaken to address the following two main objectives:

Develop a methodology to calculate RUC specific to South Dakota

The work was initiated through a search of available literature concerning the estimation of RUC methodology. Priority was placed on published literature from authoritative sources such as the Federal Highway Association (FHWA) and the American Association of State and Highway Transportation Officials (AASHTO). A long-form survey and a short-form survey were conducted with SDDOT and surrounding state DOTs, respectively. The survey response provides a synthesis of the RUC estimation methods and unit costs applied internally and externally by surrounding state DOTs and agencies, especially the states that have similar traffic volume.

Once the literature search was exhausted, the collected material was critically evaluated based on criteria established during discussions with SDDOT. With the input from the synthesis, a sensitivity analysis was then conducted to determine the effect of variable changes to each component of the proposed methodology. After suitable methodology was established, the changes to the current practices were evaluated using several case studies for the different applications considered in each stage of project development. The information collected from the literature search, the case studies and sensitivity analysis of the proposed methodology, along with comments from the technical panel were used to develop an RUC estimation method that fulfilled the unique requirements of each stage of project development.

Develop an RUC worksheet and instructions for updating it

The data gathered through the progress of this project were integrated into the design of a Microsoft Excel-based RUC estimation tool using Visual Basic for Applications (VBA). A user manual was produced outlining the development of the RUC tool, step-by-step instructions for inputting variables into the dialog boxes, project examples for several common scenarios, as well as procedures on how and when to update the unit cost values to ensure that RUC estimations remain consistent in all offices at SDDOT.

1.3 Findings and Conclusions

1.3.1 Literature Review

The literature review compared RUC estimation methods being used across the nation by state departments and agencies, as well as the criteria for application, the necessary input parameters, and the associated unit costs. The recommendations documented in AASHTO and FHWA sources were examined and analyzed for potential application. A thorough search of relevant academic papers and research was conducted that examined the recent development of RUC.

RUC quantify the impacts that road construction activities have on the mobility and safety of travelers, economics, and environment within the local community. RUCs have been applied to various aspects of decision analysis including planning, project design and development (preliminary engineering), and project construction options (work zones). During planning, user costs are a necessary component when conducting life-cycle cost analysis (LCCA) or benefit-cost analysis (BCA) relating to any future system designs, preventive strategies, safety or capacity improvements, or operation selections. During project design and development, a more refined calculation of LCCA or BCA is needed as more detailed information becomes available. The recalculated user costs may include components that were not previously considered. Before a project goes to construction, RUC information is used to determine contracting mechanisms, incentives and disincentives for construction time, and traffic control strategies that best balance construction costs with costs of delay to travelers and freight.

The AASHTO publication, “User Benefit Analysis of Highway and Bus-Transit Improvements,” has set the standard theoretical basis for RUC calculations. The algorithm presented uses three cost components: Value of Time (VOT), Vehicle Operating Costs (VOC), and Accident Costs (AC).

The recent FHWA publication, “Work Zone Road User Costs: Concepts and Applications,” provides the most up-to-date methods for calculating and applying user costs to on-site construction activities. The key components of RUC related to work zones, travel time costs, vehicle operating costs, and accident costs, are identified. Other possible components such as vehicle emissions, noise, and impacts to local businesses are presented as methods that some agencies have considered or may be using in their estimations.

Typical RUC calculations may include both monetary and non-monetary impacts. Monetary impacts include the value of time, vehicle operating costs, traffic accident costs, as well as vehicle emissions costs. Non-monetary impacts may include undesirable impacts to ecology and environment, increased noise, or impacts to local businesses as a result of construction activities. RUC calculations primarily make use of monetary impacts; other impacts are often neglected due to the difficulty of quantifying their effects. Each of these monetary impacts comprises several factors that account for lost time, vehicle depreciation, costs associated with vehicular accidents, and costs due to increased vehicle idling and fuel consumption. The Figure 1.1 illustrates these components along with the main factors that contribute to their cost.

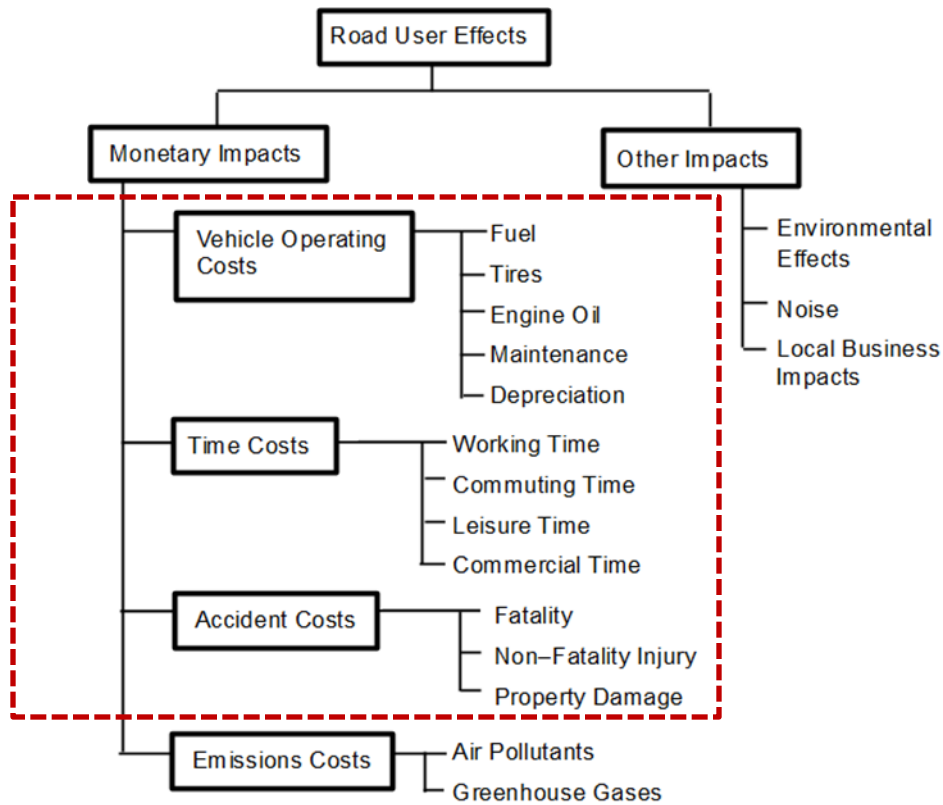


Figure 1.1 Components of RUC

1.3.2 DOT Interviews

Interviews with SDDOT personnel were conducted to collect information on the current practices of RUC calculations and expectation of possible improvements given the current method limitations and resource constraints. The interview covered questions concerning the objectives for RUC, RUC criteria for use, current methodologies (policies, processes, and procedures), data requirements, and data storage and updating methods. SDDOT offices interviewed include: Project Development, Transportation Inventory Management, and Project Identification coordinators.

The interview clarified the current uses of RUC estimation in both project planning and project construction. Planning looks at LCCA, comparing several options for improvements using an Excel worksheet. Project construction uses work zone specific RUC for projects with significant impacts to traffic using a different Excel worksheet. A preliminary engineering study between the project planning and project construction stages is usually conducted for pavement and bridge projects; however, RUC is not used in those calculations.

Ratings were given to the RUC components by participants and a list of priority components was calculated, showing VOT, VOC, AC, local impacts, and vehicle emissions as the order of importance. The ratings vary significantly among participants for most of the components except for the vehicle emissions, which was considered by all to be insignificant. Accident costs are important when in the planning use for comparing design alternatives to predict the safety performance of alternatives. It can be used in work zone analysis, but a reliable source for values must be identified.

Issues identified in the survey include 1) no specific criteria for when to use RUC calculations. It is left to the discretion of those departments based on the demands of a specific project. Impacts to traffic are considered for implementation of time provisions in work zones during project construction. 2) RUC is not required for all the new construction, capacity, or safety improvement projects. RUC is only calculated for planned projects that add or subtract mileage and/or routes to the state highway system. 3) Unit price for individual cost items in RUC comes from different sources without clear guidance and explanations. And 4) accident cost is not considered in the RUC.

A short-form survey was designed and sent to regional DOT agencies with characteristics most comparable to South Dakota to investigate the RUC methods that are being used by those agencies. The survey questions covered the RUC criteria for use, objectives for RUC, methodologies (policies, processes, and procedures), data requirements, and updating methods. The survey was sent to seven state DOT agencies, including Idaho, Iowa, Minnesota, Montana, North Dakota, Nebraska, and Wyoming. Responses were received from four out of seven of the agencies contacted, including Minnesota, Montana, North Dakota, and Wyoming.

The responses showed that most agencies use RUC for project planning purposes as well as project construction with the exception of MTDOT, which only uses RUC for work zone calculations. Many agencies do not have specific criteria for calculating RUC other than engineering judgment or if scenarios are present which require detailed cost information. NDDOT uses RUC in calculations for safety and emergency purposes. RUC calculations either follow the same methodology calculated by analysts throughout the state, or are calculated by headquarter personnel to assure estimates follow a standard methodology. The agencies surveyed use spreadsheets or more simplified hand calculations to estimate user costs.

Half of the agencies surveyed include every component (VOT, VOC, and AC), with NDDOT also including specific safety or emergency components if needed. WYDOT has only included the components of VOC and VOT, while MTDOT only uses VOC in their analysis. Although it has been an infrequent occurrence, MNDOT is the only agency that has included the additional component of vehicle emissions or impacts to local businesses in any RUC analysis.

Each agency's unit cost sources are varied and updates to the values are dependent on the selected source. Most agencies have selected AASHTO or FHWA recommended sources, while some rely on local data to determine costs. Several respondents have felt that their estimation process could be improved by finding better ways to include business impacts or include more detailed traffic analysis studies into the process.

Results of the survey sent to surrounding state DOTs revealed the similarities and differences between each agency's approaches to RUC. While most responding agencies use simplified calculations and spreadsheets, the components included in these calculations as well as the sources used for unit cost are diverse. Most agencies have selected AASHTO or FHWA recommended sources, while others rely on local data to determine unit costs. Each method with its distinct advantages and disadvantages, strengths, and limitations were evaluated to maximize its application to the SDDOT.

1.3.3 Proposed Methodology

The methodologies and components included in the estimation of RUC are based on the decision support method in which it is being analyzed, i.e., project planning and project construction options (work zones). The components that are included in the proposed methodologies are VOT, VOC, and AC. Other factors that have the potential to affect RUC are emissions costs, environmental effects, noise, and local business impacts. These components have not been included in the proposed methodologies due to the ineffective

methods for quantifying in dollar terms or monetizing them and the minimal effect found from the SDDOT survey.

RUC can be formulated as:

$$RUC = VOT + VOC + AC \quad \text{Equation 1-1}$$

Where VOT is value of time, VOC is the vehicle operating costs, and AC is accident costs.

VOT is the value attributed to a user's time, and is estimated based on the relationship to wage rates and delays associated to the trip length of a detour route or alternative route(s). The proposed VOT calculation includes two components: the VOT component caused by speed and distance change, respectively, and the VOT components caused by delay due to traffic control devices.

$$VOT = 60L \left[\frac{K}{S_1} - \frac{1}{S_0} \right] \sum_{c=1}^n M_c * VOF_c * ADT_c \quad \text{Equation 1-2}$$

$$\Delta H_{intersection,c} = 60\Delta T \left(\frac{V_{0c} + V_{1c}}{2} \right) M_c VOF_c \quad \text{Equation 1-3}$$

Where:

- L = the distance of original route (mile);
- K = distance ratio of the different route (L_D) to the original route (L);
- S_0, S_1 = speed before improvements (S_0), and after improvements (S_1) (mph);
- M_c = unit value of time for user class (\$/min);
- VOF_c = Occupancy rate of vehicles for user class, persons per vehicle;
- ADT_c = average daily traffic of vehicle class c;
- ΔT = intersection delay (minutes);
- V_{0c}, V_{1c} = annual average daily vehicle volumes without (0) and with (1) the intersections.

VOC is a composite of the costs associated with operating and owning the vehicle over the project analysis period. VOCs include fuel, oil, tire wear, vehicle maintenance and repairs; ownership costs include insurance, license and registration fees and taxes, economic depreciation, and finance charges. The daily road user benefits or costs due to the project can be measured by including excess VOC of all vehicles due to the speed changes (excess fuel, oil, tire, and vehicle maintenance due to the deceleration when entering work zones and acceleration when exiting) and VOC of all vehicles traveling extra miles on detour or alternative route(s) if there is any.

Project Planning

For planning purposes, the construction time period is relatively short compared with the life cycle of a project. Therefore, additional costs due to the speed cycle changes during construction can be omitted. The recommended measure for VOC is the same as the current SDDOT method in Equation 1-4.

$$VOC_D = \Delta D \sum_{c=1}^n ADT_c * C_c \quad \text{Equation 1-4}$$

Where:

- ΔD = detour route distance less original route distance (mile);
- ADT_c = average daily traffic of vehicle class c;
- C_c = Operating cost per mile of vehicle class c (\$/mile).

Project Construction

For project construction options, the changes in RUC for the project can be caused by several factors: 1) change in fuel costs due to the speed change with and without, or before and after a project, i.e. lower speed during a work zone or higher speed after an improvement project; 2) extra distance on a detour route if there is one; 3) additional operating costs due to vehicle deceleration when entering work zone and acceleration when exiting).

Total VOC is the sum of $VOC_{distance}$ and VOC_{sc} as specified:

$$VOC = VOC_{distance} + VOC_{sc} \quad \text{Equation 1-5}$$

Considering total vehicle miles traveled for all vehicle classes, $VOC_{distance}$ can be specified as:

Without Detour:

$$VOC_{distance} = L \sum_{c=1}^n \Delta C(S)_{fuel,c} * ADT_c$$

With Detour:

$$VOC_{distance} = L \sum_{c=1}^n \Delta C(S)_{fuel,c} * ADT_c + \Delta D \sum_{c=1}^n P_c * gal_{c,S_D} * ADT_c^D \quad \text{Equation 1-6}$$

Where:

- L = Length of construction zone or study route (miles);
- $\Delta C(S)_{fuel,c}$ = change in fuel costs as a function of speed for vehicle class c;
- ADT_c = average daily traffic of vehicle class c on study route;
- ΔD = detour route distance less original route distance (mile);
- P_c = Fuel price per gallon for vehicle class c (\$/gal);
- gal_{c,S_D} = gallons per mile for vehicle class c, posted speed limit on the detour route (gal/mile);
- ADT_c^D = average daily traffic of vehicle class c on detour route.

Where the change in fuel costs can be expressed as the function of speed as follows:

$$\Delta C(S)_{fuel,c} = (gal_{c,S_0} - gal_{c,S_1}) * P_c \quad \text{Equation 1-7}$$

Where:

- gal_{c,S_0} = gallons per mile for vehicle class c, during construction speed (gal/mile);
- gal_{c,S_1} = gallons per mile for vehicle class c, after construction speed (gal/mile);
- P_c = Fuel price per gallon for vehicle class c (\$/gal).

The VOC component due to the speed cycle changes (additional fuel consumption due to the acceleration and deceleration of vehicles for work zone ingresses and egresses) is formulated as:

$$VOC_{SC} = \frac{1}{1000} \sum_{c=1}^n ADT_c * CPC_c \quad \text{Equation 1-8}$$

Where:

- ADT_c = average daily traffic of vehicle class c on study route;
- CPC_c = costs per cycle of vehicle class c (deceleration when entering work zone and acceleration when exiting for each 1000 cycles).

AC is measured by the cost of total annual crash changes as a result of the highway project. It is anticipated that a new construction project may increase mobility and safety after its completion, while during the construction time period the safety conditions for traveling may be compromised due to the complex work zone configuration and traffic control strategies. A crash modification factor (CMF) can be employed to account for the change in traffic safety. The SDDOT Highway Needs and Project Analysis Report, presents the weighted accident rate per million vehicle miles of travel (MVMT).

The daily AC calculations for accident costs are found for the road segment:

$$AC = [(AR * CMF - AR) * L * ADT * C_{ACC}] \quad \text{Equation 1-9}$$

Where:

- AR = Pre-existing accident rate per million vehicle miles without construction;
- CMF = Crash Modification Factor;
- L = Length of Study Section (mile);
- ADT = Average Daily Traffic;
- C_{ACC} = Average cost per property damage only accident.

To monetize these RUC components, appropriate sources for unit cost values were identified. The unit cost values for VOT include wage rates by vehicle class; VOC includes the cost of vehicle operation and, for planning purposes, vehicle ownership by vehicle class; and AC includes the costs incurred by the public due to increased accident risks. The proposed resources needed for the unit costs values have taken into account the source reliability, frequency of updates, and ease of accessing the information.

The US Census for South Dakota is recommended as the data resource for the passenger car unit cost values of time because they provide a more complete representation of the average state income. The value represents mean income of every person over age 15, and includes employment wages as well as income sources such as Social Security Income (SSI), public assistance or welfare, and survivor or disability pensions. The US Department of Labor is the suggested source for the heavy truck unit cost value of time because the values are used in federal projects to dictate the required federal wages and so are reassessed and updated on a regular basis. The use of Vehicle Occupancy Factors (VOF) is also recommended to accurately represent the costs per vehicle by accounting for the average vehicle passengers. The current source of VOF has not been updated since its inclusion into the SD VOT cost calculations, and the 2009 National Household Travel Survey VOF value of 1.67 is recommended.

For project planning VOC calculations, the American Automobile Association (AAA) is the recommended source to locate the vehicle operational unit cost values for passenger cars. The AAA average cost per vehicle includes fuel, maintenance, tires, insurance, licensing, registration and taxes, depreciation, and financing expenses. The American Transportation Research Institute (ATRI) is recommended for the vehicle operational unit costs of heavy trucks. The ATRI average motor carrier cost

per mile includes fuel and oil, truck/trailer lease, repair and maintenance, insurance, licensing and permits, tires, toll fees, and also includes driver-based expenses such as driver wages and benefits.

Calculation of VOC for work zones can be accomplished by combining multiple methods that will improve estimation accuracy by including extra fuel consumption due to the speed change, speed cycle change, and additional travel distance because of detours. The AASHTO methods addressed the fuel change in consumption rates due to speed differentials. The current SDDOT usage of CPC tables produces an adequate estimation of these effects. Values for vehicle fuel prices were found at the US Energy Information Administration website for both gasoline and diesel fuels.

Accident rates can be obtained from the SDDOT Highway Needs and Project Analysis Report: State Highway System Weighted Accident Rates or calculated directly. The necessary CMF values may be found in the Highway Safety Manual (HSM) or from the CMF Clearinghouse, a website maintained by the FHWA Office of Safety. CMF values obtained from the CMF Clearinghouse include those found in the HSM, as well as values collected from published academic studies. Crash cost estimates by severity can be taken from the HSM for human capital costs and comprehensive costs. Because of the variability of CMF values due to changes in operational and physical characteristics of each project location, calculation of state specific values for roadways using historical trends is recommended to more accurately reflect local conditions.

1.3.4 Evaluation of Methodology

The evaluation of the proposed methodology involved a sensitivity analysis and case studies. The sensitivity analysis determined the contribution that variations to each significant variable will have to the overall RUC estimation. Case studies were conducted to evaluate and compare the current methodology used by SDDOT with the changes recommended in this study.

The sensitivity analysis suggests that the contributions of RUC components in the planning and project construction analysis are different. The components for planning are ranked in order of monetary contribution as VOC, VOT, and AC, while the components for project construction are ranked as VOT, VOC, and AC. The difference can be primarily attributed to the selection of unit costs which include both vehicle operating and ownership costs for the planning purpose, resulting in a higher value for VOC. The improvements to the methodology for project construction include provisions to account for operating costs due to fuel consumption and fuel efficiency caused by speed changes.

The case studies display the differences between the current methodology and the proposed methodology. The quantity of changes in value is attributed to changes in unit cost, changes to methodology, and the inclusion of AC. The planning analysis includes three examples for route removal, route addition, and a hypothetical case with AC. The first case shows that the proposed methodology almost doubles RUC compared with the current value, largely due to VOC increases. The second shows the savings to VOT that result from the addition of a route to a network, and the third illustrates that AC constitutes a small fraction of total RUC if the SDDOT weighted AR is used because SDDOT underweights the cost of a fatal or an injury crash as compared with the FHWA weights.

The project construction analysis includes six different case studies with multiple construction phases included. Overall, the increases in the VOT component can be attributed to the changes made to unit cost and VOF. The VOC component results show the variations in cost, compared with the current methodology. The change in methodology results in a more accurate view of the operating costs due to motorists, because it makes use of unit cost values for fuel consumption and speed changes without including the additional costs due to vehicle ownership. In particular, the evident decrease in VOC values can be explained by the existence of detour routes with speeds that haven't changed or have increased

compared with the existing route. Similar to the planning scenario, including AC in the calculation of RUC increases the cost for each case, but at an inconsequential rate if the SDDOT weighted AR is considered.

1.3.5 RUC Application

The proposed methodology was implemented in a Microsoft Excel-based worksheet that allows users to calculate the RUC for design alternatives for both planning and project construction to maximize its application to SDDOT. The tool was designed to provide secured and convenient access for users. The built-in safety measures allow for the administrator to regularly update the values of RUC parameters using reliable sources in a controlled manner that maintains consistent use of unit cost values in all estimations of RUC.

The RUC Tool was developed for use on a Windows® operating system (Windows Vista) using Microsoft Excel 2010. The programming of the RUC Wizard application was done using Visual Basic for Applications (VBA). This tool can be run as a stand-alone application with the file installed on a local computer, or in a multi-user configuration with the application installed on a server and used by several client computers.

The SD-RUC Tool is intended to facilitate the calculation of RUC for project planning and project construction uses within SDDOT. There are two available options for entering data, the RUC Wizard or the individual worksheet input pages, either of which can be used depending on the user's familiarity with the tool. The output is a quick report that contains the most pertinent data and is formatted to print in as condensed a page layout as possible. Additional options include the ability to save the quick report to a separate workbook for cataloging of project histories.

1.4 Summary and Recommendations

The results of the study can be summarized in the following main conclusions:

1. The current SDDOT RUC methodologies, worksheets, and associated unit costs were evaluated. The two departments conducting RUC estimations were found to have developed individual worksheets with inconsistent unit cost sources and updating practices.
2. A literature review and DOT survey was conducted to identify the current RUC practice being advocated and the regional RUC practices being used by other agencies.
3. New RUC methodologies were proposed that made changes to the components of VOT and VOC, and includes AC in future calculations.
4. Sources of unit costs were evaluated and recommendations were made based on reliability, availability, and frequency of updates.
5. An Excel-based worksheet tool was produced to facilitate future RUC estimations

In this study, the current RUC methodology and associated unit costs were evaluated and changes were implemented to the methodology to allow for a more complete analysis that aligns with the needs of each department and their use of RUC. The methodology was used to construct a worksheet that allows users to calculate the RUC for both stages of project construction for which it is currently being calculated.

Based on the results of this research effort the following recommendations can be made.

1. The South Dakota Department of Transportation implements the new worksheet in future RUC estimation practices. The RUC worksheet tool is designed for the offices of Project Development and Operations Support to estimate the changes to user costs for the purpose of establishing

incentive or disincentive compensation for contractors, quantify project-specific liquidated damages, select the ideal sequencing of a project, and forecast the long-term effects new construction will have on the traveling public.

2. It is recommended that SDDOT designate an administrator to preside over the unit cost updates within the worksheet to ensure that all calculations done at SDDOT use consistent unit cost figures. The unit cost sources that have been identified and recommended for use have been provided in the RUC User Manual along with when the updates become available. An update log is provided within the RUC worksheet tool for the administrator to record and track the date when unit cost updates were applied.

Future research may be warranted to increase the precision of RUC calculations. Increased traffic volumes due to population growth and the subsequent traffic congestion demands more complex estimations, which require more accurate estimations of hourly vehicle demand and capacity to account for work zone effects such as vehicle queuing. In the future, it may be necessary to review the RUC methods recommended here to determine if all project development needs are still met.

Recommendations to improve upon future RUC calculations include the following:

1. Vehicle efficiency rates may be constructed based on modern vehicle technology for the consumption of fuel, oil, tires, etc. to allow for the most accurate possible rates. The rates of consumption that form the basis for many vehicle operating cost models have not been sufficiently reexamined since original research set these values.
2. Accurate traffic volume, especially diverting traffic, may be estimated using travel demand forecasting models or other methodologies. Furthermore, more precise maximum capacity estimations based on work zone configurations specific to South Dakota will enhance RUC estimations.
3. Crash unit cost by injury severity should be more consistent with FHWA criteria. Aligning SDDOT-weighted accident rates with the FHWA-weighted rates will ensure that South Dakota maintains crash costs that are compatible with the national standards. This issue should be reviewed and a determination should be made to change these rates.
4. Work zone crash rates and CMFs can be estimated using South Dakota work zone crash data. By formulating crash rates and CMFs specific to work zones in South Dakota using historical crash data, the accuracy of estimates is increased and provides for statistically acceptable CMF values for the state.

2. PROBLEM DESCRIPTION

With the ever-increasing travel demand and limited capacity, traffic congestion has become part of daily life. Every year, delay from peak period traffic congestion costs \$710 per traveler (TTI 2007). The Texas Transportation Institute (TTI) 2007 mobility report shows traffic congestion is growing worse in American cities of all sizes, creating over \$78 billion in user costs due to lost time and over 2.9 billion gallons of fuel wasted annually.

Although South Dakota is primarily a rural state with relatively low traffic volume on highway facilities of any kind, congestion and travel delay incurred by inclement weather and construction zones can occur. In fact, future projections depict that more roadway repairs and new construction are anticipated as a result of the aging highway facilities. RUC will inevitably increase as delay and congestion increases on South Dakota highways. Without knowledge of RUC, it is not possible to obtain an optimal solution from the transportation infrastructure system standpoint.

The South Dakota Department of Transportation (SDDOT) uses RUC to calculate incentive/disincentive compensation for contractors, quantify project-specific liquidated damages, select the ideal sequencing of a project, and forecast the long-term effects new construction will have on the traveling public. RUC calculations were initially set by research project SD1995-07 *Criteria and Guidelines for Innovative Contracting*. The methodology for calculating RUC has not changed dramatically since then, but the unit costs used in these calculations have.

There is a growing need to update these costs and construct a worksheet that can evolve over time to adjust for changing user costs. Calculated RUC in South Dakota are currently much lower than those of surrounding states, in part due to infrequent updates. Because infrequent updates cause the incentive/disincentive values to be lower, South Dakota construction projects may be given a lower priority compared with projects managed by the same contractor in surrounding states that have greater incentive/disincentive values. There is also the possibility that more items such as accident costs, emissions, and vehicle type need to be taken into consideration when calculating road user costs. A sensitivity analysis should be used to decide which factors are to be included in the calculation of RUC.

An updated RUC worksheet would allow all offices within SDDOT to reference the same material. Since the last research project, the two offices (Project Development and Operations Support) that depend on RUC have updated these values to keep up with inflation, but have done so independently. Currently, they use different worksheets with similar fields, but the values used to calculate RUC are substantially different. An updated worksheet with well-substantiated values would allow all SDDOT offices to use the same values and could help avoid legal disputes between the SDDOT and contractors regarding incentive/disincentive contracts. Additionally, a standard procedure to update the worksheet would allow the document to stay current without individual offices updating it separately.

3. RESEARCH OBJECTIVES

The study covered in this report was undertaken to address the following two main objectives.

3.1 Develop Road User Cost Methodology

Develop a methodology to calculate road user costs specific to South Dakota.

The work was initiated through a search of available literature concerning the estimation of road user cost (RUC) methodology. The literature search included both academic and private industry research into methodology used in estimating RUC, which comprised published literature and any estimation tools developed as a result of those research efforts such as computer software or estimation spreadsheets. Priority was placed on published literature from authoritative sources such as the Federal Highway Association (FHWA) and the American Association of State and Highway Transportation Officials (AASHTO).

A thorough review of the literature was conducted to catalog existing RUC estimation methodologies used by state agencies. This included the application of RUC estimation through the stages of a project, the criteria for use, the consideration of components, the component unit costs and sources, and any tools or software used in the estimation of RUC. The literature review provides a synthesis of the RUC and unit cost estimation methods applied by surrounding state DOTs and agencies, especially the states that have similar traffic volumes, including off-the-shelf or state-of-art tools to calculate RUC.

Once the literature search was exhausted, the collected material was critically evaluated based on criteria established during discussions with SDDOT. After suitable methodology was established, the changes to the current practices were evaluated using several case studies for the different applications considered in each stage of project development. With the input from the synthesis, a sensitivity analysis was then conducted to determine the effect of variable changes to each component of the proposed methodology. The information collected from the literature search, the case studies and sensitivity analysis of the proposed methodology, along with comments from the technical panel were used to develop a RUC estimation method that fulfilled the unique requirements of each stage of project development.

3.2 Develop Road User Cost Worksheet

Develop an RUC worksheet and instructions for updating it

The data gathered through the progress of this project were integrated into the design of a Microsoft Excel-based RUC estimation tool using Visual Basic for Applications (VBA), an event-driven programming language. The RUC tool allows users to select from a RUC Wizard or input variables directly using an input worksheet. The RUC Wizard guides the user to input the necessary variables using dialog boxes and reduces the chance for user input errors. The input worksheet is available for users familiar with the input requirements of the tool and provides an alternative to the RUC Wizard that may facilitate faster input of variables and subsequent estimation outputs.

A user manual was produced outlining the development of the RUC tool, step-by-step instructions for inputting variables into the dialog boxes, project examples for several common scenarios, and directions for updating any unit costs included in the estimation tool.

4. TASK DESCRIPTIONS

In the following text, the tasks outlined in the proposal for research are itemized and the methods for their completion are summarized.

4.1 Project Scope Review

Task 1: Meet with the technical panel to review the project scope and work plan.

A meeting was conducted on June 5, 2012, in Pierre, South Dakota, with the technical panel members to establish the project scope and discuss the project work plan. The research team outlined the project work plan and any assistance that was required from the SDDOT.

4.2 Literature Review

Task 2: Perform a literature review directed towards FHWA reports and other rural surrounding states' current methodologies for calculating road user costs

This task was accomplished through a direct search of provided and published literature, as well as contacting relevant personnel within SDDOT and other state DOTs to assess current RUC methods. A comprehensive literature review was conducted to collect and synthesize available RUC estimation methods used by other state DOTs and agencies, especially the states that have low traffic volume, including off-the-shelf or state-of-art tools to estimate RUC. Review emphasis was in the areas of data requirement, estimation method, performance measures, and relevant assumptions or limitations. The results of the literature search were used as the basis for developing a methodology for computing RUC, as outlined in subsequent tasks and are compiled in this complete final report.

4.3 Survey

Task 3: Interview members of Project Development and Operations Support to become informed how road user costs are used at the SDDOT.

On July 24, 2012, the researchers interviewed staff of Project Development and Operations Support in Pierre using a verbal questionnaire. The purpose of the interviews was to obtain detailed information on SDDOT's current RUC procedures and gather new ideas and expectation of future improvements. A short-form questionnaire was also developed and sent to regional agencies with similar traffic volumes to obtain information regarding their current RUC practices and the methods they used to develop the methodology. Responding agencies included North Dakota, Minnesota, Montana, and Wyoming.

4.4 Sensitivity Analysis

Task 4: Conduct a sensitivity analysis to determine which contributing factors should be considered in calculation of road user costs in South Dakota now and in the future.

In this task, a data needs assessment and a sensitivity analysis were performed based on Tasks 1, 2, and 3 to determine which contributing factors should be considered in the calculation of RUC in South Dakota now and in the future. Factors including the percent trucks, VOF, and K value were evaluated during this analysis. Relevant data were collected with the assistance of SDDOT to facilitate the sensitivity analysis. The research team worked with SDDOT to identify the current data inventory and data collection activities that support the estimation of RUC. The data needs assessment identified the minimum data

requirements and any additional data collection and preparation effort needed for developing an appropriate RUC method in SD.

4.5 Propose Methodology

Task 5: Propose a methodology, based upon results of the sensitivity analysis and availability of data, for calculating road user costs at locations throughout South Dakota.

This research task developed a methodology for calculating RUC, based on the results of the sensitivity analysis and data availability. Proposed methodology was developed which identified usage requirements based on the stage of project development when selecting the most appropriate analysis method for calculating RUC. The evaluation included technical capabilities and merits of the method to accurately estimate RUC, input (required data), output (performance measures), interface of the method, and user training and support.

The current RUC estimation methods at SDDOT for project planning and project construction use the same methodology for each distinct stage of project development. Proposed changes to the methodology provide different RUC estimation methods for each stage of project development. A project planning analysis requires the quantified difference between project alternatives based on the results of an economic analysis over a multi-year period. Project construction requires a tool to quantify the mobility impacts of work zone strategies prior to deployment and monitor performance during construction. The proposed methodology addresses these needs and allows for a thorough analysis of available resources for the maximum benefit of the public.

4.6 Technical Memorandum

Task 6: Submit a technical memorandum and meet with the technical panel to discuss the literature review, department needs, and the proposed methodology.

The technical memorandum was presented to the Technical Panel for review on November 30, 2012. The technical memorandum contained a synthesis of current and proposed methodology for project planning and project construction, case studies, and a sensitivity analysis. A presentation was delivered to the Technical Panel on December 19, 2012, in Pierre, South Dakota, and comments concerning the proposed methods were documented and applied to the revisions outlined in the next task.

4.7 Revisions

Task 7: Revise the methodology based on comments from the technical panel.

Final comments submitted by the Technical Panel were forwarded to the research team. After careful review, a point to point written response addressing each concern was delivered to the Technical Panel. Revisions were made to the methodology to reflect these comments and the resulting changes were then presented to the Technical Panel.

4.8 Worksheet

Task 8: Develop a road user cost worksheet that executes the revised methodology and that can be regularly updated by users to adjust for changes in contributing factors.

In this task, a RUC worksheet was developed based on the revised methodology. The worksheet includes a user-friendly graphic user interface (GUI) and can be regularly updated by users to adjust for changes in contributing factors. The worksheet was built using a Microsoft Excel-based spreadsheet and programmed with Visual Basic for Applications (VBA). Modules were developed for project planning and project construction which included the components of travel time delay, vehicle operating costs, and vehicle crash costs. A report can be generated with a summary of the critical inputs, the itemized costs, and the total RUC. Reports can be saved in separate files to allow for minimal storage space and reloaded into the tool for any recalculation that may be necessary in the future.

Updates to any user costs can be done using a password protected administration module. This was developed to allow administrators to change the default unit cost values, data source paths (for update), and user log-in information to ensure that all contributing factors remain consistent. An update log was included to track any updates when they occur and by whom to safeguard against inconsistent updating.

4.9 User Manual

Task 9: Develop a user manual documenting the methodology and procedures for operating and updating the worksheet.

In this task, a user manual documenting the methodology and procedures for operating and updating the worksheet was prepared. The document contains an overview of the RUC estimation tool, step by step instructions for the inputting of variables including screen shot graphics, examples of several common project estimations, glossary, and necessary procedural comments and source data for updating the worksheet.

4.10 Final Report

Task 10: Prepare a final report and executive summary of the research methodology, findings, conclusions, and recommendations

This task is met with this report.

4.11 Executive Presentation

Task 11: Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

An executive presentation was given on April 16, 2013.

5. FINDINGS AND CONCLUSIONS

5.1 Literature Review

5.1.1 Introduction

The literature review compared Road User Cost (RUC) estimation methods being used across the nation by state departments and agencies, as well as the criteria for application, the necessary input parameters, and the associated unit costs. The recommendations documented in the American Association of State Highway and Transportation Officials (AASHTO) and Federal Highway Administration (FHWA) sources were examined and analyzed for potential application. A thorough search of relevant academic papers and research was conducted that examined the development and implementation of RUC in past efforts.

RUCs quantify the impacts that road construction activities have on the mobility and safety of travelers as well as economics and environment within the local community. RUCs have been applied to various aspects of decision analysis, including planning, project design and development (preliminary engineering), and project construction options (work zones). During planning, user costs are a necessary component when conducting life-cycle cost analysis (LCCA) or benefit-cost analysis (BCA) relating to any future system designs, preventive strategies, safety or capacity improvements, or operation selections. During project design and development, a more refined calculation of LCCA or BCA is needed with recalculated user costs that may include components that were not previously considered. Before a project goes to construction, RUC information is used to determine contracting mechanisms, incentives and disincentives for construction time, and traffic control strategies that best balance construction costs with costs of delay to travelers and freight.

The AASHTO publication, “User Benefit Analysis of Highway and Bus-Transit Improvements,” has set the standard theoretical basis for Road User Cost calculations (AASHTO 1977, 2010). The algorithm presented uses three cost components: Value of Time (VOT), Vehicle Operating Costs (VOC), and Accident Costs (AC).

The recent FHWA publication, “Work Zone Road User Costs: Concepts and Applications,” provides the most up-to-date methods for calculating and applying user costs to on-site construction activities. The key components of RUC as travel time costs, vehicle operating costs, and accident costs are identified, as well as other possible components such as vehicle emissions, noise, and impacts to local businesses presented as methods, which some agencies have considered or may be using in their estimations (Mallela and Sadasivam 2011).

Typical RUC calculations may include both monetary and non-monetary impacts (AASHTO 2010; Ellis 1997; Mallela and Sadasivam 2011). Monetary factors include the value of road user’s time, vehicle operating costs, traffic accident costs, as well as vehicle emissions costs. Non-monetary factors may include undesirable impacts to ecology and environment, increased noise, or impacts to local businesses as a result of construction activities. Work zone RUC calculations primarily make use of monetary factors; other factors are often neglected due to the difficulty of quantifying their effects. The monetary factors are further subdivided into the components of cost represented by VOC, VOT, AC, and vehicle emissions. Each of these components is composed of several factors that account for lost time, vehicle depreciation, costs associated with vehicular accidents, and costs due to increased vehicle idling and fuel consumption. Figure 5.1 illustrates these components along with the main factors that contribute to their cost.

The literature review section is organized as follows: The uses of RUC through the stages of a construction project are outlined from planning, preliminary, to work zone assessment, as well as the

steps for analysis. A review of RUC methods follows, which presents the common methods for RUC estimation along with any relevant equations. Finally, the required unit cost data needed to monetize each component are shown along with the recommended sources from the FHWA.

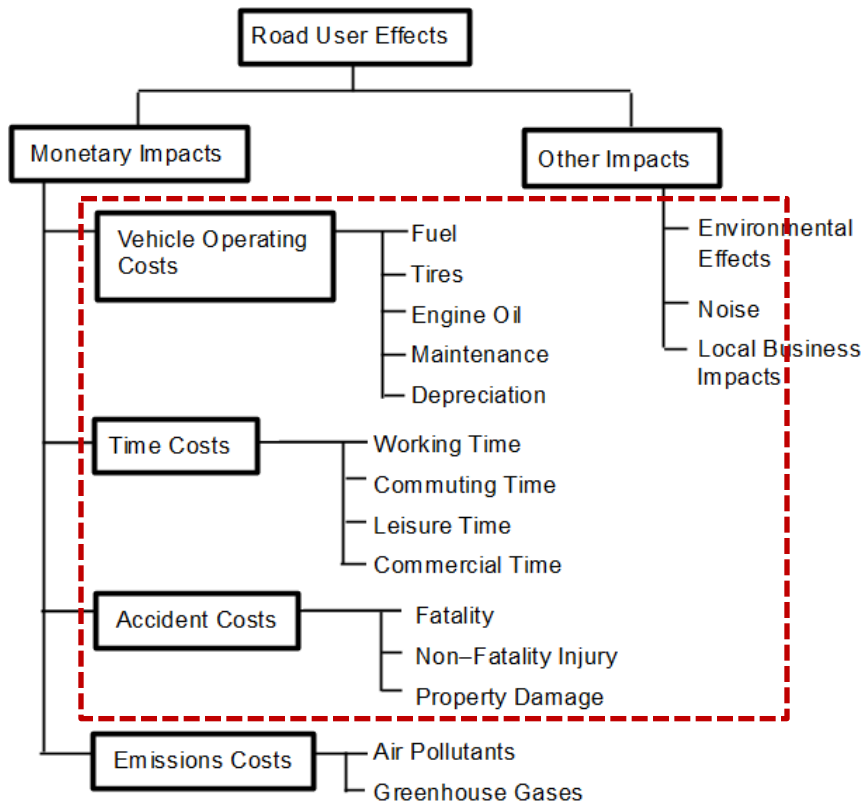


Figure 5.1 Typical Components of Road User Costs

5.1.2 RUC Applications

RUCs can be applied to various stages of a construction project. Planners can use RUC to compare the economic benefits of future projects over a multi-year period based in part on the user costs. These methods may include incremental BCA or LCCA, which include the construction costs as well as any additional maintenance costs throughout the life of the project. Selection of the most desirable plan will minimize the negative impacts of planned future rehabilitation or restoration activities on highway users. During the preliminary engineering stage, RUCs, as well as other tools, are used to refine the preferred design alternative(s) selected in the planning phase before the project proceeds to the detailed project design phase. During the project design stage, engineers must consider RUC when determining the most appropriate construction phasing, staging, traffic control strategies, and final design of a project. The optimal phasing should mitigate or avoid disruptions to traffic flow through the work zone before they are created. The uses of RUC throughout the stages of project design are illustrated in Figure 5.2.

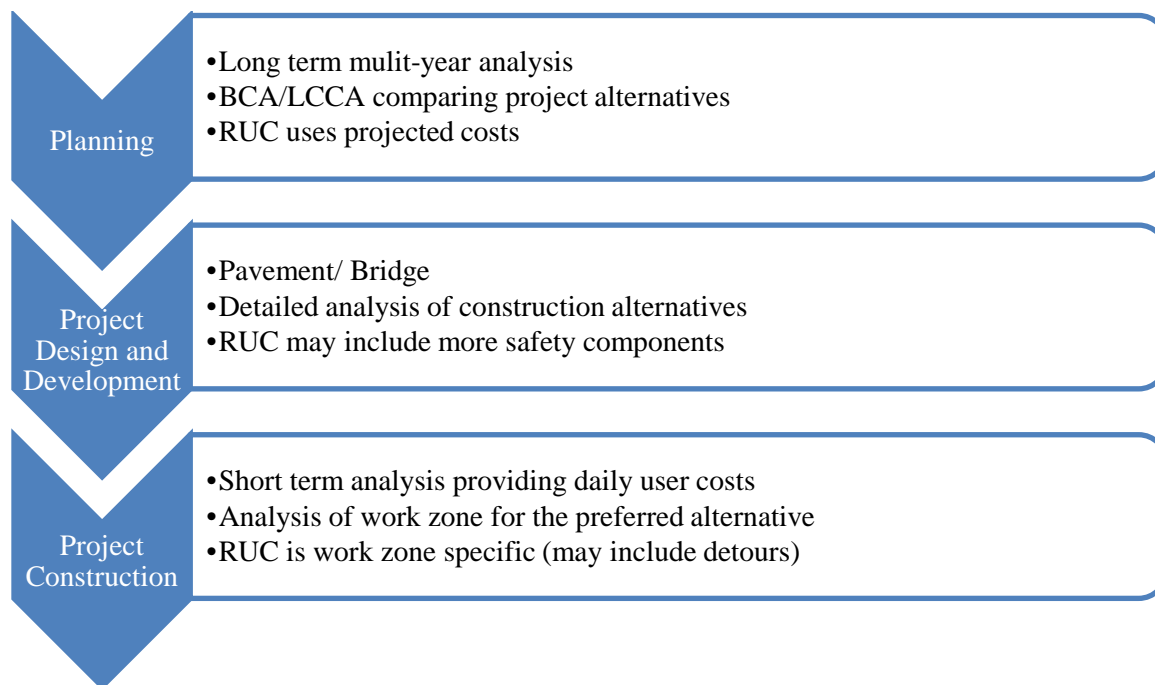


Figure 5.2 Applications of Road User Costs

5.1.2.1 Criteria for Use

The criteria for determining whether RUC usage is applicable can vary depending on the stage of the design process. Planning RUC focuses on the economic analysis of a proposed project with regard to project selection based on the benefits and costs and involves a multi-year analysis period. Project construction RUC focuses on the costs incurred during the construction process, which can be used to determine the liquidated damages, project delivery method, and project staging and phasing.

When in the early stages of a project, it must be determined whether the RUC calculation procedure is applicable. Different state departments of transportation (DOT) have set their own criteria for determining whether performing the RUC calculations for a project is necessary. Each agency may define different criteria for analysis depending on the regional needs or obligatory oversight. For example, legislative guidelines developed for the Texas DOT (Daniels et al. 1999) have defined when RUC should be incorporated into project contracting as:

1. Projects that add capacity;
2. Projects that have an economic impact on surrounding communities and businesses;
3. Rehabilitation projects in areas of high traffic volume.

Furthermore, TxDOT has identified three analysis approaches that have been recommended for use in RUC estimation, depending on which guidelines describe the characteristics of a particular project (Daniels et al. 1999):

1. Phase-by-phase approach – The RUC can be used to determine liquidated damages for milestone completion of each phase of the project. This approach is suitable to projects with severe capacity restrictions where completion time is critical.
2. Before-versus-after approach – The comparison of RUC using “before and after” project construction that focuses on the delay in final completion time. Each additional day of delay is another day that users are unable to maximize time savings from the additional roadway capacity.

3. During-versus-after approach – The comparison of RUC using “during and after” project construction to compare the user costs associated with delay caused by lane restrictions during improvements with the user costs after construction is finished. This approach is suitable to projects where the final improvements do not result in an increased capacity.

South Dakota has not developed official criteria for determining when RUC estimation is required for projects. The decision to estimate user costs is left to the discretion of the project engineers. Project planning often estimates RUC for projects that add or remove existing routes from a network. Project construction estimates RUC based on the demands of the specific project or project phase.

5.1.2.2 Planning Assessment

Planners conduct a BCA or LCCA to compare different project alternatives using an economic approach that aids in deciding the preferred alternative. This analysis may be used to compare different construction alternatives within the same project location or it can be expanded to compare which projects should be undertaken based on life-cycle costs. While the applications used in planning may be quite different from other uses, the methodology used to compute RUC remains relatively unchanged. Operational and maintenance costs are often added to the user costs when a long-term analysis is considered to include any future rehabilitation or restoration which may be required during the projects lifetime.

The AASHTO “Redbook” gives general guidelines for conducting a user benefit analysis consisting of 11 steps, which have been condensed in the following summary. (AASHTO 2010)

5.1.2.2.1 Steps for Conducting User Benefit Analysis

The first step in any planning analysis is to define the base case on which any project alternatives will be measured against in order to clearly identify the benefits of the improvements. This is the condition of the project area under current traffic demands and capacity and the projection of those conditions into the future if nothing is done, in short, “do-nothing” scenario. Project alternatives include any proposed improvements and the projections into the future of any beneficial impacts that are expected to occur from the implementation of those improvements.

The next consideration should be the level of detail that is required to establish a realistic calculation of user costs. In some instances traffic data may be required, which accounts for multiple vehicle classes, and hourly, daily, or seasonal trends in traffic patterns. Traffic data to be obtained include volume, travel speed, route length, and other performance data relating to the pavement condition of any segments involved.

Economic factors must be selected to account for inflation rates or discount rates for the analysis period. The benefits or costs that occur as a result of any potential improvements must be calculated throughout the life of the project to account for the impacts that persist over an extended period of time. Costs that occur through the life of the project, such as rehabilitation or restoration needs, may be compounded into future dollars using the appropriate inflation rate. These annually dispersed impacts are later converted into an equivalent figure in present value of the evaluation date using a discount rate to account for the devaluation of money.

User costs can be calculated from the traffic data gathered previously to determine the costs associated with the base case and any project alternatives being compared to it. These costs include any travel time costs, vehicle operational costs, accident costs, and operational costs that are associated with each specific project being examined. When user costs are calculated, the user benefits can be derived from the

reduction in costs between any alternative and the base case. This accounts for the cost savings due to reduced time delays and accidents incurred by users under the conditions of the project alternative.

When long-term analysis is being considered, the estimation of salvage value is determined for the end of the service life of the facility. This is a negative cost attributed to the end of project life and must be converted to present value for the comparison. User benefits must be expanded for every year in the analysis period using any growth factors for traffic demand or models to represent future conditions. The annual costs and benefits can then be converted into a single number representing the entire lifetime project costs in present value of the evaluation date using the appropriate discount rate. A comparison of total life cost for a project can then be compared using the value of money for the evaluation date. (AASHTO 2010)

5.1.2.3 Preliminary Assessment

Preliminary analysis is essential for the effective management of time, and costs and ensures actions are environmentally responsible. This often includes multiple design alternatives that are compared to a base case scenario or do-nothing approach. The project design may change or the parameters may be reconsidered before being forwarded to the next phase where the plans for the project are proposed. The analysis includes user costs in the comparison, but can also include a wide range of other engineering activities and analysis, including (FHWA 2012), environmental assessments, topographic surveys, geotechnical investigations, traffic studies, etc.

When alternatives have been fully analyzed, including potential safety concerns and environmental challenges presented by the project, they are documented and presented in a report along with the project needs, existing conditions, an impact analysis, and design criteria. Once a complete assessment of the project has been concluded, the preparation of construction plans and specifications may begin in the final design phase.

Multiple software suites are used to estimate the effects of various factors on the functionality of design projects. Interactive Highway Safety Design Module (IHSDM) and Pontis bridge management system are two programs used by traffic planners to estimate the effects that changes to existing designs will have on safety or overall level of service with consideration to user costs. Although RUC are not currently used by the pavement management system, dTIMS could be modified to do so if so desired.

5.1.2.3.1 IHSDM

IHSDM is a software analysis tool, developed through funds provided by the FHWA, which is used to evaluate the safety and operational impacts that result from geometric design changes on highways including rural 2-lane, rural multilane highways, urban/suburban arterials, and freeways. This tool is primarily used to predict performance conditions that result from proposed changes to existing designs. Different modules within the software suite can be used to evaluate the proposed changes from different perspectives that apply estimate measures for safety or operational performances, such as crash frequency and severity, or expected speed and quality of service for the proposed design. (FHWA 2003) Without calibration using local data, this tool is not appropriate for predicting expected number of crashes for individual alternatives but may still be available for comparing alternatives for their relative safety performance.

5.1.2.3.2 Pontis

Pontis is a network level bridge management tool originally developed for the FHWA in 1989 and is currently being used at SDDOT. It is capable of cataloging bridge inspection and inventory data which

are used to model future bridge deterioration conditions for the recommendation of bridge preservation projects to optimize agency and user benefits. The software makes use of separate modules for preservation actions, where only agency costs are considered, and functional improvements, which measure the benefits derived from user costs. Functional improvements include bridge widening, which reduces accident costs, and bridge raising, strengthening and replacing, which reduces truck operating costs and travel time delay caused by detours. (AASHTO 2004)

Pontis uses RUC as one of the factors in determining the recommended design alternatives based on the impacts of the selected functional improvements. To be specific, RUC is calculated for truck traffic using user-modifiable formulas embedded in the software, which are based upon the travel time, vehicle operation and accident cost savings resulting from the elimination of detours due to the bridge load, and clearance restrictions. These benefits are measured as the user cost per hour of additional travel time required by heavy trucks that would normally use a structure and the reductions to average user cost per accident gained from widening or replacing a deficient structure. (Thompson et al. 1999)

5.1.2.4 Work Zone Assessment

When conducting an analysis in the project construction phase, an initial assessment of the work zone must be made to establish the relevant work zone impacts. After all work zone impacts have been identified, unit cost data must be collected. Each type of work zone impact requires accurate unit cost data to calculate the work zone RUC components.

5.1.2.4.1 Work Zone Safety

Work zone safety should be a priority when planning any work zone Traffic Management Plan (TMP) or Maintenance of Traffic (MOT) strategy. The FHWA *Final Rule on Work Zone Safety and Mobility* (Mallela and Sadasivam 2011) has set guidelines that address MOT requirements for projects that include any federal aid. MOT includes Temporary Traffic Control (TTC) strategies and devices, transportation operations strategies, and public information strategies. The development of good strategies for the operation and the raising of public awareness of the project location and duration of work zone activities can have a positive effect on reducing the amount of vehicle demand in the work zone. The use of appropriate traffic control strategies will also have a reduced impact on the vehicle demand and improve the level of safety within the work zone.

Work zone vehicle crashes and work zone-related detour crashes are a function of the expected change in the crash rates due to the presence of work zones. Necessary data for the calculation of the monetary value of crashes include the crash rate and frequency at work zones, crash severity rating, and the unit cost of crashes. Computing work zone crashes relies on regional historical accident data and crash modification factors (CMF) to estimate the increased likelihood of a crash occurring in the work zone (Mallela and Sadasivam 2011).

The crash rate is the number of crashes that occur or are expected to occur along a given segment of roadway during a specified time period taking into account the length and traffic volume of the roadway. The units are typically expressed as crashes per vehicle-mile-traveled (VMT) or crashes per million VMT (Mallela and Sadasivam 2011). The crash frequency is the number of crashes in relation to the roadway length and time period of interest. The units are typically expressed as crashes per mile per year.

Studies have shown that work zones can increase crash rates by 20% to 70% (Mallela and Sadasivam 2011), a considerably large range. The application of CMFs to pre-work zone crash rates at the project location can provide estimates for work zone crash rates. Work zone CMFs are available from the FHWA Office of Safety, which maintains an online repository of factors at the CMF Clearinghouse to address

specific work zone issues (Mallela and Sadasivam 2011). The values in Table 5.1 represent some typical CMFs that have been used on freeway lane closures. FHWA did not specify under what freeway or expressway base conditions or circumstances should these CMFs be applied, but it warned the users that the likelihood of a work zone crash varies from location to location. Many factors pertaining to the operational and design characteristics of the work zone may affect the crash occurrence but they are different by work zone. To increase the accuracy of CMFs, it is suggested that agencies develop their own values from historical crash data that will reflect local trends.

Table 5.1 Work Zone CMF for Temporary Lane Closures on Freeways (FHWA)

Crash Types	Crash Severity	CMF
All	All	1.77
All	Property damage only (PDO)	1.9
All	Serious injury, Minor injury	1.6
Nighttime	All	1.57
Nighttime	Property damage only (PDO)	1.63
Nighttime	Serious injury, Minor injury	1.34

The crash severity ratings are expressed in either the KABCO injury scale or Abbreviated Injury Scale (AIS). They fall into one of three categories, including fatal crashes, injury crashes, or property damage only incidents. The crash severity ratings are used to report the extent of a roadway crash and the severity of injury (Mallela and Sadasivam 2011).

The unit costs of crashes are easily obtained from the FHWA Highway Safety Manual (HSM), which compiles the societal crash cost estimates by crash severity in a table; a more thorough analysis can be found in the FHWA report, *Crash Cost Estimates by Maximum Police-Reported Injury Severity Within Selected Crash Geometries* (Al-Kaisy and Hall 2002). The report compiles estimates for 22 scenarios of crash geometry, two common vehicle speed categories, and six levels of KABCO crash severity rating combinations (Mallela and Sadasivam 2011).

5.1.2.4.2 Work Zone Configuration

Work zone configurations include many factors, such as the number of lanes closed, length and layout of the work zone, any turn restrictions, and the time of day construction activities take place. Most of these values are easily identified, but when they are not they have to be estimated. The configuration of the work zone is an important factor in determining the capacity of the work zone. The presence of any detour routes used during the construction period must also be included in the analysis for the traffic using these routes.

The work zone configuration (lane width, tape width, lane closure/reduction, cross-over closures, speed limit, etc.) as well as traffic control type (flaggers, pilot car, etc.) will all affect its capacity. General SDDOT practice is to use the existing ADT as the maximum work zone capacity in user cost estimations. This method works well for the state's needs due to the low traffic volumes, but future growth or projects causing significant traffic impact may necessitate a more precise estimation to address effects such as vehicles queuing through work zones. Although, estimating work zone capacity is not the scope of the study, this information is presented because of its significance.

5.1.2.4.3 Demand and Capacity

When calculating the impacts of work zones, significance should be placed on the mobility analysis, as the data gathered while establishing this value are used in the calculation of the other impacts to follow. The calculation of the mobility analysis requires information regarding traffic demand and composition, the capacity of the work zone, vehicle travel speed, work zone configuration and the MOT strategy employed.

To establish RUC there is a need to determine the work zone traffic demand and capacity. Depending on the degree of accuracy that is mandated, Average Daily Traffic (ADT) volumes may be used for an approximation of the impacts. In complex situations, where more precise values are required, hourly traffic distributions with distinctions between seasonal, weekday, and weekend flows may be warranted. These are crucial input values in order to obtain queue length, delay, and delay costs estimations. The collection of traffic data has been addressed using a variety of methods at different agencies, including:

1. Field measurement of vehicles in the work zone;
2. Hand calculations using empirical formulas;
3. Use of computer estimation software.

5.1.2.4.3.1 Field Measurements

Some DOT agencies, such as New Jersey, make use of field measurements to establish compiled lists of average traffic demand within a work zone under specific work zone conditions (Mallela and Sadasivam 2011). This requires a field agent to conduct an hourly count of vehicles, making note of the composition of heavy vehicles. Hourly information must be recorded to establish any peak hour traffic pattern changes that present themselves. Vehicle operating costs and impacts on delay time vary by vehicle class, making the composition of heavy vehicles in the traffic flow an important parameter to record.

5.1.2.4.3.2 HCM Calculations

There are established empirical formulas that have been used by many agencies to estimate capacity. An example of this would be the *Highway Capacity Manual, 2000*, which has become a standard for use by many transportation departments in freeway work zone capacity analysis (ADOT 2002). The manual makes use of a multiplicative formula to determine the capacity of work zone lane closures based on an unrestricted base capacity of 1,600 passenger cars per hour per lane for short term work zones and a range of 1,500 to 2,060 pchpl for long-term work zones (Mallela and Sadasivam 2011). This value is reduced by multiple factors that take into account parameters such as lane width, ratio of cars to heavy vehicles, work intensity, and weather conditions.

Another type of empirical formula used to estimate capacity is the additive capacity model. These models use variables similar to the multiplicative method, but treat each variable as independent and examine the interaction between them using multivariate linear regression. The resulting models have included factors that show a significant interaction. A notable example is shown in research from Al-Kaisy and Hall (Al-Kaisy and Hall 2002).

While empirical formulas of these types can provide reasonable estimates for vehicle capacity, researchers have made efforts to combine the two models to achieve a model that is easy to use and includes interactive effects between variables. These “generic” capacity models use a multiplicative format, such as that proposed by Al-Kaisy and Hall (Al-Kaisy and Hall 2002), with additional variables to increase accuracy.

5.1.2.4.3.3 Computer Software Models

There have been many studies conducted to try and establish an improved model for estimation of work zone capacity. Academic and commercial research has yielded several software programs that use linear or network models to generate estimated work zone capacities. These programs use different algorithms with varying complexity of inputs in calculating the estimated work zone capacity. Some simulation models have additional capabilities for analyzing traffic operations that include economic analysis or a direct estimation of RUC.

An example of a linear model is the Queue and User Cost Evaluation of Work Zones (QUEWZ), created by Dudek and Memmott. The program estimates highway work zone capacity by input selection of lane closure configurations and application of a regression analysis. Other notable examples are the Highway Capacity Software (HCS+) developed by the University of Florida using HCM 2000 procedures, and MicroBENCOST, which can be used to evaluate the impacts on capacity due to lane closures and delays from multiple work zones along a study route (Borchardt et al. 2009).

Network models exist that require the input of traffic information and geometry that composes the entire roadway system of interest to accurately model the capacity. An example of this is QuickZone, which was developed by the FHWA in cooperation with Mitretek Systems and can be used to estimate user delays as well as traffic impact resulting from a work zone. This software requires detailed hourly traffic flow information that is entered in links and nodes to comprise the traffic network (Borchardt et al. 2009).

A recent development in network modeling is the IntelliZone software. Developed in 2004 by Jiang and Adeli and sponsored by the Ohio DOT and FHWA, the software is a work zone capacity estimator that is based on pattern recognition and neural network models. It uses 17 different input variables, and is capable of comparing 20 different scenarios to estimate work zone capacity, delay, and queue length (Jiang and Adeli 2004).

Another recent development in traffic analysis is the Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) software developed in 2002 by the University of California Pavement Research Center and supported by the FHWA. Used primarily for rehabilitation strategies, this software helps planners and designers use an economic approach to balance schedule, traffic delay, and the costs of projects (Borchardt et al. 2009).

VISSIM is another recent software analysis program which was developed by PTV AG in Germany. It is a behavior-based, multi-modal traffic simulation model capable of generating traffic flow information among streets, freeways, and other forms of public transportation (Borchardt et al. 2009). Like other network models, it requires detailed inputs concerning the geometry, traffic demand, vehicle composition, and traffic control features. It has been shown to be useful primarily in the planning stages of construction and not as a tool to determine work zone capacity because of the difficulty of use and the limited ability to model traffic through a work zone (Borchardt et al. 2009).

5.1.3 Review of RUC Methods

There are many methods currently being used by different state departments and agencies to establish RUC estimates. Typically, state departments make use of several different tools to evaluate the construction impacts to users. Some tools are useful in estimating traffic demand or capacity while others can be used in the calculation of RUC directly. A compiled list of available tools and the states that make use of them can be seen in Table 5.2. (Mallela and Sadasivam 2011)

Table 5.2 State Traffic Analysis Methods taken from FHWA

State	RUC- Specific	Non-RUC Specific (Traffic Analysis Only)
California	CA4PRS	HCM, SYNCHRO
Colorado	WorkZone RUC	-
Delaware	-	HCS, Spreadsheet, QuickZone, SYNCHRO
D.C.	QuickZone, QUEWZ-98	SYNCHRO/ SimTraffic, CORSIM
Florida	FDOT RUC	-
Hawaii	-	HCM
Illinois	DOT Spreadsheet, QuickZone	-
Iowa	QuickZone	-
Kansas	-	HCM, Travel Demand Model, Simulations
Maryland	LOPB, LCAP	HCM, SYNCHRO, CORSIM
Massachusetts	-	HCS, SYNCHRO, SIDRA, Transyt-7F, TSIS-CORSIM, GDOT Roundabout Analysis Tool, VISSIM
Michigan	CO3	HCM, SYNCHRO
Missouri	QuickZone	MoDOT WZ Impact Analysis Spreadsheet, VISSIM, CORSIM, SYNCHRO
New Hampshire	QuickZone	HCM, SYNCHRO
New Mexico	-	HCM and Simulation
New Jersey	DOT Spreadsheet	-
New York	QuickZone, AASHTO User-Benefit Analysis	CORSIM
North Carolina	QUEWZ-98	In-house detour and flagging program
Ohio	DOT Spreadsheet	Quewz-98
Oklahoma	-	HCM based Spreadsheet
Oregon	-	WZ Traffic Analysis Tool
Pennsylvania	DOT Spreadsheet	-
Rhode Island	-	HCM, QuickZone
Texas	RUC Tables	PASSER V
Utah		HCM, SYNCHRO, VISSIM
Virginia	HUB-CAP	-
Washington	QUEWZ-98	SYNCHRO
Wisconsin	-	HCM w/spreadsheet, Quadro, SYNCHRO
Tennessee	-	HCM, Web based Queue/Delay Model
Wyoming	-	HCM, SYNCHRO

Each of these available analysis tools differs in the specific inputs required to analyze the data and the method in which the data is analyzed. According to a Department of Transportation survey conducted by the University of Florida, there are six general procedures used for developing RUC. (Ellis et al. 1997)

These methods include:

1. Hand calculations using formulas;
2. Spreadsheets created for ease of use;
3. Commercial software designed specifically to address RUC;
4. AASHTO-based methods;
5. Flat rates as defined by state legislation;
6. No formal methods.

Methods used for calculating RUC vary depending on the level of analysis that is being done. The analysis period shortens as the project moves through the stages of the construction analysis and the estimation becomes more detailed. The focus on the analysis area also shifts as alternative routes or larger impact areas are considered while doing BCA or LCCA. The following methods presented may be used for any road user cost needs, but careful attention must be made when designating which components are to be included in the computations.

5.1.3.1 AASHTO method

The AASHTO method provides the foundation for many of the other methods that have been formulated. The AASHTO publication *User Benefit Analysis for Highways* (1977), also known as the “Red Book,” provides a baseline model that many agencies use for RUC estimation. Updates have been made to this manual in 2003 and 2007 to incorporate new theories, measurement methodology, and procedural guidance. The current publication, *User and Non-User Benefit Analysis for Highways* (2010) unifies the user and non-user methodologies harvested from years of research into one source. The algorithm used in this model is a function of VOT, VOC, and AC. These variables represent lost monetary value to the user based on lengthened time of travel, operating costs of the vehicle, and damages to persons and property due to the effect of the work zone (AASHTO 1977, 2010). Each of these components is composed of several factors that account for lost time, vehicle depreciation, costs associated with vehicular accidents, and costs due to increased vehicle idling and fuel consumption. Figure 5.1 illustrates these components along with the main factors that contribute to their cost.

The AASHTO formula used for calculating the RUC is:

$$RUC = VOT + VOC + AC \quad \text{Equation 5-1}$$

Where:

- VOT = Value of Time,
- VOC = Vehicle Operating Costs,
- AC = Accident Costs.

An undeniable component of user costs is the costs associated with the time spent traveling. The change in travel time is multiplied by the value of time. The travel time is generally measured in minutes, while the value of time is measured in dollars per hour requiring a unit conversion. Including average vehicle occupancy into the calculation based on trip purpose or vehicle class will increase estimation precision.

The VOT calculations for time delays are found on a per vehicle class basis:

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

Where:

- ΔH_c = Value of Time for user class c (\$/vehicle-mile)
- M_c = unit value of time for user class (\$/hr)
- O_c = Occupancy rate of vehicles for user class
- S_0 and S_1 = speed without improvements (S_0) and with improvements (S_1)

For projects that include intersection delays, travel time delays:

$$\Delta H_{int,c} = \frac{\Delta D}{3600} 100M_c O_c \left[\frac{V_{0,c} + V_{1,c}}{2} \right] \quad \text{Equation 5-3}$$

Where:

- ΔH_c = change in the value of time for user class c (\$/vehicle-mile)
- $\Delta D = D_0 - D_1$ = the change in intersection delay per vehicle in seconds

$V_{0,c}$ and $V_{1,c}$ = vehicle volumes without, (V_0) and with improvements (V_1) for each class, c

Another significant component is the costs associated with operating a vehicle. These costs are measured in dollars per vehicle-mile and may include operating costs and/or ownership costs. Operating costs include fuel, oil, tires, and maintenance. Ownership costs include insurance, license and registration fees and taxes, vehicle depreciation, and may include the inventory cost of the cargo on the vehicle.

The VOC calculations are done using two possible procedures to find fuel consumption costs as a function of speed or time delay for each vehicle class:

$$\Delta C(S)_{Fuel} = (gal_{speed0} - gal_{speed1}) * P * L \quad \text{Equation 5-4}$$

Where:

- $\Delta C(S)_{Fuel}$ = Change in fuel costs as a function of speed per vehicle class c ,
- Gal_{speed0} = Gallons per mile for vehicle class, during construction speed,
- Gal_{speed1} = Gallons per mile for vehicle class, after construction speed,
- P = Fuel price per gallon for vehicle class,
- L = The length of the work zone.

$$\Delta C(D)_{c,Fuel} = gal_{c,min} * (D_0 - D_1) * P_c \quad \text{Equation 5-5}$$

Where:

- $\Delta C(D)_{Fuel}$ = Change in fuel costs as a function of speed per vehicle class,
- Gal_{min} = Gallon per minute for vehicle class,
- D_0 = average time before the improvement (minutes)
- D_1 = average delay after the improvement (minutes)
- P_c = Fuel price per gallon for vehicle class.

More detailed estimation of operating costs may take into account the inventory costs associated with delays to heavy trucks transporting cargo. This can be calculated using speed or time delay:

$$\Delta I(S) = 100 * \frac{r}{8760} \left(\frac{1}{S_0} - \frac{1}{S_1} \right) * P_{cargo} \quad \text{Equation 5-6}$$

Where:

- $\Delta I(S)$ = Change in inventory costs (cents per vehicle mile),
- r = interest rate (opportunity cost of vehicle capital), per annum
- S_0 and S_1 = speed without improvements (S_0) and with improvements (S_1) (mph)
- P_{cargo} = Value of the cargo (dollars).

$$\Delta I(D) = 100 * \frac{r}{8760*60} * P_{cargo} * \Delta D \quad \text{Equation 5-7}$$

Where:

- $\Delta I(D)$ = Change in inventory costs (cents per minute),
- ΔD = change in delay (minutes)

$$\Delta OC(S)_c = \Delta C(S)_{c,Fuel} + \Delta I(S)_c \quad \text{Equation 5-8}$$

Where:

- $\Delta OC(S)_c$ = Change in operating costs (cents per vehicle mile) for vehicle class c,
- $\Delta C(S)_{Fuel}$ = Change in fuel costs as a function of speed (cents per vehicle mile) for vehicle class c,
- $\Delta I(S)$ = Change in inventory costs (cents per vehicle mile) for vehicle class c,

$$\Delta OC(D)_c = \Delta C(D)_{c,Fuel} + \Delta I(D)_c \quad \text{Equation 5-9}$$

Where:

- $\Delta OC(D)_c$ = Change in operating costs (cents per minute) for vehicle class c,
- $\Delta C(D)_{Fuel}$ = Change in fuel costs as a function of speed (cents per minute) for vehicle class c,
- $\Delta I(D)$ = Change in inventory costs (cents per minute) for vehicle class c,

Accident costs are a function of the expected change in the accident rates due to project improvements or the presence of work zones. Monetized crash cost values may account for fatal, injury, and property damage costs separately or can be converted to equivalent property damage only (EPDO) costs.

The method for estimation of AC is found using the change in accident rate resulting from the facility improvements:

$$\Delta AC_c = v_i * \Delta I + v_d * \Delta D + v_p * \Delta P \quad \text{Equation 5-10}$$

Where:

- ΔAC = change in accident costs for vehicle class c (cents per vehicle mile)
- v_i = perceived cost for each injury accident (cents)
- v_d = perceived cost for each fatal accident (cents)
- v_p = perceived cost for each property damage incident (cents)
- ΔI = change in the number of injury accidents per vehicle mile
- ΔD = change in the number of fatal accidents per vehicle mile
- ΔP = change in the number of property damage incidents per vehicle mile

A method for calculating the accident rate due to capacity improvements uses a volume to capacity ratio:

$$A_R = \frac{3.0234\left(\frac{V_1}{C_1}\right) - 1.11978\left(\frac{V_1}{C_1}\right)^2}{3.0234\left(\frac{V_0}{C_0}\right) - 1.11978\left(\frac{V_0}{C_0}\right)^2} - 1 \quad \text{Equation 5-11}$$

Where:

- A_R = Proportional change in accident rate per vehicle
- $\left(\frac{V_0}{C_0}\right)$ = Volume to capacity ratio for freeway segments without improvement
- $\left(\frac{V_1}{C_1}\right)$ = Volume to capacity ratio for freeway segments with improvement

Accident numbers may be estimated for rural two-lane roads using an IHSDM model based on traffic volumes and roadway features. This equation may be used to estimate accident changes with and without improvements:

$$A = \frac{AADT * 365}{1,000,000} * 0.6148 * L \quad \text{Equation 5-12}$$

Where:

- A = predicted number of accident on the segment
- L = length (miles)

5.1.3.2 Spreadsheet Method

Several state agencies have followed the lead of the Arizona DOT and developed their own Excel-based spreadsheets to determine RUC based off capacity analysis software. Arizona, Colorado, Idaho, Illinois, New Jersey, Ohio, and South Dakota are all examples of states that have developed this method of calculation. (ADOT 2002; NJDOT 2001; ODOT 2010; Caputo and Scott 1996) These spreadsheets generally retain the same basic input requirements, including traffic volume, speeds, length of study route, and unit costs related to average wages and vehicle operating expenses, but they may include components specific to the agency's needs. Most of the spreadsheets analyzed during this research effort only account for VOT and do not calculate the VOC or AC components of user cost. The reasoning behind this is that VOT is usually the highest contributor to RUC and is calculated more accurately and easily than the other components.

5.1.3.2.1 Arizona

The Arizona RUC model consists of simple calculations using an Excel spreadsheet. The calculations take into account the average annual daily traffic, the loss in time of the motorists when traversing the work zone, average hourly wage of locals, duration of the project, and factors that influence the project (ADOT 2002; Zhu et al. 2009). It must be noted that this technique only considers VOT, and not VOC or AC. The impact factor is used to account for costs incurred in construction work zones and detours.

The ADOT formula is as follows:

$$\text{DailyValue} = (AADT)(\Delta t)(w)(f)(d) \quad \text{Equation 5-13}$$

Where:

- AADT = Average Annual Daily Traffic
- Δt = Difference in time required to travel through the work zone while under construction
- w = Average hourly wage of the motorists
- f = A factor that takes into account impacts to areas other than road users, such as impacts to local businesses (default =1.0)
- d = Weighted duration of the project. This is the duration of a specific traffic control condition divided by the estimated duration of the project.

Where w, the average wage is the weighted hourly combination of commercial and noncommercial drivers:

$$w = c * \$18.50 + (1 - c) * \$10.50 \quad \text{Equation 5-14}$$

c = percentage of commercial drivers

5.1.3.2.2 South Dakota

The SDDOT practice of estimating RUC uses a series of simple calculations within a spreadsheet which are based on recommendations from research reported in 1996 by Trauner Consulting Services, Inc. (TCS) (Caputo and Scott 1996). A series of four equations are used, comprising two sets for automobile and heavy truck data. The first set is calculated during normal traffic conditions prior to construction and the second set is calculated using the construction induced delays. The difference between the two

equation sets is the increased user cost associated with the delays. The procedure established in the TCS report recommended that AC, VOF, and speed cycle change costs be included in future RUC calculations (SDDOT 2012). Prior to this report, no consideration was given to these components of user cost at SDDOT.

Current SDDOT RUC estimation practices have resulted in Planning and Project Construction using two separate spreadsheets derived from the original produced from the TCS research report (Caputo and Scott 1996). This has resulted in variations to the included components used by each department, as well as differences in the methods and frequency of updates which are applied to the spreadsheet tools. Planning estimation does not include AC, VOF, or speed cycle changes in their calculations. Project construction estimation includes VOF and speed cycle changes into their calculations but does not include AC in most estimates, although it has been included in projects deemed as having significant safety impacts.

The Cost of Motorist Delay equation:

$$\text{Auto Delay Cost} = \text{No. of autos} * \text{VOF} * T_{avg} * C_a \quad \text{Equation 5-15}$$

$$\text{Truck Delay Cost} = \text{No. of trucks} * T_{avg} * C_T \quad \text{Equation 5-16}$$

Where:

- No. of autos = ADT * % autos
- No. of trucks = ADT * % trucks
- VOF = Vehicle Occupancy Factor (current SD standard=1)
- T_{avg} = Average time delay per vehicle (WZ or Detour)
- C_a = Cost per unit time (autos)
- C_T = Cost per unit time (trucks)

And:

$$T_{avg} (\text{work zone}) = L_{CZ} * (1/S_L - 1/S_P) \quad \text{Equation 5-17}$$

Where:

- L_{CZ} = Length of construction zone (miles)
- S_L = Operating speed on roadway prior to construction (MPH)
- S_P = Operating speed through construction zone (MPH)

$$T_{avg} (\text{detour}) = L_{CZ} / S_L - D_D / S_D \quad \text{Equation 5-18}$$

Where:

- D_D = Length of detour (miles)
- S_D = Speed limit through detour (MPH)

The Additional Vehicle Operating Costs for a Detour:

$$\text{Auto Operating Expense} = \text{No. of autos} * D_{delta} * C / M_A \quad \text{Equation 5-19}$$

$$\text{Truck Operating Expense} = \text{No. of trucks} * D_{\text{delta}} * C/M_T \quad \text{Equation 5-20}$$

Where:

D_{delta} = Construction detour route distance less original route distance.

C/M_A = Operating cost per mile (autos)

C/M_T = Operating cost per mile (trucks)

The Additional Vehicle Operating Costs for Speed Changes:

$$\text{Auto Operating Expense} = \text{No. of autos} * CPC \quad \text{Equation 5-21}$$

$$\text{Truck Operating Expense} = \text{No. of trucks} * CPC \quad \text{Equation 5-22}$$

Where:

CPC = Costs per Cycle (deceleration when entering WZ and acceleration when exiting for each 1000 cycles)

The Accident Costs:

$$\text{Accident Costs} = (AR_C - AR_P) * L_{CZ} * ADT * A_{ACC} \quad \text{Equation 5-23}$$

Where:

AR_C = Estimated accident rate per million vehicle miles during construction

AR_P = Preexisting accident rate per million vehicle miles without construction

A_{ACC} = Average cost per accident

5.1.3.2.3 New Jersey

New Jersey DOT uses a system to establish RUC that makes use of several data worksheets and simple calculations. The calculations use 10 potential cost components based on traffic flow conditions in the work zone, five of which are considered to be essential and used in the majority of RUC estimates (NJDOT 2001). Three cost components are used for unrestricted traffic flow in the base case, four components account for a queue situation present in forced flow scenarios, two components are associated with detour situations, and one component accounts for the crash costs. The individual components include speed change delays, stopping delays, queue delays, detour delays, and the costs due to accidents. Essential components account for the majority of user costs and are calculated with the most accuracy; they include work zone delay, queue delay, queue idling delay, queue idling VOC, circuitry (detour) VOC, and circuitry (detour) delay.

The New Jersey RUC worksheet produces results in daily RUC; a 50% reduced Calculated Road User Cost (CRUC) to account for traffic variations, roadway capacities, and cost rates; and total RUC that uses the CRUC value multiplied by the number of anticipated work zone days. These values are computed using the five essential components: queue delay, queue idling VOC, work zone delay, circuitry (detour) delay, and circuitry (detour) VOC. Each component is calculated individually to determine the component RUC, and the component RUC values are added together to establish the Daily RUC (NJDOT 2001).

The component RUC equation for each vehicle class (i) is as follows:

$$RUC_i = P_{\text{class}} * v * \Delta t * \Delta d * C \quad \text{Equation 5-24}$$

Where:

- P_{class} = Percent of the vehicle class (car or truck)
- v = Total number of vehicles
- Δt = Difference in time required to travel through the work zone while under construction
- Δd = Added travel length for any detour (mile/veh)
- C = Cost rate for vehicle class

5.1.3.3 Commercial Software

There are many commercial agencies that have developed software for determining RUC. Many of these programs feature dual output options to compute capacity or user costs. QuickZone, QUEWZ, and HERS-ST are a few examples of programs that may be used to provide work zone traffic capacities as well as estimate RUC (Borchardt et al. 2009). These programs can vary widely in both the complexity of input requirements and output options.

5.1.3.3.1 QuickZone

The QuickZone model, employed by agencies in the District of Columbia, New York, New Hampshire, and others, uses five components in the calculation of RUC, including travel time cost, vehicle operating cost, inventory cost (freight costs), economic cost, and miscellaneous cost (Zhu and Ahmad 2008). Miscellaneous costs are not found using any calculations, but are included for use in specific construction projects that have costs not associated with road user costs, such as additional administrative or quality control costs that accompany an accelerated construction schedule. The RUC is the sum total of these components. The built-in calculations used in the model are represented below as a cost per day.

$$RUC = C_T + C_V + C_i + \text{Economic Costs} \quad \text{Equation 5-25}$$

The travel time cost is calculated as follows:

$$C_T = w * m * \Delta t * ADT \quad \text{Equation 5-26}$$

Where:

- w = The unit value of time
- m = Average vehicle occupancy
- Δt = Delay per vehicle
- ADT = Average daily traffic

The vehicle operating costs are found using:

$$C_V = c * d * v \quad \text{Equation 5-27}$$

Where:

- c = Vehicle Operating Cost, per mile
- d = Distance traveled on detour
- v = Daily traffic volume

Inventory cost is found using:

$$C_i = a * p * r * t * v \quad \text{Equation 5-28}$$

Where:

- a = Average payload
- p = Payload value per ton
- r = Hourly discount rate
- t = Delay per vehicle
- v = Daily freight volume

Economic costs relate to local businesses impacted by detoured traffic, and are found using:

$$\text{Economic Cost} = \text{Daily Income} * \% \text{Volume Taking Detour} \quad \text{Equation 5-29}$$

5.1.3.3.2 QUEWZ

The QUEWZ (Queue and User Cost Evaluation of Work Zones) model processes the user inputs using four modules to estimate capacity, process speed-volume relationships, queuing and diversions, and estimate RUC (Zhu and Ahmad 2008). The RUC calculations are done using the following equation:

$$\text{THC} = \text{CQUE} + \text{CDWZ} + \text{CDSC} + \text{CSPC} + \text{OC} + \text{OCQ} \quad \text{Equation 5-30}$$

Where:

- THC = Total hourly cost
- CQUE = Cost of delay due to queuing
- CDWZ = Cost of delay while going through work zone at reduced speed
- CDSC = Cost of delay due to speed changes
- CSPC = Additional operating cost of speed change cycle with queue
- OC = Vehicle operating cost
- OCQ = Vehicle running cost with queue

5.1.3.3.3 HERS-ST

HERS-ST (Highway Economic Requirement System-State Version) is an engineering/economic analysis tool that provides cost estimates for use in benefit cost analysis to determine the optimal program to implement. The software uses different computer models to determine the impacts of alternative highway investments and program structures on highway conditions, performance, and user costs. This program has been used by the FHWA to determine future National highway investment needs by predicting system conditions and user cost levels. (FHWA 2005)

Within the HERS model are calculations for user costs, including vehicle operating costs, travel time costs, and crash costs. Vehicle operating costs include the excess costs of fuel, oil, tires, maintenance and repair, and depreciation. Three different calculations are used to account for constant speed costs, speed change costs, and costs due to curves. Estimates for constant speed costs are a function of the average effective speed, average grade, and the present serviceability rating (PSR). (Mallela and Sadasivam 2011; FHWA 2005)

Constant Speed Operating Costs:

$$CSOPCST_c = CSFC * PCAFFC * \frac{COSTF_c}{FEAF_c} + CSOC * PCAFOC * \frac{COSTO_c}{OCAF_c} + 0.01 * CSTW * PCAFTW * \frac{COSTT_c}{TWAF_c} + 0.01 * CSMR * PCAFMR * \frac{COSTMR_c}{MRAF_c} + 0.01 * CSVD * PCAFVD * \frac{COSTV_c}{VDAF_c}$$

Equation 5-31

Where:

- CSOPCST_{vt} = constant speed operating cost for vehicle class c;
- CSFC = constant speed **fuel** consumption rate (gallons/ 1000 miles);
- CSOC = constant speed **oil** consumption rate (quarts/1000 miles);
- CSTW = constant speed **tire wear** rate (% worn/1000 miles);
- CSMR = constant speed **maintenance and repair** rate (% of average cost/1000 miles);
- CSVD = constant speed **depreciation** rate (% of new price/ 1000 miles);
- PCAFFC = pavement condition adjustment factor for fuel consumption;
- PCAFOC = pavement condition adjustment factor for oil consumption;
- PCAFTW = pavement condition adjustment factor for tire wear;
- PCAFMR = pavement condition adjustment factor for maintenance and repair;
- PCAFVD = pavement condition adjustment factor for depreciation expenses;
- COSTF_{vt} = unit cost of fuel for vehicle class c (dollars per gallon);
- COSTO_{vt} = unit cost of oil for vehicle class c (dollars per quart);
- COSTT_{vt} = unit cost of tires for vehicle class c (dollars per tire);
- COSTMR_{vt} = unit cost of maintenance and repair for vehicle class c (dollars per 1000 miles);
- COSTV_{vt} = depreciable value for vehicle class c (dollars per vehicle);
- FEAF_{vt} = fuel efficiency adjustment factor for vehicle class c;
- OCAF_{vt} = oil consumption adjustment factor for vehicle class c;
- TWAF_{vt} = tire wear adjustment factor for vehicle class c;
- MRAF_{vt} = maintenance and repair adjustment factor for vehicle class c; and
- VDAF_{vt} = depreciation adjustment factor for vehicle class c.

Excess costs due to Speed Cycle Change:

$$VSOPCST_{VT} = VSFC * \frac{COSTF_c}{FEAF_c} + VSOC * \frac{COSTO_c}{OCAF_c} + VSTW * \frac{COSTT_c}{TWAF_c} + VSMR * \frac{COSTMR_c}{MRAF_c} + VSVD * \frac{COSTV_c}{VDAF_c}$$

Equation 5-32

Where:

- VSOPCST_c = excess operating cost due to speed variability for vehicle class c;
- VSFC = excess **fuel** consumption rate due to speed variability (gallons/1000 miles);
- VSOC = excess **oil** consumption rate due to speed variability (quarts/1000 miles);
- VSTW = excess speed **tire wear** rate due to speed variability (% worn/1000 miles);
- VSMR = excess speed **maintenance and repair** rate due to speed variability (% of average cost/1000 miles);
- VSVD = excess **depreciation** rate due to speed variability (% of new price/1000 miles);

Travel time costs:

$$TTCST_{vt} = \frac{1000}{AES_{vt}} * TTVAL_{vt} \quad \text{Equation 5-33}$$

Where:

$TTCST_{vt}$ = average travel time cost (dollars per thousand vehicle miles) for vehicles of type vt,

AES_{vt} = average effective speed (mph) for vehicles of type vt,

$TTVAL_{vt}$ = average value of time (dollars) for occupants and cargo of type vt,

Crash costs are estimated by adding the value of lives lost with the cost of injuries, property damages, and delays to users as a result of accidents. The costs due to fatalities, injuries, and property damage are found by multiplying the number of injuries of that severity level by the value attributed by the US Department of Transportation. (FHWA 2005)

Table 5.3 Component Prices (1997 dollars) in HERS-ST

Vehicle Type	Fuel (\$/ gallon)	Oil (\$/ quart)	Tires (%/ tire)	Maintenance and Repair (\$/ 1000 miles)	Depreciable Value (\$/ vehicle)
AUTO					
Small	\$ 0.87	\$ 3.57	\$ 45.20	\$ 84.10	\$ 18,117.00
Medium/Large	\$ 0.87	\$ 3.57	\$ 71.50	\$ 102.10	\$ 21,369.00
TRUCK					
4 tire (pickup)	\$ 0.87	\$ 3.57	\$ 78.80	\$ 129.80	\$ 23,028.00
6 tire	\$ 0.87	\$ 1.43	\$ 190.10	\$ 242.90	\$ 34,410.00
3+ axle	\$ 0.76	\$ 1.43	\$ 470.70	\$ 343.50	\$ 75,702.00
3-4 axle	\$ 0.76	\$ 1.43	\$ 470.70	\$ 355.80	\$ 87,690.00
5+ axle	\$ 0.76	\$ 1.43	\$ 470.70	\$ 355.80	\$ 95,349.00

Table 5.4 Fuel Efficiency Adjustment Factor (2000)

Vehicle Class	Factor
Small Car	1.550
Medium Car	1.550
Large Car	1.550
4 tire (pickup)	1.666
6 tire	1.344
3+ axle	1.396
3-4 axle	1.396
5+ axle	1.396

5.1.3.3.4 CA4PRS

Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) was developed by the University of California through funding provided by the FHWA. This is a construction schedule, staging, and traffic analysis tool that is used to identify optimal rehabilitation strategies that balances project schedules with agency costs and impacts to drivers.

The program uses “what if” scenarios for variables such as rehabilitation strategy, construction window, the number of lanes to be closed, material selection, pavement base type, and production rates to determine which strategy maximizes production while minimizing traffic delays. It can be used to establish schedules, develop construction staging plans, estimate A + B contracts, and calculate incentives and disincentive rates (Mallela and Sadasivam 2011).

The input requirements for evaluating the scenarios include (Mallela and Sadasivam 2011):

- Work Zone Constraints – Number of lanes before and during construction, number of lane closures, lane width, lateral clearance, roadway capacity, traffic composition, hourly traffic demand, unit cost for delay time, unit cost for vehicle operating costs
- Construction Window – Nighttime closures, weekend closures, continuous closure, or any combinations
- Rehabilitation Strategy – PCC reconstruction, asphalt overlay of crack and seat PCC, or full depth asphalt concrete replacement
- Material Constraint – Mix design and curing time for concrete or cooling time for asphalt
- Pavement Cross Section – Cross section thickness of new concrete or asphalt concrete
- Contractor’s Logistical Resource Constraints – Location, capacity, and number of rehabilitation equipment used, including the batch plant, pavers, and delivery or haul trucks
- Scheduling – Mobilization and demobilization time, traffic control time, activity lead-lag time relationships, and buffer time

The available outputs produced include (Mallela and Sadasivam 2011):

- Mobility Impacts – The maximum delay time and queue lengths before and during construction
- Road User Costs – Daily, per lane closure, and total road user costs
- Project Costs – All pavement, non-pavement, and indirect costs
- Traffic Handling and Management Costs – Daily traffic handling, extra TMP, and incident management costs

5.1.3.3.5 FDOT Developed Software

Florida’s DOT has undertaken research aimed at developing a software version of RUC estimation. Florida has improved upon previous models and developed a new program combining the established AASHTO and HCM procedures. The program is based on the Microsoft.NET framework and was designed to be both user friendly and produce results comparable to existing models (Zhu and Ahmad 2008).

The software produced by the FDOT uses the basic AASHTO equation with the inclusion of a general impact factor (GIF) to reflect the impact of detours, lane closures, and work zones on aspects other than vehicle road users, such as pedestrians (Zhu and Ahmad 2008). The value of GIF is not supported by any specific data, but follows guidelines established for the impact factor used in the ADOT model, which adds 20% if traffic volumes, vehicle accidents, or pedestrian numbers in the vicinity are exceptionally high. The calculations used in the software tool developed by the FDOT include:

$$RUC = GIF * (VOT + VOC + AC) \qquad \text{Equation 5-34}$$

Where:

GIF = General Impact Factor (default = 1.0)
VOT = Value of Time
VOC = Vehicle Operating Cost
AC = Accident Cost

The Value of Time equation:

$$VOT = V * (PC * AWCD + PT * AWTD) * \Delta t * O_C \quad \text{Equation 5-35}$$

Where:

V = Daily traffic volume affected by construction
PC = Percentage of passenger vehicle
AWCD = Average wage of passenger car drivers
PT = Percentage of trucks
AWTD = Average wage of truck drivers
 Δt = Time delay
 O_C = Occupancy rate

And:

$$\Delta t = L * \left(\frac{1}{S'_A} - \frac{1}{S_A} \right) + \Delta t' \quad \text{Equation 5-36}$$

Where:

L = Length of the work zone
 S'_A = Average travel speed during construction
 S_A = Average travel speed after construction
 $\Delta t'$ = Estimated additional delay time

The Vehicle Operating Cost equation:

$$VOC = V * (gal_{speed1} - gal_{speed0}) * P * L \quad \text{Equation 5-37}$$

Where:

V = Daily traffic volume affected by construction
 Gal_{speed0} = Gallons per mile for vehicle, during construction speed
 Gal_{speed1} = Gallons per mile for vehicle, after construction speed
P = Fuel price per gallon for vehicle
L = Length of the work zone

The Accident Cost equation:

$$AC = \frac{A * R_{wz} * V * L}{1000000} * C \quad \text{Equation 5-38}$$

Where:

A = Crash rate per million vehicle miles
 R_{wz} = Percentage change of the accident rate in work zone
L = Length of the work zone
V = Total hourly traffic volume during construction per day
C = Average crash dollar value per accident

And:

$$V = \frac{AADT}{N * 24} \quad \text{Equation 5-39}$$

Where:

- V = Average hourly volume per lane
- AADT = Average Annual Daily Traffic counts
- N = The total number of lanes for two directions.

The value of A, the crash rate, and C, the average crash dollar value per accident, are determined from a table compiling crash reports collected in the state of Florida (Zhu and Ahmad 2008).

Spreadsheet methods are quite similar in their requirement of input parameters and require the least effort from the user. For most project construction applications, the spreadsheet method is suitable, but planning may require a more detailed approach. Most spreadsheets used by state agencies only calculate VOT and do not include any VOC or AC estimates in their RUC analysis. (NJDOT 2001; ODOT 2010)

5.1.4 Unit Cost

Contemporary RUC methods require current data to achieve monetary values for travel time delay, vehicle operating costs, work zone vehicle crashes, and vehicle emissions. Sources of national data are available for use; however, the use of regional or state data is suggested, when available, to obtain more accurate results.

5.1.4.1 Value of Time

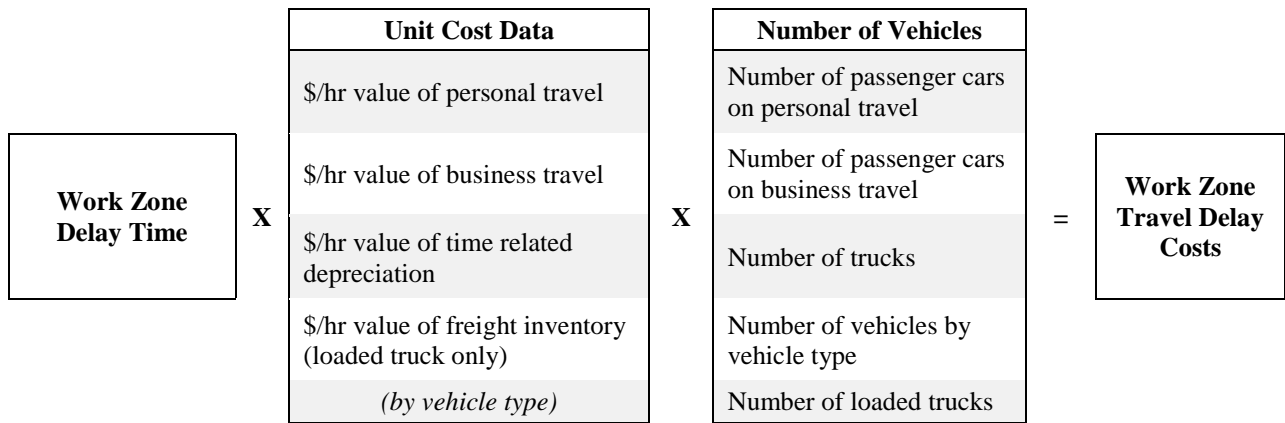


Figure 5.3 Value of User’s Time Components

The calculation of travel time delay costs requires data pertaining to the travel delay time, unit cost data for each mode of transportation, the number and type of vehicles per hour using the work zone, vehicle occupancy rates, and could include factors to discount personal travel time and time-related vehicle depreciation. Figure 5.3, taken from FHWA *Work Zone RUC: Concepts and Applications*, depicts the components needed in the calculation of VOT. Travel delay time may be estimated based on the predicted work zone travel demand, work zone capacity, and work zone management plan. If regional data are unavailable, many of these values may be estimated from national averages available from sources such as the National Household Transportation Survey (NHTS) for vehicle occupancy rates, Nationwide Personal Transportation Survey (NPTS) for travel patterns and trip purposes, and the United States Census Bureau (USCB) for median wage rates. Unit costs data often do not reflect current year statistics and must be adjusted to current year values by using the appropriate adjustment factors found in sources such as the Consumer Price Index (CPI) or Producer Price Index (PPI). (Mallela and Sadasivam 2011)

Table 5.5 US Census Bureau State & County Quick Facts

People QuickFacts	South Dakota	USA
Population, 2011 estimate	824,082	311,591,917
Population, 2010 (April 1) estimates base	814,180	308,745,538
Housing units, 2011	366,540	132,312,404
Homeownership rate, 2006-2010	68.90%	66.60%
Housing units in multi-unit structures, percent, 2006-2010	18.50%	25.90%
Median value of owner-occupied housing units, 2006-2010	\$122,200.00	\$188,400.00
Households, 2006-2010	315,468	114,235,996
Persons per household, 2006-2010	2.43	2.59
Per capita money income in past 12 months (2010 dollars) 2006-2010	\$ 24,110.00	\$ 27,334.00
Median household income 2006-2010	\$ 46,369.00	\$ 51,914.00
Persons below poverty level, percent, 2006-2010	13.70%	13.80%

5.1.4.2 Vehicle Operating Costs

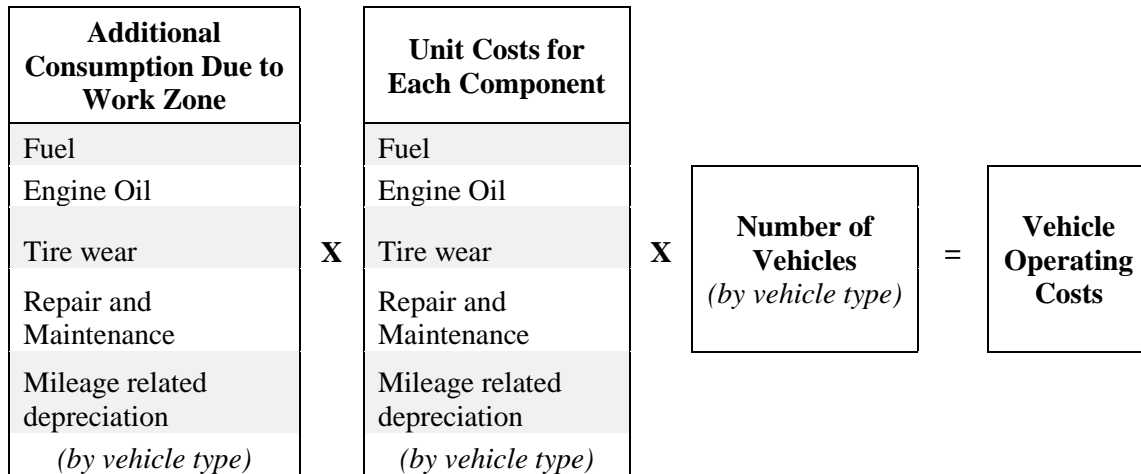


Figure 5.4 Vehicle Operating Cost Components

Vehicle operating costs are calculated based on the expenses that occur while a vehicle is in use and are mileage dependent. The calculation of vehicle operating costs requires data pertaining to the additional consumption of materials, unit costs data regarding the materials consumed, and the number and type of vehicles per hour using the work zone. Calculations for VOC include the consumption costs of materials such as fuel, engine oil, tire wear, repair and maintenance, and mileage-related depreciation. These components can be seen in Figure 5.4, taken from FHWA *Work Zone RUC: Concepts and Applications* along with the unit cost values necessary for the calculation. The FHWA *Work Zone Road User Costs* recommends using one of three VOC models for estimating the additional consumption of materials: the National Cooperative Highway Research Program (NCHRP) method, the Texas Research and Development Foundation method, or the HERS-ST method. Unit cost data can be found using publications such as *AAA - Your Driving Costs*, the American Transportation Research Institute (ATRI), or values tabulated from prior DOT studies. These values may need to be adjusted to current year values using adjustment factors found in the CPI (Mallela and Sadasivam 2011).

There are various models that have been used to calculate VOC that use detailed methodology to account for costs due to excessive wear during operation. The NCHRP Report 133 proposed a method to calculate user costs which included operating costs due to vehicle idling, stopping, and speed changes in work zones. This method was based on research done in 1969, and the dated technologies used in the study may not make it suitable for current use. The Texas Research and Development Foundation (TRDF) constructed a model that incorporated vehicle speed, vehicle class, and roadway grade in the operational calculations. This method was also based on the vehicle technology of the research period (1970s) and did not have a method to update for newer technologies. The FHWA produced the HERS-ST model after commissioning research to update the TRDF model with adjustments for commodity cost fluctuations and improvements in vehicle efficiency. This method includes separate models for each resource component to calculate constant speed costs, speed change costs, and costs due to roadway curvature. (Mallela and Sadasivam 2011)

Table 5.6 American Transportation Research Institute – Average Carrier Costs per Mile

Motor Carrier Costs	2008	2009	2010	2011
<i>Vehicle-based</i>				
Fuel & Oil Costs	\$ 0.633	\$ 0.405	\$ 0.486	\$ 0.590
Truck/Trailer Lease or Purchase Payments	\$ 0.213	\$ 0.257	\$ 0.184	\$ 0.189
Repair & Maintenance	\$ 0.103	\$ 0.123	\$ 0.124	\$ 0.152
Truck Insurance Premiums	\$ 0.055	\$ 0.054	\$ 0.059	\$ 0.067
Permits and Licenses	\$ 0.016	\$ 0.029	\$ 0.040	\$ 0.038
Tires	\$ 0.030	\$ 0.029	\$ 0.035	\$ 0.042
Tolls	\$ 0.024	\$ 0.024	\$ 0.012	\$ 0.017
Subtotal	\$ 1.074	\$ 0.921	\$ 0.940	\$ 1.095

Table 5.7 American Automobile Association – Average Cost per Vehicle

Miles per Year	10,000	15,000	20,000
small sedan	57.6 cents	44.9 cents	38.4 cents
medium sedan	74.9 cents	58.5 cents	50.1 cents
large sedan	98.8 cents	75.5 cents	63.6 cents
Composite Average	77.1 cents	59.6 cents	50.7 cents

5.1.4.3 Accident Costs

Unit cost data for work zone vehicle accidents can be found in the FHWA document *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries* (Forrest et al. 2005). This report compiles human capital and comprehensive costs for a variety of scenarios and crash geometries using two ranges of vehicle speeds (< 45 mph and > 50 mph). The data are presented in 2001 dollar values and must be converted to current dollar values using the CPI and Employment Cost Index (EPI) conversions.

The Highway Safety Manual (HSM) also provides crash costs by crash severity in both human capital and comprehensive costs using the KABCO injury severity rating. Table 5.8 depicts the values associated with each level of injury severity. The monetary value of crash severity can be represented as human capital cost, which include the costs directly related to the crash or comprehensive costs that may include the human capital costs as well as costs related to any physical and mental suffering or diminished quality of life. (AASHTO 2010)

Table 5.8 Societal Crash Cost Estimates by Crash Severity

Collision Type	Comprehensive Societal Crash Costs
Fatal (K)	\$4,008,900
Disabling Injury (A)	\$216,000
Evident Injury (B)	\$79,000
Fatal/Injury (K/A/B)	\$158,200
Possible Injury (C)	\$44,900
PDO (O)	\$7,400

5.1.4.4 Vehicle Emissions

Additional vehicle emissions due to the increased queuing and idling of vehicles through work zones have been shown to contribute negatively to the environment. These vehicle emissions include air pollutants, which have been shown to have harmful environmental effects, and greenhouse gases, which are not yet recognized as air pollutants (Mallela and Sadasivam 2011). There have been many factors identified that may affect the rate of vehicle emissions, including roadway, traffic, driver, vehicle, and weather characteristics. A list of variables that have been determined to increase the rate of emissions from vehicles in a work zone can be seen in Table 5.9.

There are several models used for estimating roadway emissions and are classified as either static emission models or dynamic instantaneous emission models (Mallela and Sadasivam 2011). Static emission factor models calculate emissions using average vehicle operating conditions and multiplicative emission factors. Dynamic emission factor models use the effects of instantaneous changes in vehicle operating conditions in emission estimations. The monetary costs associated with vehicle emissions are costs that are estimated based on the impacts to society in general. Currently, there is no recognized method to assign a monetary value to the impact of each pollutant type. These models use unit costs that are based on the economic analysis of health impacts caused by air pollutants in the geographic area, and vary widely based on population density.

Table 5.9 Characteristics That Increase Vehicle Emission Rates

Roadway Characteristics	Traffic Characteristics	Driver Characteristics	Vehicle Characteristics	Weather Characteristics
Number of lanes	Volume	Attitude	Age	Temperature
Lane width	Capacity	Experience	Mileage	Humidity
Sight distance	Volume/ Capacity ratio	Gender	Weight	Visibility
Horizontal curves	Vehicle composition	Age	Fuel type	
Vertical curves	Vehicle speed	Aggressiveness	Engine size	
Grades		Driving modes	Engine type and cycle	
Roadway type			Air to fuel mass ratio	
Speed limit			Catalyst	
Pavement quality			Maintenance	
Signal coordination			Aerodynamics	
Other traffic control measures			Emission control devices	
			Acceleration and deceleration characteristics	

5.1.5 Summary

From review of the literature provided, it can be noted that the existing methods of estimating road user costs are quite diverse, ranging from simple calculations and spreadsheets to sophisticated computer software programs that require knowledgeable operators. Numerous studies have been done to compare these systems and formulate new methodology with varied amounts of success (Borchardt et al. 2009; Ellis et al. 1997; Zhu et al. 2009; Mallela and Sadasivam 2011; Caputo and Scott 1996). Advancements in computer modeling software have contributed to more accurate user cost estimators. However, comparisons have shown common limitations due to the absence of input parameters that apply to specific work zone areas.

Multiple state departments also have determined that some specific cost components relating to RUC are insignificant or that the scarcity of data makes them too hard to quantify. Environmental effects, accident costs, increases in noise, and effects on local businesses due to the work zone are some of the components that are often left out of the RUC calculation process for these departments. Furthermore, some agencies have left out vehicle operating costs as well, leaving the value of time as the only component in the user cost computation.

Environmental effects are often overlooked in the analysis of a project's impact because they are hard to quantify into a dollar value. Monetary values are usually derived based on the economic analysis of health impacts attributed to the air pollution in a given area (Mallela and Sadasivam 2011). Unit costs that are used in current calculations vary widely based on the fact that population density and geographical coverage areas are specific to each work zone location.

Accident costs are hard to accurately estimate and, depending on the specific accident rate, may be found to increase the RUC at a rate that is unreasonably high. Costs related to fatality accidents commonly run in the millions of dollars and are hard to distribute into daily monetary values. Because of this, they are commonly neglected. However, accidents have been shown to increase within work zones and some estimates have shown that the increase may be as high as 27.5% compared with pre-construction rates (Zhu and Ahmad 2008).

Data regarding the effects that increased noise levels and reduced business accessibility due to a work zone have on local business is hard to obtain and specific to each work zone and is often deemed insignificant to overall RUC calculations (Mallela and Sadasivam 2011). However, addressing these issues may result in increased expenses of the construction project from noise mitigation strategies and devising more accessible MOT alternatives.

5.2 DOT Interview and Survey

Interviews with personnel deemed relevant by the Technical Panel were conducted at SDDOT to collect information on the current practices of RUC calculations and expectation of possible improvements given the current method limitations and resource constraints. Additionally, a short-form survey was designed and sent to regional DOT agencies with characteristics most comparable to South Dakota to investigate the RUC methods that are being used.

5.2.1 SDDOT Interviews

A survey containing 24 questions was constructed and disseminated to the SDDOT personnel prior to the meeting to assist in the interview process. SDDOT offices interviewed include: Project Development, Transportation Inventory Management, and Project Identification Coordinators. The interview covered questions concerning the RUC criteria for use, objectives for RUC, current methodologies (policies, processes, and procedures), data requirements, and data storage and updating methods.

The interview established the current uses of RUC estimation in both project planning and project construction. Planning looks at LCCA comparing several options for improvements using an Excel worksheet. Project construction uses work zone specific RUC for projects with significant impacts to traffic using a different Excel worksheet. A preliminary engineering study between the project planning and project construction stages is usually conducted for pavement and bridge projects; however, RUC is not used in those calculations.

There are currently no specific criteria for when to use RUC calculations; it is left to the discretion of those departments based on the demands of a specific project. Impacts to traffic are considered for implementation of time provisions in work zones during project construction. RUC is only calculated for planned projects that add or subtract mileage and/or routes to the state highway system. The current practice of a minimum allowable RUC of \$500 per day is used, but it is not enforceable by any numbers.

Ratings were given to the RUC components by participants and a list of priority components was calculated, showing VOT, VOC, AC, local impacts, and vehicle emissions as the order of importance. The ratings vary significantly among participants for most of the components except for the vehicle emissions, which was considered by all to be insignificant. Accident costs are important when in the planning use for comparing design alternatives to predict the safety performance of alternatives. It can be used in work zone analysis, but a reliable source for values must be identified.

Data availability for most of the state road network includes ADT and accident rates which may be found in the SD Highway Needs and Project Analysis Report. Monitor sites throughout the state collect 24

hours of data for one day a year every few years. Delay is calculated based on the peak hour values for any project planning use. Project planning uses the expertise of the data department to calculate any projected values based on a compiled list of growth factors for counties. Project Construction uses the non-construction ADT values for work zone demand.

Both Project Development and Construction Support programs currently maintain the unit cost related data in their respective spreadsheets manually. When ACs have been included in the safety studies, the crash unit cost is taken from the HSM. The resources used to update the unit costs have been located and applied by each department independently and updates are applied within each department when necessary. They include the use of CPI for speed cycle change adjustments, AAA and OOIDA for vehicle mileage costs used in VOC, U.S. Census Bureau and the U.S. Dept. of Labor for wages used in VOT, etc. Construction Support updates the unit costs associated with the worksheet on a yearly basis; Project Development updates the values periodically, or whenever the worksheet is used (three years or so). The consensus is that a single person should be responsible for updates of the unit cost values.

5.2.2 Regional DOT Surveys

This survey contained seven questions intended to maximize the quantity of responses while addressing the most significant concerns relating to the development and use of RUC methodology. The survey was mailed and emailed to seven state DOT agencies: Idaho, Iowa, Minnesota, Montana, North Dakota, Nebraska, and Wyoming. Responses were received from four out of seven of the agencies contacted: Minnesota, Montana, North Dakota, and Wyoming. The survey questions covered the RUC criteria for use, objectives for RUC, methodologies (policies, processes, and procedures), data requirements, and updating methods.

Most agencies use RUC for project planning purposes as well as project construction with the exception of MTDOT, which only uses RUC for work zone calculations. Many agencies do not have any criteria for calculating RUC other than engineering judgment or if scenarios which require detailed cost information are present. NDDOT uses RUC in calculations for safety and emergency purposes. RUC calculations either follow the same methodology calculated by analysts throughout the state, or are calculated by headquarter personnel to assure estimates follow a standard methodology. The agencies surveyed use spreadsheets or more simplified hand calculations to estimate user costs.

Half of the agencies surveyed include every component (VOT, VOC, and AC), with NDDOT also including specific safety or emergency components if needed. WYDOT has included the components of VOC and VOT, while MTDOT only uses VOC in its analysis. Although it has been an infrequent occurrence, MNDOT is the only agency that has included the additional component of vehicle emissions or impacts to local businesses in any RUC analysis.

Agencies' unit cost sources are varied, and updates to the values are dependent on the selected source. Most agencies have selected AASHTO or FHWA recommended sources, while some rely on local data to determine costs. Several respondents have felt that their estimation process could be improved by finding better ways to include business impacts or include more detailed traffic analysis studies into the process.

After discussion of the survey results with SDDOT, additional concerns were raised and a subsequent follow up survey was sent to the regional DOT respondents. The supplementary questions concerned the legal defense of the methodology and the reasons for selecting the preferred methodology. The majority of respondents have chosen a methodology based on recommendations from FHWA and AASHTO, while NDDOT had developed an original methodology based on national practices. Not one of the DOTs surveyed had any defense of their methodology in legal proceedings.

5.3 Current and Proposed Methodologies

This section provides a detailed review of the current methodologies and unit prices for calculating RUC at SDDOT and proposes changes, measures, and resources in order to improve the consistency and accuracy of RUC estimation.

5.3.1 Value of Road Users' Time (VOT)

The calculation of travel time delay costs requires data pertaining to the travel delay time, unit cost data for each mode of transportation, the number and type of vehicles per hour using the work zone, vehicle occupancy rates and could include factors to discount personal travel time and time-related vehicle depreciation. VOT is the value attributed to a users' time and is estimated based on the relationship to wage rates and delays related to the trip length of a detour route or alternative route(s) illustrated in Figure 5.5.

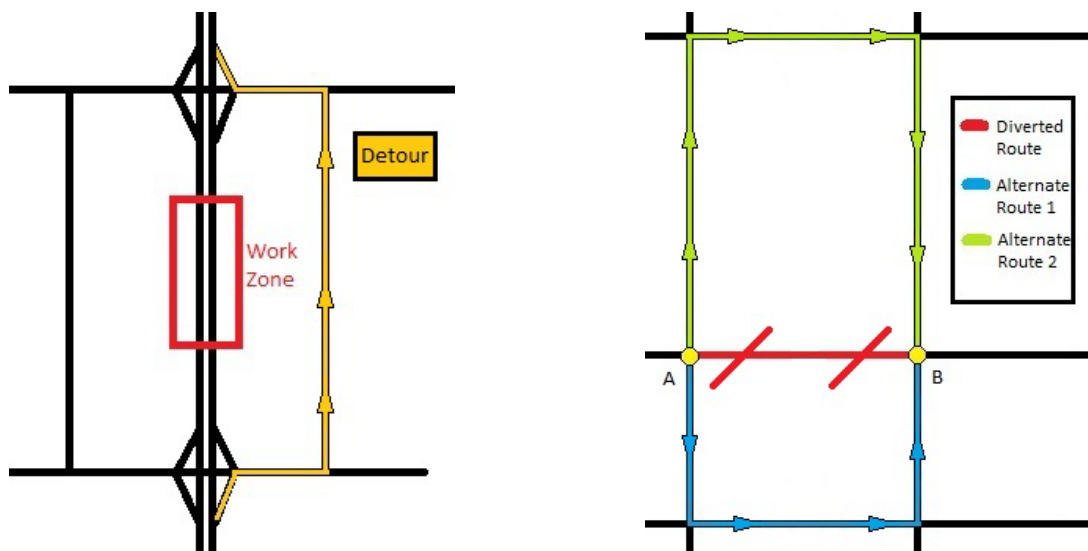


Figure 5.5 Detour Route (Work Zone) and Alternate Route(s) Due to Route Removal

The value of travel time associated with each vehicle class may account for the vehicle type (general purpose passenger vehicles and commercial trucks) and vehicle occupancy.

The daily unit VOT is measured by time delays on a per vehicle class basis as below:

$$\text{Same route distance: } \Delta H_c = 60 * M_c * VOF_c * \left[\frac{1}{s_1} - \frac{1}{s_0} \right]$$

$$\text{Different route distance: } \Delta H_c = 60 * M_c * VOF_c * \left[\frac{K}{s_D} - \frac{1}{s_0} \right]$$

Equation 5-40

Where:

- ΔH_c = Value of time for user class c (passenger vehicles and commercial trucks);
- M_c = unit value of time for user class (\$/min);
- VOF_c = Occupancy rate of vehicles for user class, persons per vehicle;
- S_0, S_1, S_D = speed before improvements (S_0), after improvements (S_1), and on the route with different distance than the original route (S_D) (mph);
- K = distance ratio of the different route (L_D) to the original route (L).

The total VOT can be measured by the summation of ΔH_c over daily ADT for all vehicles:

$$VOT = L \sum_{c=1}^n \Delta H_c * ADT_c \quad \text{Equation 5-41}$$

Where:

- ADT_c = average daily traffic of vehicle class c
- L = the distance of original route (mile)

5.3.1.1 Current Methodologies

Planning

Planning applies economic analysis techniques such as LCCA or BCA to project cost and performance within a multi-year timeframe to aid in the selection of project alternatives. At SDDOT, the use of RUC in the planning stage primarily involves the long-term analysis of projects that add or remove routes from existing highway systems, such as the removal of obsolete or structurally deficient bridges or the new construction of a highway overpass. Typically, planners conduct a preliminary LCCA for analysis, then bridge or pavement engineers conduct their own LCCA or preliminary engineering study.

The resource needed for the current values (cost per minute) for the VOT calculation in the planning stage at SDDOT is from the South Dakota Occupational Wage Estimates (BLS 2011). Wage estimate values are provided for occupations using mean and median hourly wage rates as well as annual starting and average salary numbers. South Dakota Occupational Wage Estimates are provided by the U.S. Department of Labor and are updated annually. The value used comprises heavy and tractor truck for all occupations. The value can be easily located at the Bureau of Labor Statistics website: http://www.bls.gov/oes/current/oes_sd.htm.

Table 5.10 South Dakota Occupational Wage Estimates (2010)

OCC Code	Occupation	Employed	Hourly Mean	Annual Mean	Percentile					Annual Median
					10th	25th	Median	75th	90th	
00-0000	All Occupations	387,590	\$16.53	\$34,390	\$ 8.22	\$ 9.96	\$13.42	\$19.09	\$27.91	\$27,900
53-3032	Heavy and Tractor-Trailer Truck Drivers	7,070	\$16.78	\$34,900	\$11.86	\$13.30	\$15.80	\$19.22	\$23.08	\$32,860
53-3033	Light Truck or Delivery Services Drivers	2,190	\$14.11	\$29,340	\$ 8.33	\$ 9.96	\$12.20	\$17.09	\$23.41	\$25,370

The current SDDOT method to calculate the costs for autos involves averaging the mean hourly wage rate and the starting hourly wage rate (10th percentile). A weighted average of the wage rate is calculated for trucks by multiplying the mean wage rates given for truck drivers (heavy and light trucks) by the number of workers in that field, combining them and dividing by the total amount of truck driver workers. These values are then converted to a cost per minute by dividing the rate by 60. Auto unit cost M_c is found by:

$$M_c = \frac{W_{10th} + W_{Mean}}{2} \quad \text{Equation 5-42}$$

Where:

- M_c = unit value of time for vehicle class of autos (\$/hr);
- W_{10th} = Starting wage rate at 10th percentile (\$/hr);
- W_{Mean} = Mean wage rate (\$/hr).

Truck unit cost, M_c is found by:

$$M_c = \frac{W_{HT} * E_{HT} + W_{LT} * E_{LT}}{E_{Total}} \quad \text{Equation 5-43}$$

Where:

- M_c = unit value of time for vehicle class of trucks (\$/hr);
- W_{HT} W_{LT} = Mean wage rate for heavy trucks (W_{HT}) and light trucks (W_{LT}) (\$/hr);
- E_{HT} , E_{LT} = Numbers of workers employed as drivers of heavy trucks (E_{HT}) and light trucks (E_{LT}).
- E_{Total} = $E_{HT} + E_{LT}$

Converted to cost per minute using:

$$\text{Cost per Minute} = \frac{M_c}{60} \quad \text{Equation 5-44}$$

In the current SDDOT application, \$0.21 per minute for passenger cars and \$0.27 per minute for heavy trucks and, in both cases, VOF equals to one. When the study route includes intersections, the control delay caused by traffic control devices is estimated by traffic control type. In the current SDDOT application, the control delay is estimated for 10 seconds per stop and 5 seconds per left-turn movement.

Project Construction Options

RUC is considered for project construction options when establishing contract provisions (project prioritization, contracting mechanism, etc.). The resources currently used for VOT unit cost values at SDDOT are from the U.S. Census for South Dakota Average Annual Income (U.S. Census 2011) and the U.S. Department of Labor for the cost per minute values of passenger cars and trucks (U.S. DOL 2011), respectively. The U.S. Census provides statewide average annual wage rates per capita. The Wage and Hour Division of the U.S. Department of Labor provides Davis-Bacon Act wage determinations for use in federal contracts at a rate per hour.

The U.S. Census for South Dakota presents estimations of mean money income received in the past year for every resident over the age of 15. These are five-year estimate values of the annual wage and are updated every year. However, the values provided may be conservative because the data rely on participant surveys and divides by the total population in the state, even though income data do not include residents under the age of 15. These values can be located at the U.S. Census website:

<http://quickfacts.census.gov/qfd/states/46000.html>

Table 5.11 U.S. Census Bureau State & County Quick Facts

People QuickFacts	South Dakota	USA
Population, 2011 estimate	824,082	311,591,917
Population, 2010 (April 1) estimates base	814,180	308,745,538
Housing units, 2011	366,540	132,312,404
Homeownership rate, 2006-2010	68.90%	66.60%
Housing units in multi-unit structures, percent, 2006-2010	18.50%	25.90%
Median value of owner-occupied housing units, 2006-2010	\$122,200.00	\$188,400.00
Households, 2006-2010	315,468	114,235,996
Persons per household, 2006-2010	2.43	2.59
Per capita money income in past 12 months (2010 dollars) 2006-2010	\$ 24,110.00	\$ 27,334.00
Median household income 2006-2010	\$ 46,369.00	\$ 51,914.00
Persons below poverty level, percent, 2006-2010	13.70%	13.80%

Converted to cost per minute using:

$$M_c = \left(\frac{W_{PC}}{52}\right) * \left(\frac{1}{40}\right) * \left(\frac{1}{60}\right) \quad \text{Equation 5-45}$$

Where:

W_{pc} = the Value per capita money income in past 12 months (2010 dollars) 2006-2010;
currently used value is \$0.19 per minute auto (2010 value)

VOF=1.59 (obtained from the U.S. Department of Energy (U.S. DOE), which presents a comparison of vehicle occupancy factors for six travel modes (cars, van, sport utility, pickup, other truck, and motorcycle) at time periods of 1995, 2001, and 2009. The values can be found at the Department of Energy website: http://www1.eere.energy.gov/vehiclesandfuels/facts/2010_fotw613.html (U.S. DOE).

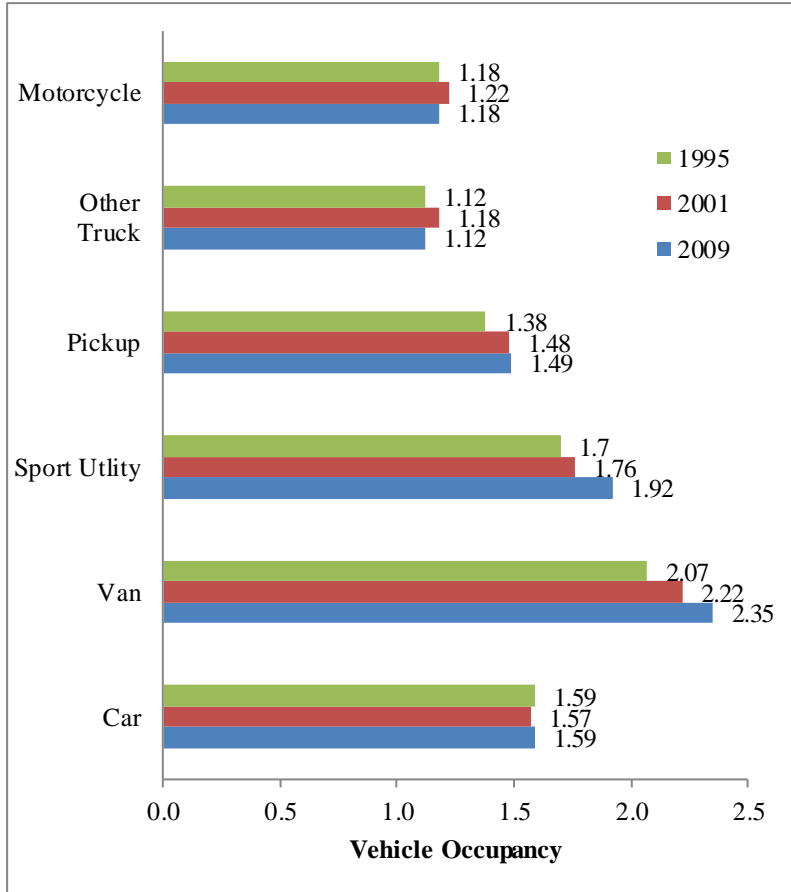


Figure 5.6 Department of Energy Vehicle Occupancy Rates (2010)

U.S. Department of Labor provides Davis-Bacon Act wage determinations for use in official federal contract actions, which are categorized by state and construction type. These values are updated by the National Technical Information Service every two years. The values can be located at the Department of Labor site using a database with the appropriate search criteria, or collected from records available at SDDOT.

Table 5.12 U.S. Department of Labor - Wage and Hour Division for South Dakota (2011)

Truck Drivers	Rates	Fringes
GROUP GT1		
Tandem Truck without trailer or pup; Single Axle Truck over 26,000 GVW with Trailer	\$ 15.34	\$ -
GROUP GT2		
Semi-Tractor and Trailer; Tandem Truck with Pup	\$ 17.90	\$ -

Value is provided as a rate per hour and converted to cost per minute using:

$$M_c = \frac{W_{TD}}{60}$$

Equation 5-46

Where:

W_{TD} = the mandated federal hourly wage rate for group GT2; current value used is \$0.30 per minute truck (2011 value) and $VOF=1.0$

5.3.1.2 Proposed Method, Measure, and Resources

Proposed VOT calculation includes two components: the VOT component caused by speed and distance change, respectively; and the VOT components caused by delay due to traffic control devices.

Same route distance: $VOT = 60L \left[\frac{1}{S_1} - \frac{1}{S_0} \right] \sum_{c=1}^n M_c * VOF_c * ADT_c$

Different route distance: $VOT = 60L \left[\frac{K}{S_1} - \frac{1}{S_0} \right] \sum_{c=1}^n M_c * VOF_c * ADT_c$ **Equation 5-47**

$$\Delta H_{intersection,c} = 60\Delta T \left(\frac{V_{0c} + V_{1c}}{2} \right) M_c VOF_c$$
 Equation 5-48

Where:

$\Delta H_{intersection,c}$ = change in the value of time per intersection for user class c (passenger vehicles and commercial trucks);

V_{0c}, V_{1c} = annual average daily vehicle volumes without (0) and with (1) the intersections;

ΔT = intersection delay (minutes); and

Other variables are previously defined.

In HCM, LOS can be characterized for the entire intersection, each intersection approach, and each lane group. Control delay alone is used to characterize LOS for the entire intersection or an approach. As a conservative approach, users can specify an LOS and select the corresponding upper limit of the control delay. LOS criteria for unsignalized intersections include Two-way Stop Controlled (TWSC), All-way Stop Controlled (AWSC), and Roundabout intersections (TRB HCM 2010). For instances in which intersections are included in alternate routes, an estimation of the impacts due to the increased traffic through those routes may be performed to increase the accuracy of those delays. However, if ADT is not significantly affected an approximation may provide reasonable LOS estimates.

Table 5.13 LOS Criteria for Intersections*

Signalized Intersections			Unsignalized Intersections		
Control Delay	V/C Ratio		Control Delay	V/C Ratio	
(s/veh)	≤ 1.0	≥ 1.0	(s/veh)	≤ 1.0	≥ 1.0
≤ 10	A	F	≤ 10	A	F
>10-20	B	F	>10-15	B	F
>20-35	C	F	>15-25	C	F
>35-55	D	F	>25-35	D	F
>55-80	E	F	>35-50	E	F
>80	F	F	>50	F	F

*Exhibit 18-4, Exhibit 19-1, Exhibit 20-2 and Exhibit 21-2 (HCM 2010)

The U.S. Census for South Dakota is recommended as the data resource for the passenger car unit cost value of time because they provide a more complete representation of the average state income. The value represents mean income of every man, woman, and child over age 15 and which includes employment wages as well as income sources such as Social Security Income, public assistance or welfare, and survivor or disability pensions. However, the accuracy of the value is questionable because it

is produced from five-year estimates. The values available from the U.S. Census for South Dakota are represented as mean money income per year, so there is a need to convert to an hourly rate.

$$\text{Cost per Minute} = \text{Per Capita Income} * \left(\frac{1}{52}\right) * \left(\frac{1}{40}\right) * \left(\frac{1}{60}\right) \quad \text{Equation 5-49}$$

The U.S. Department of Labor Davis-Bacon Act wage determinations (Table 5-12) is the suggested source for the heavy truck unit cost value of time, because the values are used in projects to dictate the required federal wages and so are reassessed and updated on a regular basis.

The use of VOF is also recommended to accurately represent the costs per vehicle by accounting for the average vehicle passengers. The National Household Travel Survey collects daily personal travel information from national surveys and combines historical data to provide estimates of trips and mile of travel by mode, purpose and household attributes. The most current (2009) publication gives an average VOF value of 1.67 for all vehicles by trip purpose, which follows an increasing trend evident since 1995 (FHWA NHTS 2009).

5.3.2 Vehicle Operating Costs (VOC)

VOC is a composite of the costs associated with operating and owning the vehicle over the study project analysis period. VOC include fuel, oil, tire wear, vehicle maintenance and repairs; ownership costs include insurance, license and registration fee and taxes, and economic depreciation and finance charges. The daily road user benefits or costs due to the project can be measured by including *excess* VOC of all vehicles due to the speed changes (excess fuel, oil, tire, and vehicle maintenance due to the deceleration when entering work zones and acceleration when exiting) and VOC of all vehicles traveling extra miles on a detour or alternative route(s) if there is any. Current SDDOT use of VOC:

Detours:

$$VOC_D = \Delta D \sum_{c=1}^n ADT_c * C_c \quad \text{Equation 5-50}$$

Where:

- VOC_D = vehicle operating costs due to detours;
- ADT_c = average daily traffic of vehicle class c;
- ΔD = detour route distance less original route distance (mile); and
- C_c = Operating cost per mile of vehicle class c (\$/mile).

Speed changes:

$$VOC_{SC} = \frac{1}{1000} \sum_{c=1}^n ADT_c * CPC_c \quad \text{Equation 5-51}$$

Where:

- VOC_{sc} = vehicle operating costs due to speed changes;
- CPC_c = costs per cycle of vehicle class c (deceleration when entering work zone and acceleration when exiting for each 1000 cycles).

5.3.2.1 Current Methodologies

Planning

In the planning stage, the additional costs due to speed changes are not considered. The resource for current values (cost per mile) being used for VOC calculation in the RUC worksheets for planning are from the South Dakota Fleet and Travel Rates (SD Fleet and Travel Rates 2012). The South Dakota Bureau of Administration compiles a list of current rates charges by the Office of Fleet and Travel Management (FTM) for each class of vehicle.

South Dakota fleet and travel rates are provided for every vehicle that is available to state agencies on a permanent or short-term basis. These rates are calculated periodically throughout the year and are available on a cost per mile basis. These rate values can be located at the South Dakota Bureau of Administration website: <http://www.state.sd.us/boa/fleet&tr.htm>. The current 2011 values used: \$0.34 per mile auto and \$1.78 per mile truck. Note that the values are based on South Dakota fleet costs. Fleet use is primarily highway or interstate travel and may not accurately reflect an average driver's costs.

Table 5.14 South Dakota Fleet and Travel Rates (May 2012)

Description	Class	Rate (per mile)	Description	Class	Rate (per mile)
Intermediate Sedan	AE	\$0.37	Pick-up Compact 4X4	CD	\$0.49
Intermediate Wagon	AF	\$0.35	Pick-up 1/2T 2X4	CF	\$0.49
Full Size Sedan	AG	\$0.35	Pick-up 1/2T 4X4	CH	\$0.49
Police Intermediate	AK	\$0.52	Pick-up 3/4T 2X4	CJ	\$0.64
Police Full Size	AL	\$0.52	Pick-up 3/4T 4X4	CL	\$0.64
Suburban 2X4	BA	\$0.50	Pick-up 1T 2X4	CN	\$0.96
Suburban 1/2T 4X4	BC	\$0.50	Pick-up 1T 2X4 w\Opt Body	CP	\$0.96
Suburban 3/4 T 2X4	BE	\$0.50	Pick-up 1T 2X4 DSL	CQ	\$0.96
Suburban 3/4T 4X4	BG	\$0.50	Pick-up 1T 2X4 DSL w\Opt Body	CR	\$0.96
Utility Compact 4X4	BJ	\$0.50	Pick-up 1T 4X4	CS	\$0.96
Utility Full Size 4X4	BK	\$0.50	Pick-up 1T 4X4 w\Opt Body	CT	\$0.96
Van-1/2 & 3/4 T Cargo	BN	\$0.46	Pick-up 1T 4X4 DSL	CU	\$0.96
Van-1 T Cargo	BP	\$0.46	Pick-up 1T 4X4 DSL w\Opt Body	CV	\$0.96
Van-Compact Passenger	BQ	\$0.39	Truck Single Axle	DA	\$2.31
Van-Intermediate Passenger	BR	\$0.46	Truck Single Axle DSL	DB	\$2.31
Van-Large Passenger	BS	\$0.46	Truck Dump Style	D Class	\$2.31
Police Utility 4X4 Compact	BT	\$0.50	Bus	ID	\$1.32
Pick-up Compact 2X4	CB	\$0.49	Mail Van	IP	\$0.96

Project Construction Options

Increased costs due to fluctuations in vehicle speed through project areas are calculated using cost per cycle (CPC) tables given in cost per 1,000 cycles or vehicles using an initial speed and the speed reduced to and returned from. The resource for current values (cost per mile) being used for calculating extra detour distance-related VOC at SDDOT for work zone construction options are from the American Automobile Association (AAA 2012) and the Owner Operator Independent Drivers Association (OOIDA 2012) for the cost per mile values of passenger cars and trucks, respectively.

American Automobile Association (AAA) publishes “Your Driving Costs,” an annual brochure that provides a composite average per-mile cost using three size categories of sedans: small, medium, and large. The costs are based on consumption of fuel, maintenance, tires, insurance, licensing, registration and taxes, depreciation, and financing expenses. The values provided by AAA can be found at the website: <http://exchange.aaa.com/automobiles-travel/automobiles/gas-pricing>. Note that this unit cost is the inclusive costs which cover both vehicle operating and ownership costs. Additionally, AAA costs are readily available and are updated on a yearly basis. However, the average value may not accurately reflect current price fluctuations (gasoline, oil, etc.).

Table 5.15 American Automobile Association - Average Costs per Vehicle (2012)

Miles per Year	10,000	15,000	20,000
small sedan	57.6 cents	44.9 cents	38.4 cents
medium sedan	74.9 cents	58.5 cents	50.1 cents
large sedan	98.8 cents	75.5 cents	63.6 cents
Composite Average	77.1 cents	59.6 cents	50.7 cents

Owner Operator Independent Driver’s Association (OOIDA) provides owner operators in the trucking business with tools, information, and resources to keep up with current industry practices. A cost per mile spreadsheet is available for download to allow truck operators to track and control their costs. Within the description of the use of this worksheet was an example of the decrease in costs per mile when the total miles driven increase. The figure can be found at:

http://www.ooida.com/Education%26BusinessTools/Trucking_Tools/costpermile.shtml

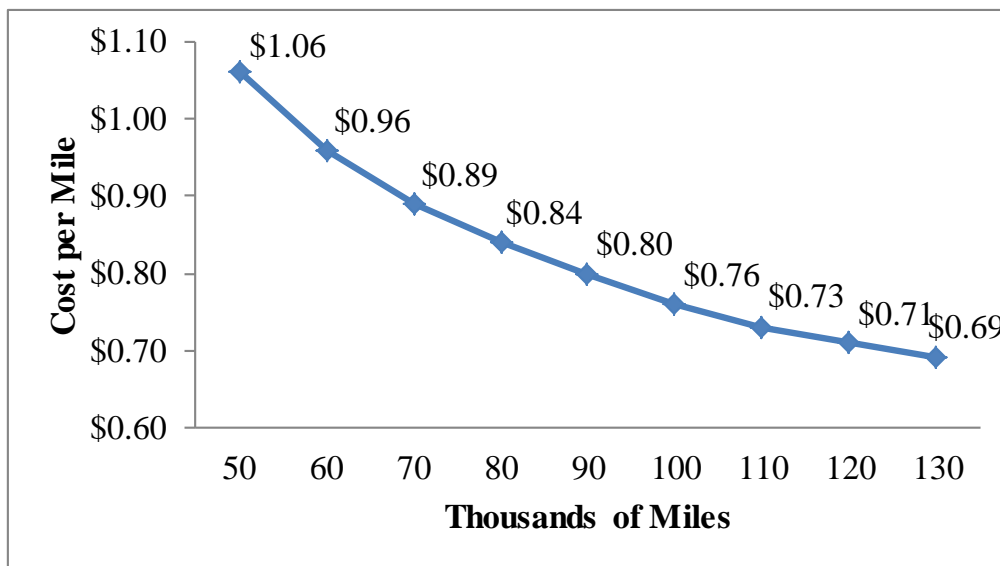


Figure 5.7 OOIDA Truck Operating Costs per Mile

The current value used is \$0.80 per mile truck, and the year of update is unknown. This value does not have any documentation to support the cost estimation presented and may be for comparison purposes only.

Speed Change Cycle tables were provided in the SD95-07 report, “Criteria and Guidelines for Innovative Contracting,” that was prepared by Trauner Consulting Services, Inc. in 1996 (Caputo and Scott 1996). This table was based on data provided in the 1977 AASHTO publication, “A Manual on User Benefit

Analysis of Highway and Bus-Transit Improvements,” for excess costs due to speed cycle changes above cost of continuing at initial speed for automobiles and trucks, separately. These tables were presented in 1995 values, updated from 1977 using CPI (U.S. City Average, All Items). They have since been updated to reflect 2010 values using the same technique.

EXCESS COST OF SPEED CHANGE CYCLES
ABOVE COST OF CONTINUING AT INITIAL SPEED FOR CARS
(Dollars per 1,000 Cycles)

2012 Updated Table

Initial Speed (mph)	SPEED REDUCED TO AND RETURNED FROM (mph)															
	Stop	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
5	\$3.68															
10	\$11.26	\$5.18														
15	\$22.59	\$13.16	\$6.25													
20	\$34.30	\$23.09	\$13.95	\$5.89												
25	\$49.85	\$35.93	\$24.64	\$14.44	\$7.54											
30	\$64.24	\$48.92	\$36.29	\$25.03	\$16.31	\$8.54										
35	\$78.65	\$62.30	\$48.25	\$36.51	\$26.31	\$17.10	\$7.67									
40	\$93.04	\$76.51	\$61.80	\$48.74	\$37.39	\$26.81	\$16.49	\$8.29								
45	\$107.45	\$91.67	\$76.47	\$62.87	\$49.58	\$37.48	\$26.19	\$17.15	\$8.47							
50	\$121.84	\$106.48	\$91.40	\$77.14	\$62.03	\$49.13	\$36.56	\$26.01	\$16.74	\$8.50						
55	\$136.25	\$121.18	\$105.81	\$91.22	\$76.21	\$61.94	\$47.94	\$35.81	\$25.17	\$15.90	\$7.88					
60	\$150.82	\$135.89	\$120.56	\$103.64	\$85.28	\$74.70	\$60.08	\$46.39	\$34.21	\$23.98	\$15.19	\$7.63				
65	\$165.92	\$151.39	\$136.46	\$119.85	\$103.50	\$87.90	\$72.62	\$57.82	\$44.83	\$33.67	\$24.10	\$15.69	\$8.68			
70	\$181.22	\$166.76	\$151.71	\$134.74	\$117.05	\$101.42	\$85.21	\$69.91	\$56.75	\$44.67	\$34.12	\$24.41	\$16.40	\$8.82		
75	\$198.80	\$184.14	\$168.93	\$151.00	\$132.25	\$115.42	\$99.02	\$82.76	\$68.81	\$55.65	\$44.40	\$33.71	\$24.41	\$16.03	\$9.00	
80	\$217.46	\$202.71	\$187.20	\$167.34	\$148.06	\$129.90	\$113.34	\$96.10	\$80.94	\$66.59	\$55.11	\$43.12	\$33.05	\$24.05	\$15.99	\$12.10

Figure 5.8 Speed Change Cycle (2012, Autos)

EXCESS COST OF SPEED CHANGE CYCLES
ABOVE COST OF CONTINUING AT INITIAL SPEED FOR TRUCKS
(Dollars per 1,000 Cycles)

2012 Updated Table

Initial Speed (mph)	SPEED REDUCED TO AND RETURNED FROM (mph)															
	Stop	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
5	\$15.02															
10	\$29.02	\$15.28														
15	\$51.48	\$32.75	\$19.50													
20	\$77.67	\$57.02	\$38.23	\$22.47												
25	\$117.41	\$90.74	\$68.63	\$45.24	\$23.39											
30	\$154.27	\$124.72	\$99.46	\$73.42	\$47.37	\$27.70										
35	\$194.42	\$160.07	\$130.79	\$104.16	\$74.57	\$50.91	\$27.95									
40	\$214.75	\$187.64	\$161.58	\$133.14	\$103.64	\$77.54	\$50.11	\$26.98								
45	\$249.09	\$219.68	\$191.84	\$164.29	\$132.69	\$105.23	\$74.04	\$52.90	\$29.91							
50	\$274.08	\$246.56	\$220.55	\$192.46	\$162.70	\$134.24	\$105.97	\$79.36	\$54.76	\$27.91						
55	\$294.54	\$268.00	\$242.04	\$216.44	\$186.84	\$157.60	\$129.20	\$102.13	\$77.63	\$49.31	\$26.15					
60	\$315.94	\$289.10	\$263.23	\$236.64	\$213.86	\$180.19	\$152.76	\$127.21	\$101.72	\$73.19	\$46.61	\$26.76				
65	\$357.64	\$328.28	\$291.83	\$264.31	\$237.56	\$209.75	\$177.12	\$150.67	\$124.11	\$96.73	\$68.97	\$42.18	\$24.76			
70	\$387.18	\$357.37	\$328.21	\$288.63	\$261.13	\$231.66	\$206.25	\$172.85	\$147.12	\$118.44	\$92.15	\$67.38	\$38.11	\$23.63		
75	\$416.72	\$386.46	\$356.62	\$326.63	\$285.38	\$253.79	\$227.47	\$203.08	\$167.68	\$140.63	\$112.13	\$94.14	\$64.29	\$34.04	\$22.50	
80	\$446.25	\$415.54	\$385.02	\$354.43	\$325.41	\$277.21	\$248.78	\$223.55	\$198.74	\$159.53	\$133.03	\$112.26	\$91.96	\$61.20	\$29.97	\$21.37

Figure 5.9 Speed Change Cycle (2012, Trucks)

5.3.2.2 Proposed Method, Measure, and Resources

A review of the available methods and vehicle operational unit cost indicates a variety of scopes and contents. The most comprehensive unit cost, a composite of the costs associated with operating and owning the vehicle, is provided by The American Automobile Association (AAA 2012) and the American Transportation Research Institute (ATRI 2012). HERS-ST (Highway Economic Requirement System-State Version) (FHWA HERS-ST 2005) includes all the vehicle operational costs but no ownership costs.

The data input for vehicle operating costs is very extensive, including fuel and oil consumption, tire wear, maintenance and repair, economic depreciation for constant speed and variable speed, and adjustment factors account for the change in consumption rates due to technological advances. AASHTO Redbook (AASHTO Redbook 2010) has the operating and ownership costs module where operating costs are measured by fuel consumption due to speed change and ownership costs are measured by an amortization approach, which also requires extensive data input such as capital value of the vehicle, interest rate, expected life of the vehicle, salvage value, and inventory costs of cargo (for truck shipping services). The current SDDOT VOC for work zone applications only consider the excess costs due to speed cycle changes above cost of continuing at initial speed for automobiles and trucks, separately. The relationship between the methodologies can be illustrated in Figure 5.10.

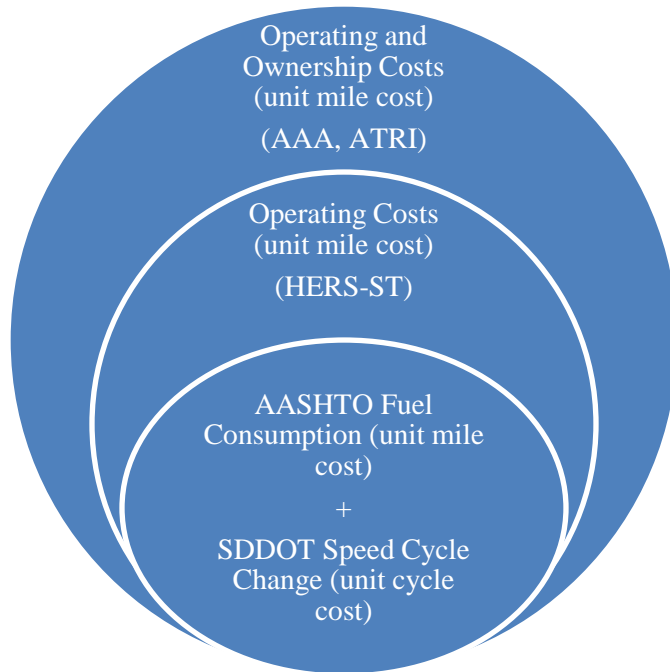


Figure 5.10 Relationship Between Methods

For planning purposes, the construction time period is relatively short compared with the life cycle of a project. Therefore, additional costs due to the speed cycle changes during construction can be omitted. The recommended measure for VOC is the same as the current SDDOT method in Equation 5-50. When selecting the operating cost per mile of vehicle class *c*, AAA and ATRI are the recommended sources for passenger cars and trucks, respectively. Their rate values include both operating costs and ownership costs, which are more appropriate for justifying a long-term VOC.

For project construction options, the changes in RUC for the project can be caused by several factors: 1) change in fuel costs due to the speed change with and without, or before and after a project, i.e., lower speed during a work zone or higher speed after an improvement project; 2) extra distance on a detour route if there is one; 3) additional operating costs due to vehicle deceleration when entering a work zone and acceleration when exiting). Considering all three factors, the proposed fuel costs include two components: the first component is measured by cents per VMT, and the second is measured by 1,000 cycles or 1,000 vehicles.

The change in fuel costs can be expressed as the function of speed as follows:

$$\Delta C(S)_{fuel,c} = (gal_{c,s_0} - gal_{c,s_1}) * P_c \quad \text{Equation 5-52}$$

Where:

- $\Delta C(S)_{fuel,c}$ = change in fuel costs as a function of speed for vehicle class c;
- gal_{c,s_0} = gallons per mile for vehicle class c, during construction speed (gal/mile);
- gal_{c,s_1} = gallons per mile for vehicle class c, after construction speed (gal/mile) (Table 5.16);
- and
- P_c = Fuel price per gallon for vehicle class c (\$/gal).

Table 5.16 Fuel Consumption by Operating Speed*

Speed	Gallons per Mile	
	AUTOS	TRUCKS
5 mph	0.117	0.503
10 mph	0.075	0.316
15 mph	0.061	0.254
20 mph	0.054	0.222
25 mph	0.05	0.204
30 mph	0.047	0.191
35 mph	0.045	0.182
40 mph	0.044	0.176
45 mph	0.042	0.17
50 mph	0.041	0.166
55 mph	0.041	0.163
60 mph	0.04	0.16
65 mph	0.039	0.158

*Table 5-5, AASHTO Redbook (2010)

Considering total vehicle miles traveled for all vehicle classes, $VOC_{distance}$ can be specified as:

$$\begin{aligned} \text{Without Detour: } VOC_{distance} &= L \sum_{c=1}^n \Delta C(S)_{fuel,c} * ADT_c \\ \text{With Detour: } VOC_{distance} &= L \sum_{c=1}^n \Delta C(S)_{fuel,c} * ADT_c + \Delta D \sum_{c=1}^n P_c * gal_{c,s_D} * ADT_c^D \end{aligned} \quad \text{Equation 5-53}$$

Where:

- ADT_c = average daily traffic of vehicle class c on study route;
- ADT_c^D = average daily traffic of vehicle class c on detour route;
- L = Length of construction zone or study route (miles);
- L_D = Length of detour route (miles). If there is no detour route, $L_D=L$.
- gal_{c,s_D} = gallons per mile for vehicle class c, posted speed limit on the detour route (gal/mile);

The VOC component due to the speed cycle changes is formulated as:

$$VOC_{SC} = \sum_{c=1}^n \frac{ADT_c * CPC_c}{1000} \quad \text{Equation 5-54}$$

Note, the Cost per Cycle, CPC_c is in 2010 dollars and has been updated using CPI multiple times through multiple agencies since the original research in 1967. The consumption rates and unit costs on which it is originally based may no longer accurately represent current technology standards. Furthermore, the process used to update the CPC_c uses a CPI (US City Average for All Items) which does not yield as precise price updates as using specific CPI (US City Average for gasoline, motor oil, tires, etc.) for each individual component of cost. Further research may be warranted to determine a more precise rate of consumption based on new vehicle technology.

Total VOC is the sum of $VOC_{distance}$ and VOC_{sc} as specified in Equation 5-55.

$$VOC = VOC_{distance} + VOC_{sc} \quad \text{Equation 5-55}$$

Although changes in fuel consumption may comprise a relatively small portion of total vehicle ownership and operating costs, it comprises the majority or even all of the changes in operating costs as a result of a project during its construction or with a short analysis period. For work zone analysis or projects with a short analysis period, considering only fuel consumption or only operating costs may be appropriate, while for a project with a long analysis period (life cycle), considering both vehicle operating and ownership costs may be more comprehensive. Therefore, for project construction options (work zone), the VOC is calculated by using AASHTO fuel consumption rates and excess costs generated from variable speed changes (Table 5.5 and Figures 5.8 and 5.9).

5.3.3 Accident Costs (AC)

Highway safety may be improved or compromised as a result of highway construction activities or completed highway projects. For example, crash rate is usually higher in a work zone than that of the same roadway conditions without a work zone. After the completion of a highway project, the crash frequency or severity is generally lower due to the improvement. The changes in safety performance can be measured by the costs of crashes borne by users of the facility.

5.3.3.1 Current Methodologies

Accident costs are not considered in any of the decision support analysis except for safety improvement projects and unique projects that have a greater potential to impact public safety. Accident costs have not been included in the majority of user costs calculated for planning or project construction because the accident costs are hard to quantify and the quality of accident rate data is questionable.

5.3.3.2 Proposed Method, Measure, and Resources

The accident cost is measured by the cost of total annual crash changes as a result of the highway project. In the SDDOT Highway Needs and Project Analysis Report, the economic cost of a crash with different injury severity is expressed as the corresponding equivalent property damage only (EPDO) crash, the EPDO method, i.e., one fatal accident is equivalent to 12 PDOs or 12 points, one injury accident is equivalent to three PDOs or three points, and one PDO accident is equivalent to one point (SDDOT 2012). Using these figures, the weighted accident rate per million vehicle miles of travel (MVMT) is computed as follows:

$$AR = \frac{N * 10^6}{T * L * ADT * 365} \quad \text{Equation 5-56}$$

Where:

- AR = number of accident per million vehicle miles of travel;
- N = total accident points or equivalent PDO crashes along the roadway segment;
- T = duration of the analysis period;
- L = length of roadway segment; and
- ADT = average daily traffic (in both directions).

The daily AC calculations for accident costs are found for the road segment:

$$AC = [(AR * CMF - AR) * L * ADT * C_{ACC}] \quad \text{Equation 5-57}$$

Where:

- AR = Pre-existing accident rate per million vehicle miles without construction (SDDOT Highway Needs and Project Analysis Report: State Highway System Weighted Accident Rates for the segment);
- L = Length of Study Section (mile);
- C_{ACC} = Average cost per property damage only accident

Table 5.17 Unit Crash Cost by Severity

Collision Type	FHWA		
	Comprehensive Societal Crash Costs	FHWA Weight	SDDOT Weight
Fatal (K)	\$4,008,900	541	12
Disabling Injury (A)	\$216,000	29	N.A.
Evident Injury (B)	\$79,000	10	N.A.
Fatal/ Injury (K/A/B)	\$158,200	21	N.A.
Possible Injury (C)	\$44,900	6	N.A.
Injury (A/B/C)	\$22,200	N.A.	3
PDO (O)	\$7,400	1	1

*Table 7-1, HSM (1st Edition)

CMF = Crash Modification Factor for the following scenarios:

- Planning or project development for general highway improvement projects;
- Work zone (project management/construction option): customized CMF from SD crash data; and
- Safety improvements (suggest using other tools for AC costs such as HSM, IHSDM, SafetyAnalyst, etc.)

For planning, the number of estimated crashes may increase annually, as it is the linear function of AADT which has a growth factor during the project life cycle. Work zone CMFs are available from the FHWA Office of Safety, which maintains an online repository of factors at the CMF Clearinghouse (www.CMFClearinghouse.org) to address specific work zone issues (Mallela and Sadasivam 2011). The CMF Clearinghouse presents some typical CMF values that have been used on freeway lane closures, as seen in Table 5.1. These factors are sorted by countermeasure categories, crash type, crash severity, and roadway type.

The Highway Safety Manual (HSM) provides the crash effects of work zone design elements for different treatments, e.g., modify work zone duration and length and use crossover closure or single lane closure (AASHTO HSM Vol. 3, Chapter 16). However, for the work zone condition of crossover closure or single lane closure, the HSM only qualitatively warns of a trend regarding the potential change in crashes or user behavior, but a CMF is not provided (AASHTO HSM Vol. 3, Chapter 16, appendix 16-A3 and 16-A4). For freeway work zones, CMFs can be used to modify the safety performance based on the work zone duration in the number of days and the length in miles. The base condition of the CMFs (CMF=1.0) is a work zone duration of 16 days and/or work zone length of 0.51 miles. The linear relationship between the CMF value and percentage increase in duration and length can be formulated as below:

CMF as the effect of increasing work zone duration (from 16 days):

$$CMF_{duration} = 1.0 + \frac{\% \text{ increase in duration} \times 1.11}{100} \quad \text{Equation 5-58}$$

CMF as the effect of increasing work zone length (from 0.51 miles):

$$CMF_{length} = 1.0 + \frac{\% \text{ increase in length} \times 0.67}{100} \quad \text{Equation 5-59}$$

The combined CMF_{total} work zone condition can be specified as the product of the two.

$$CMF_{total} = CMF_{duration} * CMF_{length} \quad \text{Equation 5-60}$$

The expected crashes under the proposed work zone scenario are specified as:

$$N_{expected} = (Fatal + Injury + PDO)CMF_{total} \quad \text{Equation 5-61}$$

If CMFs are related to work zone traffic control treatment such as temporary lane closures, FHWA provides a set of CMFs for all and crash by injury severity for all and nighttime, respectively (FHWA 2011).

Table 5.18 Work Zone CMF for Temporary Lane Closures on Freeways (FHWA, 2011)

Crash Types	Crash Severity	CMF
All	All	1.77
All	Property damage only (PDO)	1.9
All	Serious injury, Minor injury	1.6
Nighttime	All	1.57
Nighttime	Property damage only (PDO)	1.63
Nighttime	Serious injury, Minor injury	1.34

Note: Reported for work zones with active work and temporary lane closure

In the SDDOT Highway Needs and Project Analysis Annual Report, weighted accident rate, number of fatalities, number of injury, and number of property damage only crashes are provided for each highway segment (SDDOT 2012). Table 5.19 shows the South Dakota state highway system average weighted accident rates by highway classification.

Table 5.19 State Highway System Weighted Accident Rates

Highway Class	Weighted Rate
Rural interstate	0.91
Rural Principal Arterial	1.74
Rural Minor Arterial	1.9
Rural Major Collector	2.56
Urban Interstate	1.11
Urban Principal Arterial	2.23
Urban Minor Arterial	3.02
Urban Collector	-

Note: Urban Collector has no miles on the state system with the deletion of SD 139

*2012 SDDOT Highway Needs and Project Analysis Report

5.3.4 Other Impacts

5.3.4.1 Emissions

Additional vehicle emissions, including air pollutants and greenhouse gases, have been shown to contribute negatively to the environment. Reduced speeds, closed lanes, and the subsequent queuing of vehicles in work zones increase the rate of emissions from vehicles due to idling. Several agencies have studied the negative health impacts of emissions in an attempt to monetize the effects that are passed on to users. There have been several vehicle emission models developed by government agencies (EPA, NCHRP, etc.) and incorporated into some software (QUEWZ-98, MOVES, CMEM) to estimate the effects. These models use unit costs that are based on the economic analysis of health impacts caused by air pollutants in the geographic area, and vary widely based on population density and land area of project work zones.

Currently, there is no consensus regarding a recognized method to assign a monetary value to the impact of each pollutant type. The unit costs of emissions are based on the adverse health effects on inhabitants within a geographical area. Because these values are region specific, they cannot be applied to all situations. Metropolitan areas with high population densities will experience more negative health effects, requiring higher unit costs compared with rural areas with lower population densities. It is recommended that analysts use region-specific emission costs that have been developed for each emission type by the regional planning agency based on population density (Mallela and Sadasivam 2011).

The following estimation procedures are recommended in the FHWA report:

$$Emissions\ Cost = \sum_{et=1}^n VMT * Emissions\ Rate_{et} * Cost/ton_{et} \quad \text{Equation 5-62}$$

Where:

- VMT = vehicle mile traveled
- Emissions Rate_{et} = emission rate by type of emission
- Cost/ton_{et} = unit cost per ton by type of emission

$$WZ \text{ Emissions Cost} = \text{Emissions Cost}_{wz} - \text{Emission Cost}_0$$

Equation 5-63

Where:

$\text{Emissions Cost}_{wz}$, Emissions Cost_0 = Emissions cost due to work zone and pre-construction

5.3.4.2 Noise

Work zone construction activities produce noise levels above what is common in any highway scenario. Excessive noise levels in residential and business areas may require the use of noise mitigation strategies such as installation of noise barriers to decrease the potential health problems that may be posed. However, there is little information available of methods to monetize the damages due to construction noise.

5.3.4.3 Business and Local Community Impacts

Potential impacts to local businesses from the presence of work zone activity may include business access and parking issues, utility outages, and decreases in sales revenues due to traffic pattern changes. Residents may experience similar issues that include resident access, on-street parking issues, and decreases to their property value. These issues are specific to the project area and do not have a universal method for monetization. The presence of construction work zones may provide certain businesses with an increase of customers in one instance and a reduction of customers in others. Construction phasing, geometry, and time of day are all factors in the potential impacts imposed on a business due to work zones.

5.4 Evaluation of Proposed Methodologies

The evaluation of the proposed methodology involved a sensitivity analysis and a case study. The sensitivity analysis determined the contribution that variations to each significant variable will have on the overall RUC estimation. A case study was conducted to evaluate and compare the current methodology used by SDDOT with the proposed changes recommended in this study.

5.4.1 Sensitivity Analysis

To compare the components of RUC, independent variables were required to remain consistent across all calculations. Existing speed and alternative speed(s), project length and length of detour/alternate route(s), truck percentage, and incremental increases to average daily traffic were all controlled variables. The values associated with each are listed in Table 5.20. The unit cost values were determined along with the proposed methodologies in the previous chapter; and the values are listed in Table 5.21. Values for VOC include operating costs and fuel costs: operating costs were found at AAA and ATRI for automobiles and heavy trucks, respectively; and vehicle fuel prices were found at the U.S. Energy Information Administration website for both gasoline and diesel based on yearly averages. Wage values for VOT were found at the U.S. Census for South Dakota and the U.S. Department of Labor for automobiles and heavy trucks, respectively. Accident costs were taken from the HSM, Table 7.1, which lists the comprehensive costs of PDO crashes at \$7,400. The cost for injury and fatal severity accidents have been calculated based on the weight factors established by SDDOT.

Table 5.20 Controlled Variables

	Initial Speed (mph)	Improvement/ Construction Speed (mph)	Length (miles)	Detour/ Alternate Length (miles)	Average Daily Traffic	Percent Trucks (%)	VOF
Symbol	$S_{0,c}$	$S_{1,c}$	L	L_D	ADT	P_T	VOF_C
Initial Value	65	55	5	Variable $K = L_D / L_0$	1000	Variable	Variable
Range	—	—	—	[0.5-2]	[1000-20000]	[10%-30%]	[1-1.6]

Table 5.21 Default Unit Costs

	VOC	VOC	VOT	AC				AR (Crashes/mvmt)	CMF		
				Unit Cost (\$/incident)			PDO			INJ	FA
				Unit Cost (\$/mile)	Unit Cost (\$/gallon)	Unit Cost (\$/min)					
AUTO	\$0.60	\$3.58	\$0.19								
TRUCK	\$1.10	\$3.85	\$0.30	\$7,400	\$22,200	\$88,800	1.9 (rural minor arterials)		1.2		

5.4.1.1 Value of User's Time

The value of road user's time represents the delay cost incurred from decreased speeds through a work zone or the additional travel distance of a detour/alternate route. The vehicle delays can be converted to a monetary value by using the mean wage rate for each vehicle class multiplied by the average daily traffic count and a factor to account for the average vehicle occupancy. The value of road user's time may be presented as a daily cost or a total project cost by accounting for the number of project work days.

The methodology proposed in the preceding chapter is appropriate for either planning or project construction estimations. For more precise estimates, the values for vehicle minutes traveled must be calculated separately using the length and travel speed of each route segment if variations in travel speeds exist on each segment. If traffic count data are available, the proportion of vehicles traveling the detour route may be included to accurately account for the components comprising delays to work zone and detour traffic. After inputting the default unit costs, Equation 5-47 can be simplified to Equation 5-69, where p is the proportion of traffic taking the detour.

$$VOT = ADT * L * [(1 - p)(0.03186 * VOF * (1 - P_T) + 0.05034 * P_T) + p(1.092 * k - 0.9228)(0.3 * P_T + 0.19 * VOF * (1 - P_T))] \quad \text{Equation 5-64}$$

5.4.1.2 Vehicle Operating Cost

The vehicle operating costs account for the increased cost of operating a vehicle through conditions imposed by a work zone or as a result of increased travel miles. These costs may include costs such as fuel, oil, tires, maintenance, etc., and in some cases have also included ownership costs such as licensing, insurance, registration fees, and taxes. Additional vehicle operation costs occur as the result of travel speed differentials from the increase or decrease of speeds along alternate routes or through work zones.

An established method for estimating vehicle operating costs incorporates a linear function of the difference in travel distance between a work zone detour or alternate route and the original route. The product of the route difference and ADT can be monetized by using an appropriate unit cost per mile for each vehicle class. A disadvantage to this method is that it only produces changes to costs with a difference in the route length and does not contribute to VOC if the route length remains constant. Therefore, this method is more suitable for planning when RUC estimations involve the addition or removal of existing roadways in which the length of the study route will always change.

The proposed method for calculating the vehicle operating costs for project construction estimations involves the change in fuel costs as a function of speed, length, and the price of fuel. This method accounts for the changes to fuel consumption that result from decreases in travel speeds and may be calculated separately for each segment to achieve more precise cost values. The costs due to speed cycle changes through a work zone are included to provide a more complete estimation. If traffic count data are available, the proportion of vehicles traveling the detour route may be included to accurately account for the components comprising additional costs to work zone and detour traffic. After inputting the default unit costs, Equation 5-55 and 5-60 can be simplified to Equation 5-70 and 5-71, where p is the proportion of traffic taking the detour.

Planning:

$$VOC = ADT * L * (k - 1) * [0.6(1 - P_T) + 1.1P_T] \quad \text{Equation 5-65}$$

Project Construction:

$$VOC = ADT * \{(1 - p)(0.01569 * (1 - P_T) + 0.04218 * P_T) + L * [(1 - p)(0.00716 * (1 - P_T) + 0.01925 * P_T) + p(k - 1)(0.1468 * (1 - P_T) + 0.6275 * P_T)]\} \quad \text{Equation 5-66}$$

5.4.1.3 Accident Cost

Accident costs account for the change in the accident rate prior to and after or during any proposed project improvements. The change in the accident rate may result in increased accident costs due to the probability of more work zone crash occurrences or a decrease due to the implementation of proposed safety improvements. The factors that have the greatest influence on the total accident costs are the number of accidents of each severity type occurring along the study route and the value of crash costs used in the calculation. The proposed methodology includes methods for computing the existing accident rate and crash modification factors that are used to estimate the accident rate under the analysis conditions. After inputting the default unit costs, Equation 5-62 can be simplified to Equation 5-72.

$$AC = ADT * L * 0.014060 * (CMF * k - 1) \quad \text{Equation 5-67}$$

5.4.1.4 Planning Scenario

The sensitivity analysis for planning use was performed for Truck Percentage, Vehicle Occupancy Factor, and the K value to represent Detour/Alternate Lengths, respectively, with other variables being held constant. The following figures depict the effects that incremental changes to the selected variable will have on the overall RUC along with the individual RUC component contributions at a fixed level. The variable, Percent Trucks, is analyzed in Figure 5.11(a), while Figure 5.11(b) shows the individual components influence on the RUC with 20% trucks. The Vehicle Occupancy Factor (VOF) is represented in Figure 5.12(a), while Figure 5.12(b) shows the individual component contributions to the RUC at a VOF of 1.6. The effects of the K value, or increases to the route length, are seen in Figure 5.13(a), while Figure 5.13(b) shows the component influence on RUC at a K value of 1.5.

Planning projects without an alternate route simplifies the estimation process leaving VOT and AC as the only components that are susceptible to change. These components increase with the changes to ADT to dictate the cost increases that may occur along the route. VOC is dependent on the change in vehicle miles traveled and without a change in route length there is no change in operating costs.

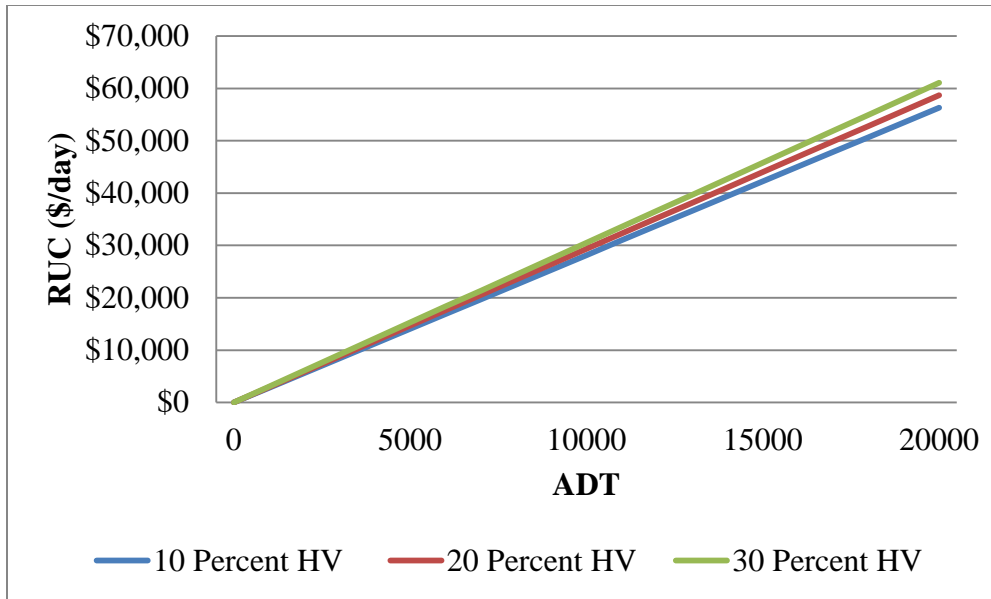


Figure 5.11(a) RUC by Percent Truck*

*Assume: $k=1.5$, $AR=1.9$ crashes/mvmt, $CMF=1.2$, $L=5$ miles, and $VOF=1.67$

$$RUC = ADT * \{0.06 * [0.317(1 - P_T) + 0.30P_T] + 2.5 * [0.6(1 - P_T) + 1.1P_T] + .05624\}$$

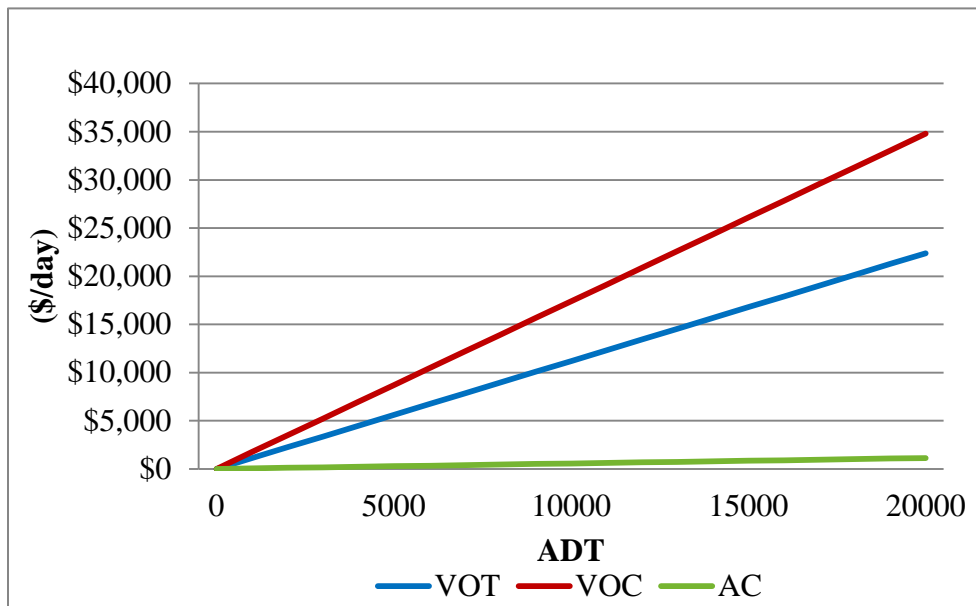


Figure 5.11(b) RUC Components (20 Percent Trucks)*

*Assume: $k=1.5$, $AR=1.9$ crashes/mvmt, $CMF=1.2$, $L=5$ miles, and $P_T=20\%$;

$$VOT = ADT * 3.592 * [0.152 * VOF + .06]; \quad VOC = ADT * 1.75; \quad AC = ADT * .0562$$

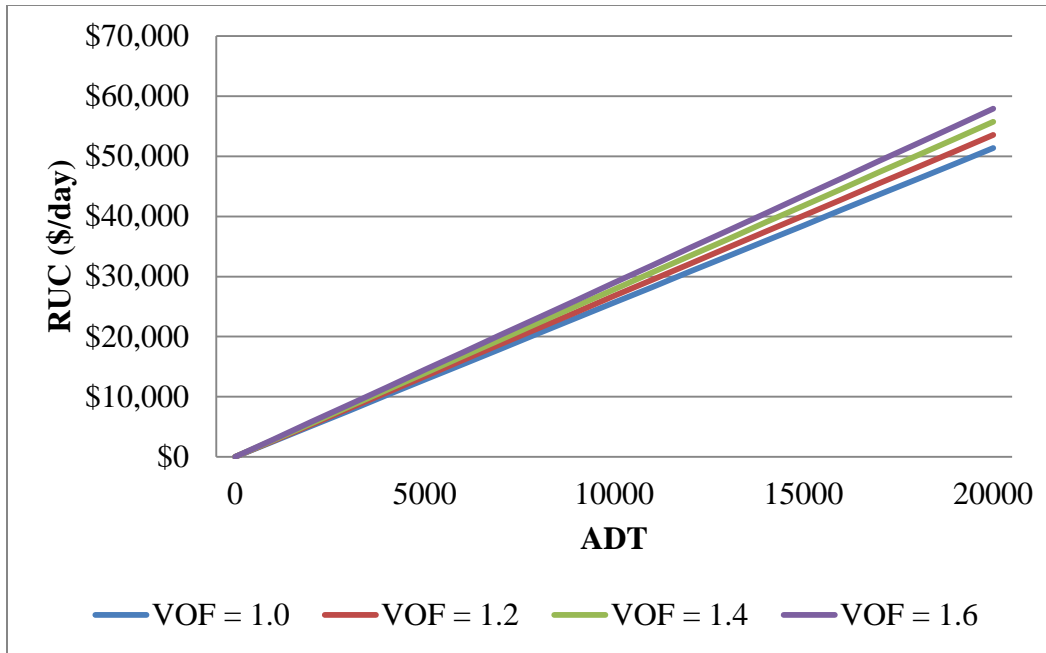


Figure 5.12(a) RUC by VOF*

*Assume: $k=1.5$, $AR=1.9$ crashes/mvmt, $CMF=1.2$, $L=5$ miles, and $P_T=20\%$,

$$RUC = ADT * \{60 * [0.00912 * VOF + 0.036] + 1.75 + .05624\}$$

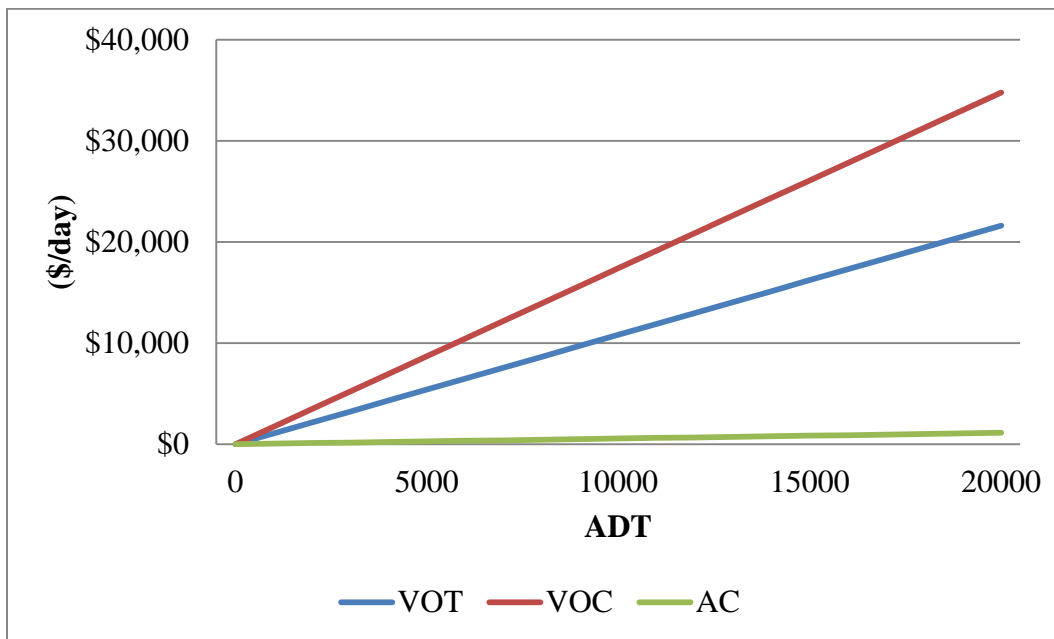


Figure 5.12(b) RUC Components (VOF = 1.6)

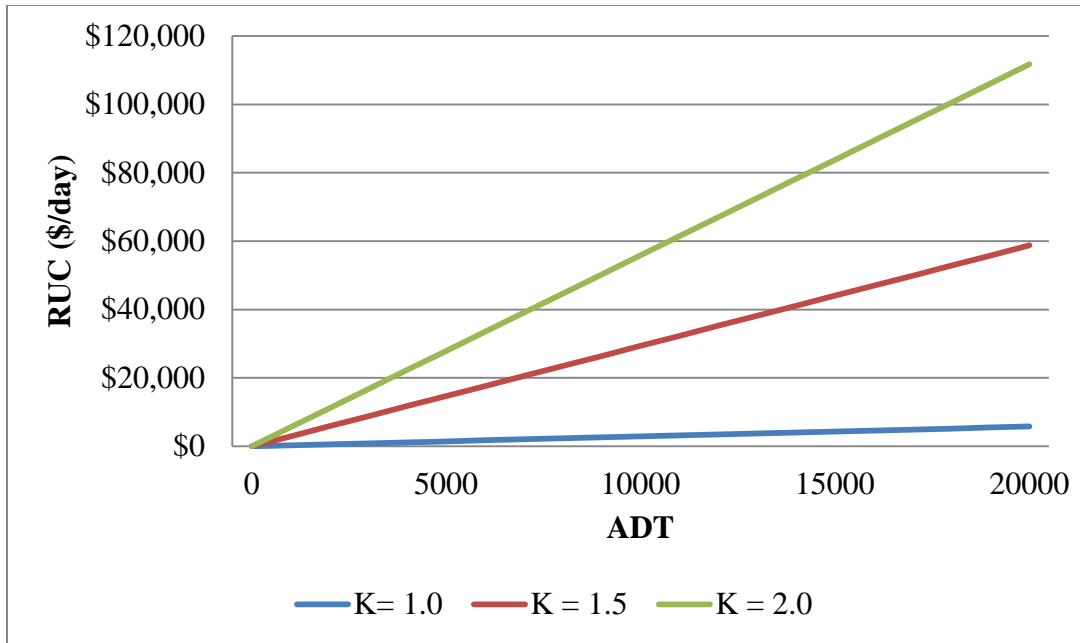


Figure 5.13(a) RUC by K Value*

* Assume: AR=1.9 crashes/mvmt, CMF=1.2, L=5 miles, P_T=20%, and VOF=1.67

$$RUC = ADT * [(1.714k - 1.44) + (3.5k - 3.5) + (84360 * k - 70300)]$$

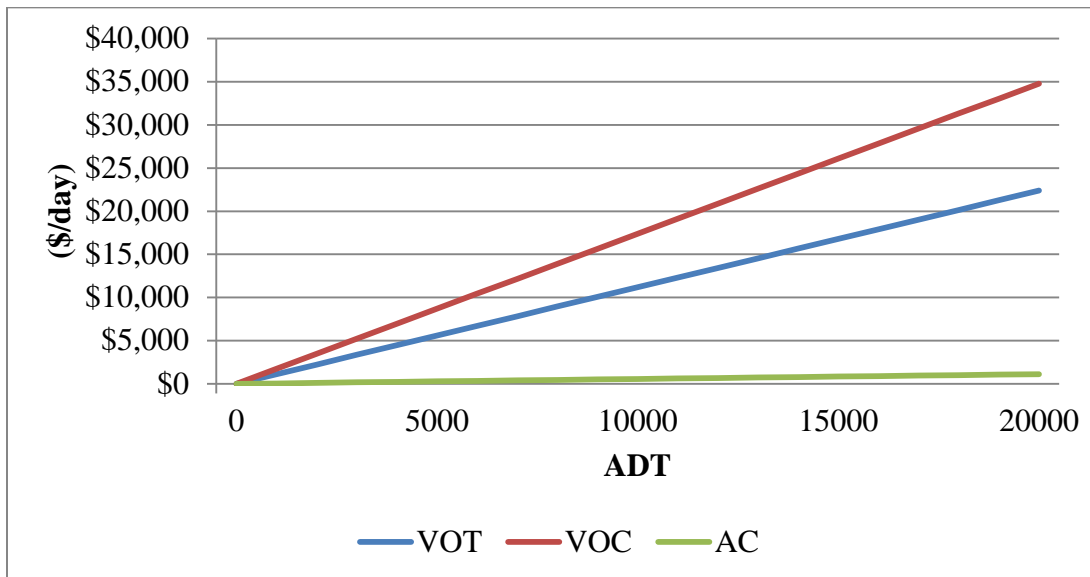


Figure 5.13(b) RUC Components (K = 1.5)

5.4.1.5 Project Construction Scenario

The sensitivity analysis for project construction use was conducted using two scenarios that included a project with a reduced speed work zone only and a project with an increased K value, or detour route. The value for K was equal to one for the analysis with no detour route and remained consistent with the lengths established in Table 5.20 for the detour route analysis. The VOC analysis includes the cost of fuel as a function of the travel speed and the cost per cycle to reduce to and accelerate back to the prior

operating speed. VOT and AC are calculated using the same method as the planning analysis. Project construction analysis without a detour increases RUC with increases to the ADT (Figure 5.14(a)). The costs of VOT increase with the additional ADT and reduced travel speeds present within a work zone. Figure 5.14(b) shows that the VOC contributes less significantly to the RUC; however, the contribution to the overall cost will increase as the travel speed decreases.

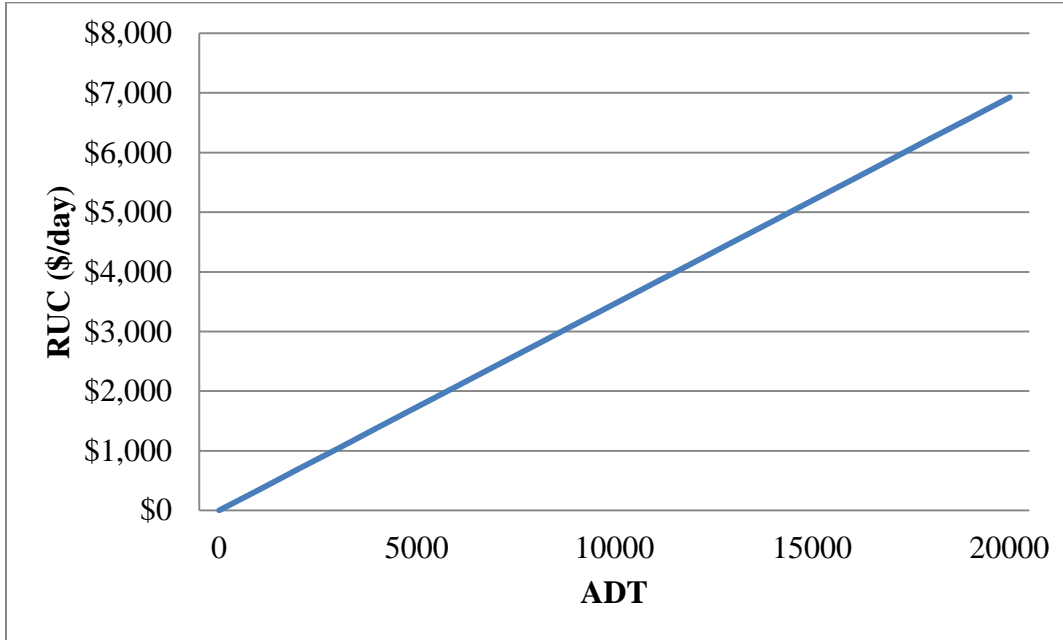


Figure 5.14(a) RUC without Detour

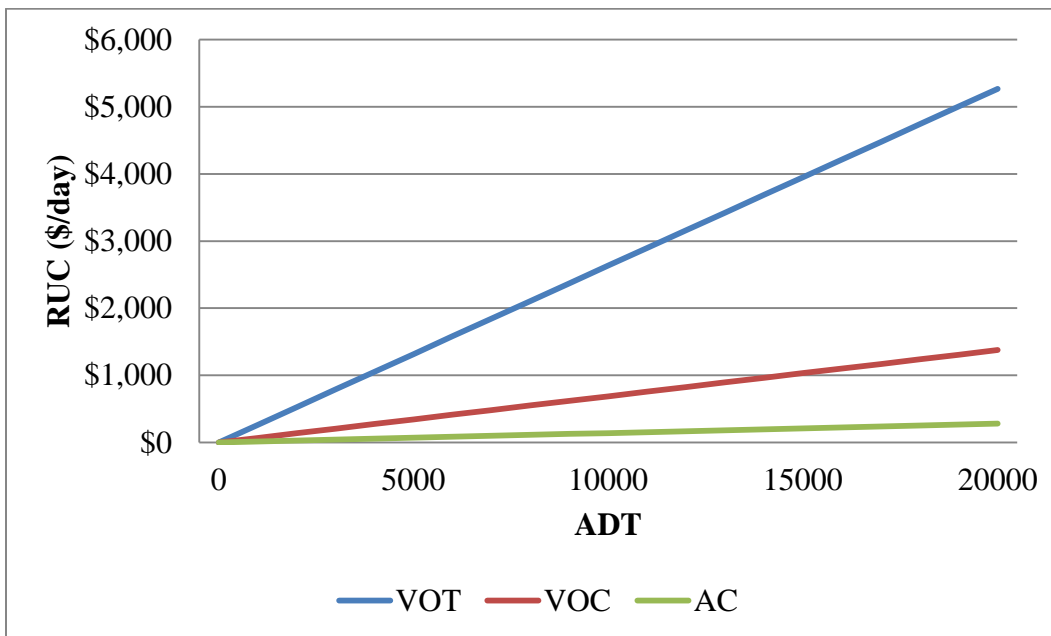


Figure 5.14(b) RUC Components without Detour

Project construction analysis with a detour can be made using proportional differences in the vehicles that travel on the detour or through the work zone. This analysis assumed that there was a 50% split for

vehicles traveling the detour route and the work zone. Project construction analysis, with a detour, increases RUC with increases to the ADT [Figure 5-15(a)]. The costs of VOT and VOC increase with the additional ADT and detour route length coupled with the variations to travel speeds present within a work zone. The individual component contributions can be seen in Figure 5.15(b).

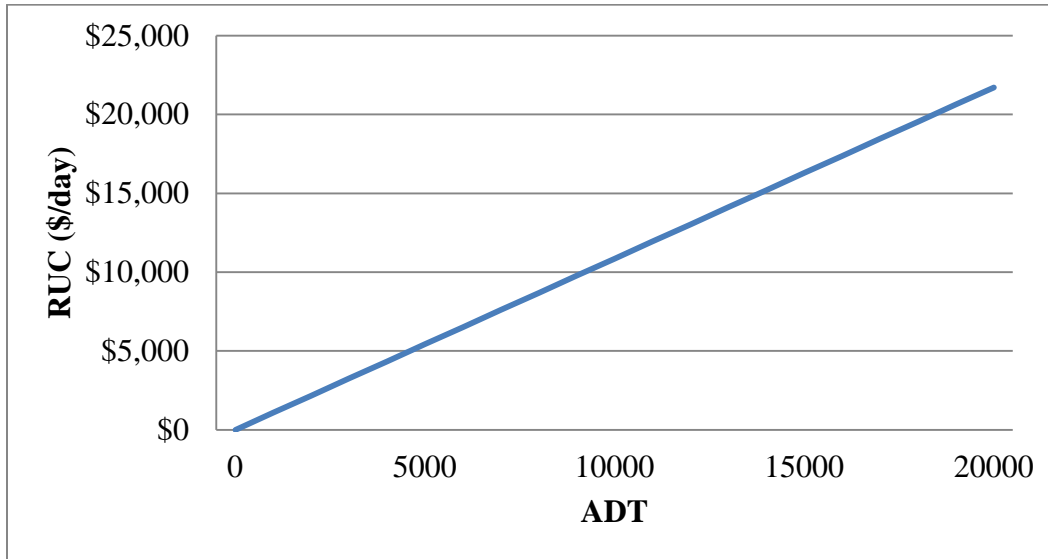


Figure 5.15(a) RUC with Detour

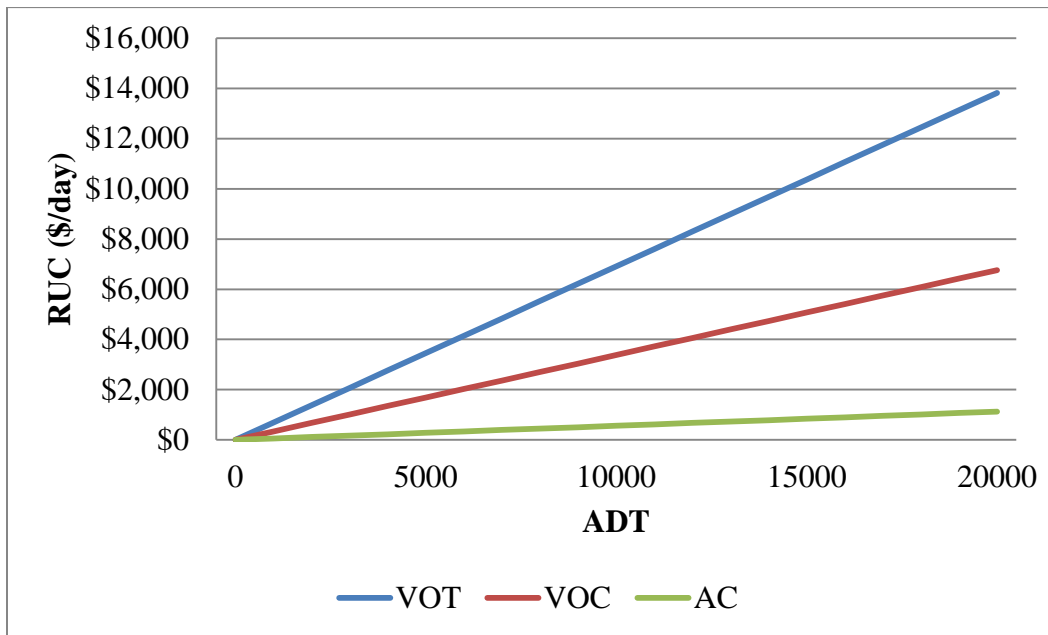


Figure 5.15(b) RUC Components with Detour

*Assume AR=1.9 crashes/mvmt, CMF=1.2, L=5 miles, $P_T=20\%$, and VOF=1.67,

$$VOT = ADT * (0.002195 + 0.002194k)$$

$$VOC = ADT * [0.01049 + 0.02395 + (k - 1) * 0.37248] \text{ (50\% ADT uses WZ and 50\% ADT uses detour)}$$

$$AC = ADT * 70300(1.2 * k - 1)$$

$$RUC = ADT * [(1.714k - 1.44) + (0.02098 + k * 1.2146 - 1.1667) + (84360 * k - 70300)]$$

The impact that changes in work zone length or using a detour route that changes the route length can be seen in Figure 5.16.

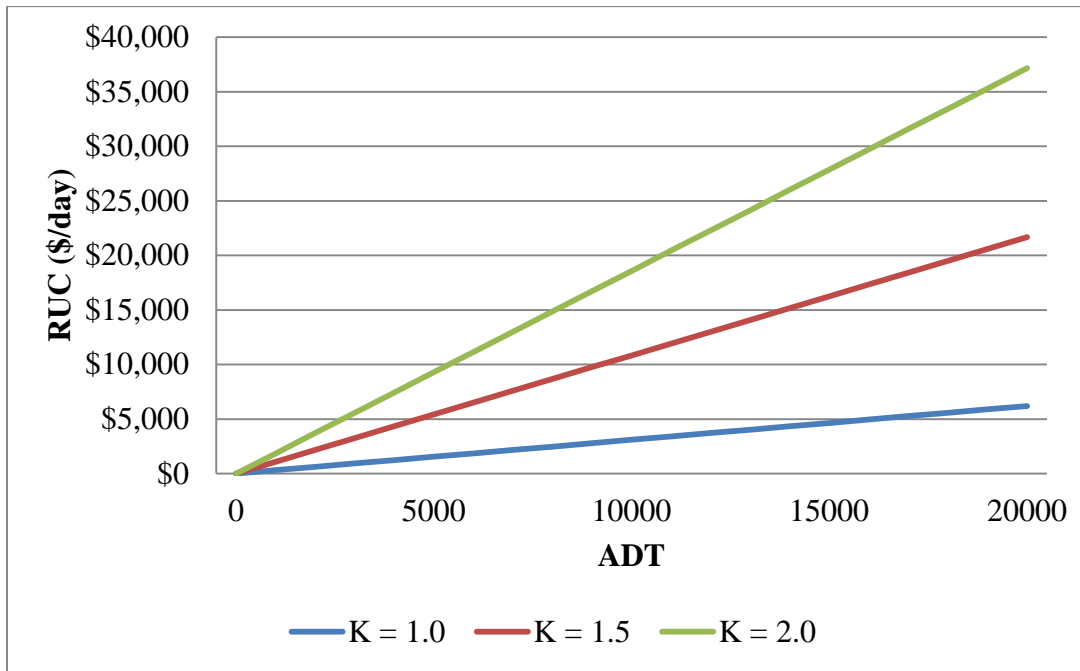


Figure 5.16 RUC by K Value

5.4.1.6 Summary of Sensitivity Analysis

The results of the sensitivity analysis show the existence of a linear relationship between variables with respect to ADT. The contributions of RUC components in the planning and project construction analysis indicate that there is a difference in the hierarchical order among methods. The components for planning are ranked in order of monetary contribution as VOC, VOT, and AC, while the components for project construction are ranked as VOT, VOC, and AC. The difference can be explained by the fact that planning analysis makes use of unit costs, which include operating and ownership costs, and the VOC methodology is a function of length and not speed. The calculations result in a higher value for VOC than computed values using the unit costs and methodology presented for project construction. The changes to the methodology for project construction include provisions to account for operating costs due to fluctuations in fuel efficiency caused by speed changes and do not include ownership costs. The AC, in both planning and project construction, are based on the SDDOT equivalent PDO weighted crash rates, which evaluate fatalities as 12 times the cost of a property damage accident and may undervalue the cost of accidents as compared with the FHWA accident costs, which use a multiple of 541 to account for fatalities. It is recommended that crash unit cost by injury severity should be more consistent with FHWA criteria.

The contribution of other variables to RUC can be seen in the previous tables. The planning analysis consisted of incremental changes to the variables for Percent Trucks, the Vehicle Occupancy Factor, and the K value. Changes to the variable for the percent of trucks present in the ADT serve to increase the RUC, but have insignificant impact on the overall user costs because the proportion of trucks is only considered in the estimation of VOT and the difference in unit cost between vehicle classes is very small when the VOF is included. The VOF also serves to increase RUC, but has limited impact on the overall user cost because it is only considered in the estimation of VOT to account for additional passengers present in automobile traffic. Increases to the K value, or route length, can be seen to increase RUC

substantially due to the inclusion of length in every component of the RUC calculation. The project construction analysis included changes in the K value to represent scenarios with and without a work zone detour present. The findings indicate that increases to the K value will increase the overall RUC at a rate comparable to planning.

5.4.2 Case Study

A comparative analysis has been made between the current methodology used by SDDOT and the proposed changes recommended in this study. Examples provided by SDDOT using the current methodology have been recalculated to determine the effects that the changes to the current methodology will have on the overall RUC as well as the individual components.

5.4.2.1 Planning

The planning cases include an example of estimations for a route addition and a route removal. The planning estimations included provisions for annual increases to ADT based on traffic growth factors for the counties, which were then projected for a 20-year period. Present value estimations were calculated using a discount rate of 4% for each of the years in the 20-year period. A net present value for each case was also presented to illustrate the differences.

Case 1:

The removal of route example includes two alternative routes of different lengths. Figure 5.17(a) and Figure 5.18(a) show the alternate route estimations using a 20-year present value analysis. The net present value comparison can be seen in Figure 5.17(b), for alternative route 1, and Figure 5.18(b), for alternative route 2.

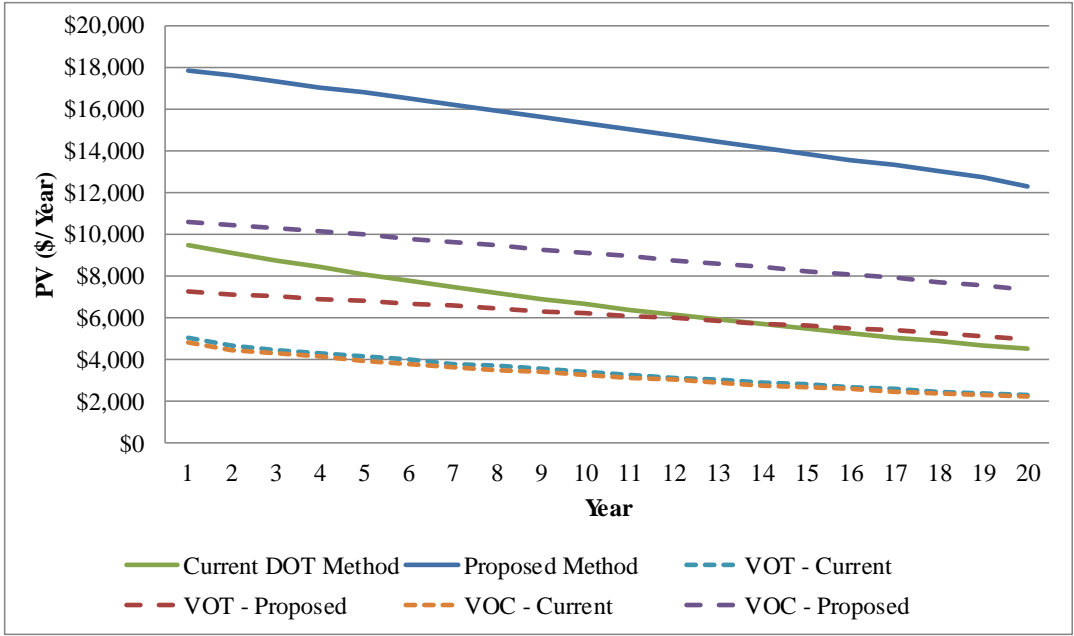


Figure 5.17(a) Present Value for Alternative 1

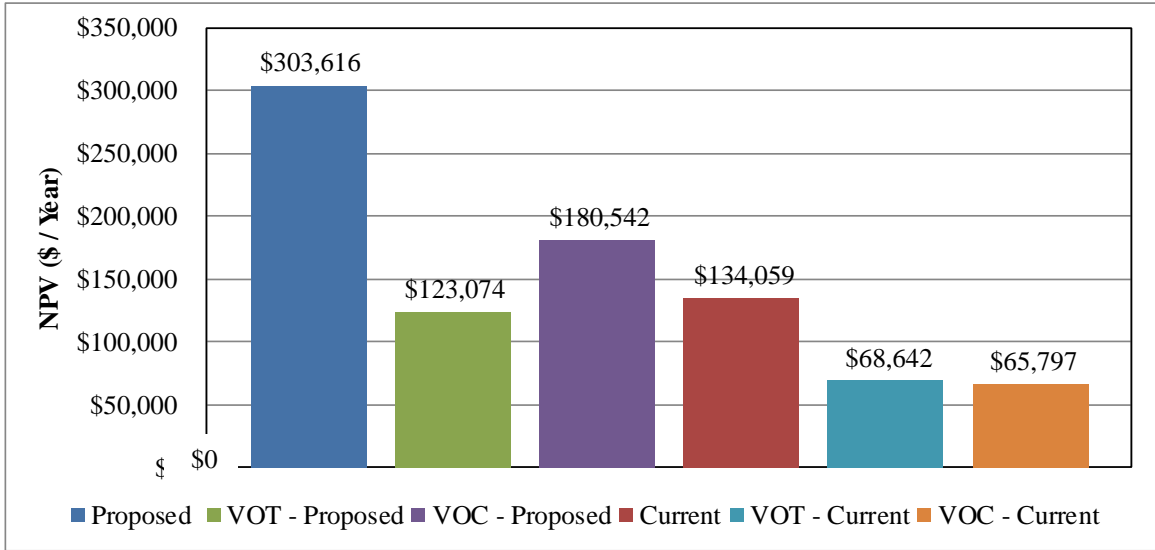


Figure 5.17(b) Net Present Value for Alternative 1

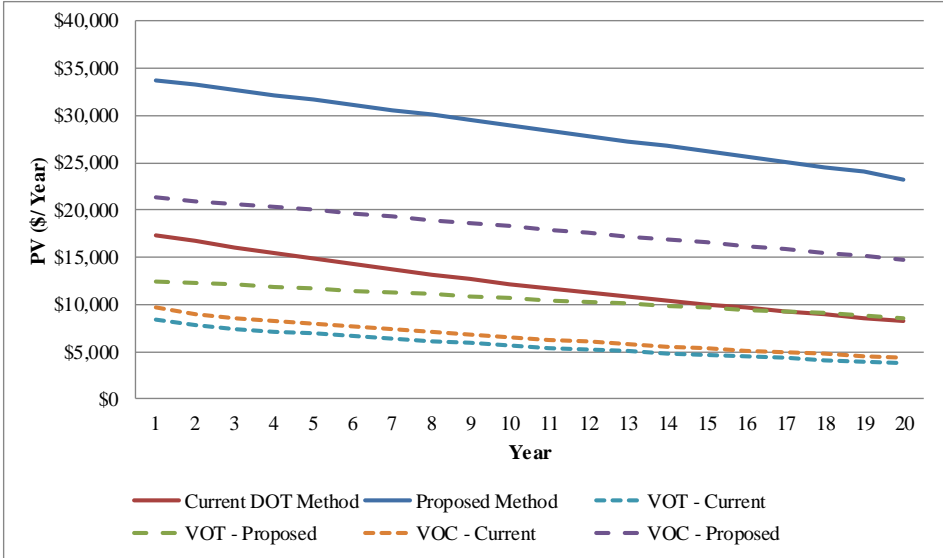


Figure 5.18(a) Present Value for Alternative 2

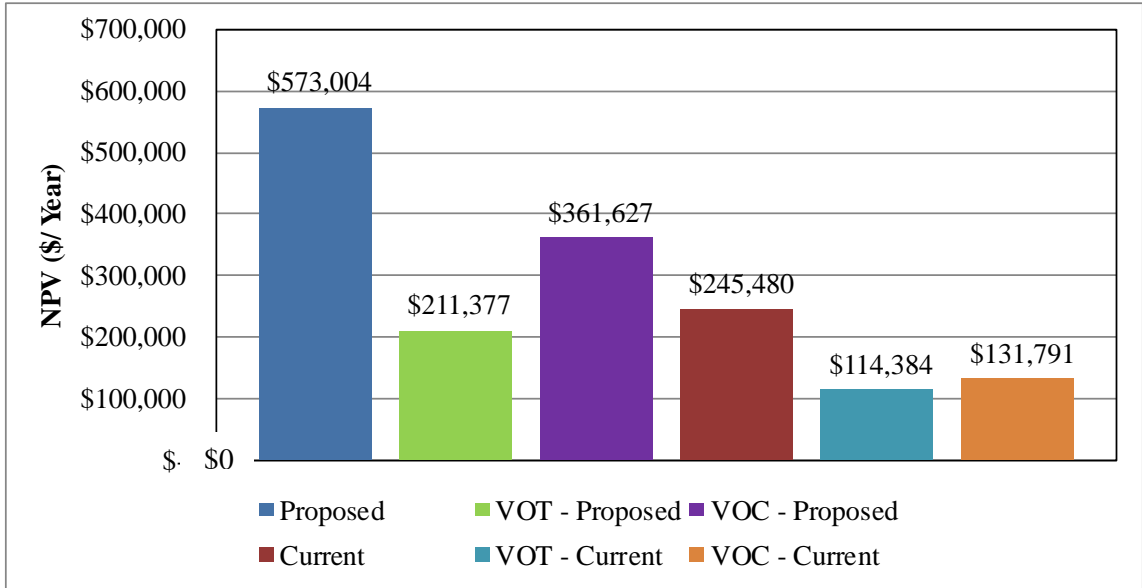


Figure 5.18(b) Net Present Value for Alternative 2

Case 2:

The route addition example includes a delay analysis for the entire network affected by the addition of the proposed route. The overall delays and affected traffic was included in the analysis; however, VOT is the only component which was calculated in the example making the component of VOT the only comparison that was possible. Figure 5.19(a) depicts the present value analysis for this route addition, while Figure 5.19(b) shows the net present value of both the current and proposed methodologies. This example illustrates the savings due to reduced delay times that a route addition can have on a network.

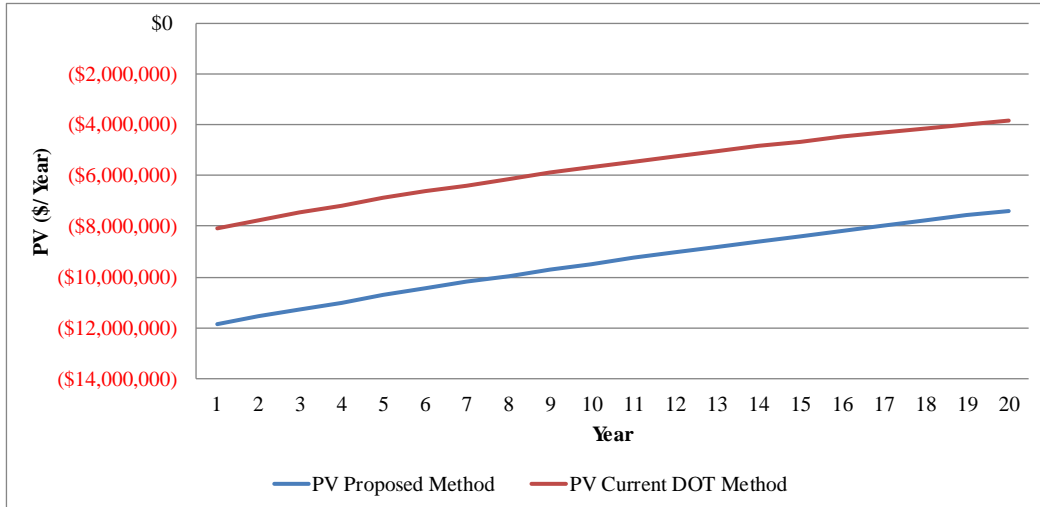


Figure 5.19(a) Present Value Comparison

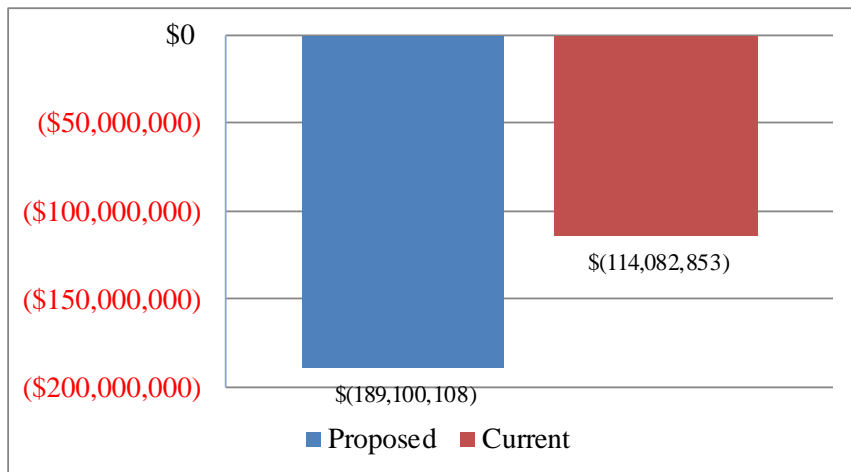


Figure 5.19(b) Net Present Value Comparison

Case 3:

A planning analysis was constructed with accident costs using a route selected from the 2012 Needs book. An alternate route was proposed, assuming the route length and speed; these values are listed in Table 5.22. In Figure 5.20(a), a 10-year present value was determined for the current and the proposed methodology with the accident cost included. Figure 5.20(b) depicts the differences in AC when estimates are made with the SDDOT and FHWA accident weights.

Table 5.22 Assumptions for Analysis

Estimate of Daily Road User Costs Moody County Analysis of US Highway 32	Beginning		
	MRM:	414.24	
	Segment		
	Length:	7.13	miles
	Alternate Route Length:	15.00	miles
	Route Speed:	65	mph
	Alternate Route Speed:	55	mph
	Current ADT:	2473	vehicles
	20 yr ADT:	2856	vehicles
	Trucks:	431	
	Growth		
	Factor:	1.28	%
	Discount		
	Rate:	4.00	%
	Accident		
Rate:	1.90		
Cost/ PDO:	\$ 7,400.00		

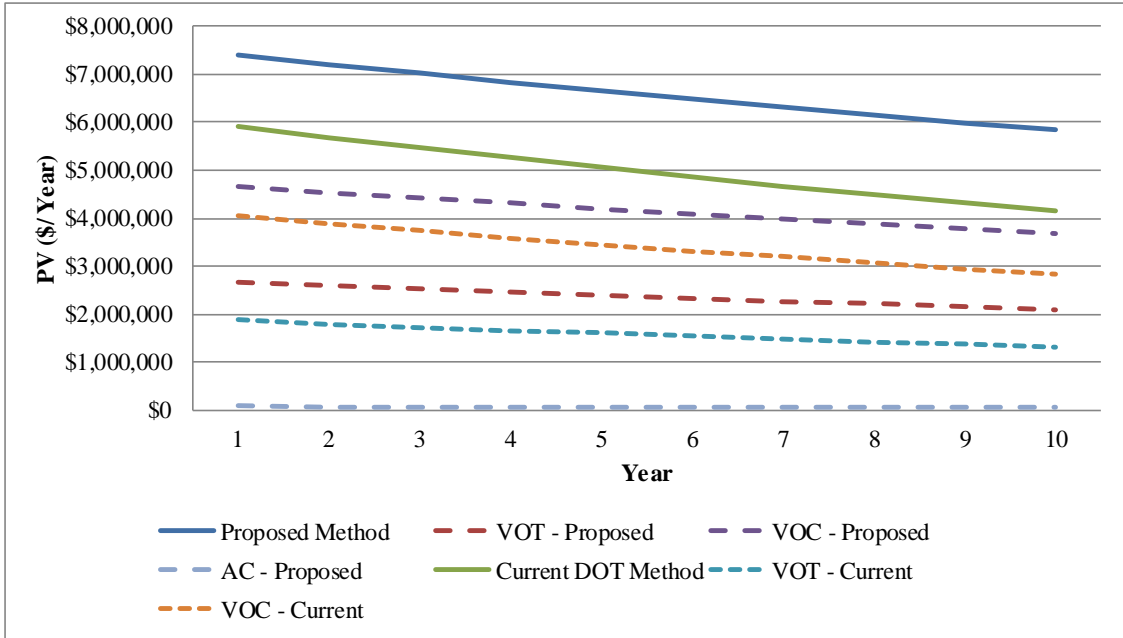


Figure 5.20(a) PV of Proposed and Current Methodologies

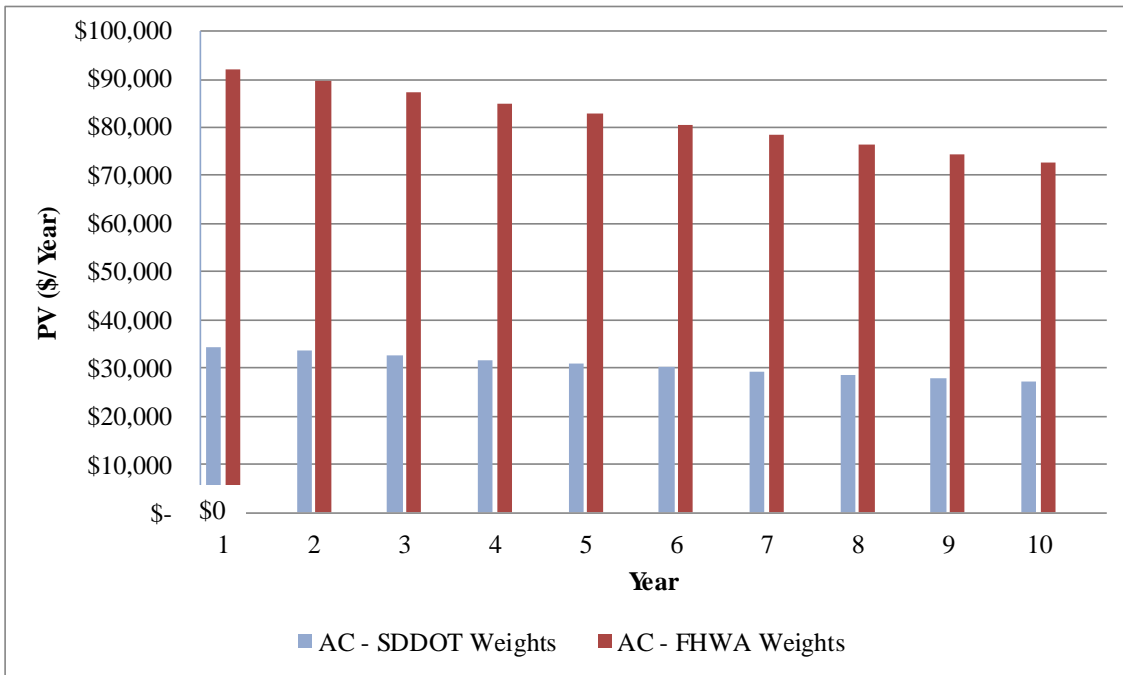


Figure 5.20(b) PV AC with SDDOT and FHWA Crash Severity Weights

5.4.2.2 Project Construction

The case study of project construction includes multiple phases of construction for each project that was provided by SDDOT personnel. There were six separate projects that were recalculated using the proposed methodology for project construction. Each RUC component was identified and a comparison was made to determine the difference in costs. Each case is explained in brief detail below along with an accompanying table, which includes each component value and the change in percentage between the proposed and current values. Assumptions had to be made to determine the length of each phase of construction within the time frame provided by DOT personnel.

Case 1:

Jackson Boulevard in Rapid City, including intersection work at Sheridan Lake Road and Mountain View Road

Table 5.23 Case Study 1

		VOT		VOC		AC	RUC
		(\$/day)	% Change	(\$/day)	% Change	(\$/day)	(\$/day)
Phase1	Current	1,663.00		327.00		–	1,990.00
	Proposed	1,764.81	6%	501.06	53%	916.73	3,182.59
SLR-N	Current	1,664.00		1,918.00		–	3,582.00
	Proposed	1,768.15	6%	560.66	-71%	1,015.09	3,343.90
SLR-N (2)	Current	132.00		100.00		–	232.00
	Proposed	139.52	6%	117.76	18%	72.48	329.76
MVR-N	Current	1,632.00		1,882.00		–	3,514.00
	Proposed	1,728.24	6%	548.00	-71%	981.78	3,258.02
MVR-N (2)	Current	70.00		100.00		–	170.00
	Proposed	74.71	7%	112.01	12%	38.81	225.53
Phase3	Current	2,334.00		327.00		–	2,661.00
	Proposed	2,475.64	6%	564.14	73%	694.69	3,734.46
SLR N&S	Current	3,673.00		4,236.00		–	7,909.00
	Proposed	3,937.33	7%	1,248.48	-71%	1,248.02	6,433.84
State St	Current	275.00		224.00		–	499.00
	Proposed	296.08	8%	69.54	-69%	37.83	403.45
Phase 2&3	Current	7,477.00		327.00		–	7,804.00
	Proposed	7,939.23	6%	851.71	160%	1,607.07	10,398.01

Case 2:

I-90 from Oacoma to Chamberlain and Exit 263 into Chamberlain

Table 5.24 Case Study 2

		VOT		VOC		AC	RUC
		(\$/day)	% Change	(\$/day)	% Change	(\$/day)	(\$/day)
I-90	Current	2,399.00	30%	342.00	110%	–	2,741.00
	Proposed	3,121.17		718.81		590.91	4,430.89
Exit	Current	1,691.00	42%	4,531.00	-57%	–	6,222.00
	Proposed	2,392.93		1,962.93		294.67	4,650.53

Case 3:

Lane rental calculation for US-14 in Hughes County

Table 5.25 Case Study 3

		VOT		VOC		AC	RUC
		(\$/day)	% Change	(\$/day)	% Change	(\$/day)	(\$/day)
US-15	Current	1,276.65		152.00		–	1,428.65
	Proposed	1,805.21	41%	343.13	126%	218.39	2,366.73

Case 4:

I-29 in Roberts County

Table 5.26 Case Study 4

		VOT		VOC		AC	RUC
		(\$/day)	% Change	(\$/day)	% Change	(\$/day)	(\$/day)
I-29	Current	3,491.00		109.00		–	3,600.00
	Proposed	3,584.13	3%	115.20	6%	2,991.14	6,690.48

Case 5:

US-83 in Campbell County (new grading, traffic detoured for duration of project)

Table 5.27 Case Study 5

		VOT		VOC		AC	RUC
		(\$/day)	% Change	(\$/day)	% Change	(\$/day)	(\$/day)
Option 1	Current	3,673.00		6,410.00		–	10,083.00
	Proposed	6,678.15	82%	7,343.56	15%	2,574.91	16,596.62
Option 2	Current	5,862.00		10,231.00		–	16,093.00
	Proposed	10,658.89	82%	11,720.95	15%	3,554.21	25,934.05

Case 6:

I-90 Exit 10 reconstruction including US-85 & US-14 in Spearfish in Lawrence County

Table 5.28 Case Study 6

		VOT		VOC		AC	RUC
		(\$/day)	% Change	(\$/day)	% Change	(\$/day)	(\$/day)
Phase 1	Current	3,881.75		703.00		–	4,584.75
	Proposed	5,501.45	42%	1,501.84	114%	653.62	7,656.90
Phase 2	Current	1,293.92		235.00		–	1,528.92
	Proposed	1,833.82	42%	500.61	113%	148.92	2,483.35
Phase 3	Current	5,089.64		742.00		–	5,831.64
	Proposed	7,187.16	41%	1,683.03	127%	804.69	9,674.88
Phase1 (cco)	Current	5,089.64		742.00		–	5,831.64
	Proposed	7,187.16	41%	1,683.03	127%	1,176.02	10,046.21
Phase2&3 (cco)	Current	1,696.54		248.00		–	1,944.54
	Proposed	2,401.21	42%	508.53	105%	268.24	3,177.98

5.4.2.3 Summary of Case Comparisons

The case studies illustrate the differences between the current methodology and the proposed methodology. The planning analysis depicts three case studies: with route removal, with route addition, and a hypothetical estimation with the inclusion of accident costs. The first case study shows that the proposed methodology almost doubles RUC to the current value. The net present value comparison of this case clearly shows that this increase is due in large part to VOC, which is near triple the value of the current methodology. The second case study shows the savings to VOT that result from the addition of a route to a network. The third case study illustrates that AC constitutes a small fraction of total RUC if the SDDOT weighted accident rate is used. However, the FHWA crash weighting factors presented in the HSM may drastically increase AC.

The project construction analysis depicts six different case studies with multiple construction phases included. The individual components of the current and proposed methodologies are presented along with the percentage of difference change between the values. The increases in the VOT component can be attributed to the changes made to unit cost and VOF, since the methodology has remained unchanged. The VOC component results show the variations in cost, compared with the current methodology. The change in methodology results in a more accurate view of the operating costs due to motorists, because it makes use of unit cost values for fuel consumption and speed changes without including the additional costs due to ownership. The decrease in VOC values evident in some phases of Cases 1 and 2 can be explained by the detour routes with speeds that do not change or have increased compared with the existing route. The inclusion of AC increases the RUC for each case, but at a rate far less than any other component.

5.4.3 Summary

The methodologies and components included in the estimation of RUC are based on the decision support method in which it is being analyzed, i.e., planning and project construction options (work zones). The components that are included in the proposed methodologies are the VOC, VOT, and AC. Other factors that have the potential to affect road user costs are emissions costs, environmental effects, noise, and local

business impacts. These components have not been included in the proposed methodologies due to the ineffective methods for monetizing them and the minimal effect found from the SDDOT survey. Table 5.29 presents a summary of the equations.

Table 5.29 Summary of Equations Applied For RUC Cost Components

RUC Component	Current		Proposed	
	Planning	Project Construction	Planning	Project Construction
VOT	5-40; 5-41; 5-42; 5-43; 5-44	5-40; 5-41; 5-45; 5-46	5-47; 5-48; 5-49	5-47; 5-48; 5-49
VOC	5-50	5-50; 5-51	5-50	5-52; 5-53; 5-54; 5-55
AC	—	—	5-56; 5-57; 5-58; 5-59; 5-60; 5-61	5-56; 5-57; 5-58; 5-59; 5-60; 5-62

The proposed resources needed for the unit cost values have taken into account the source reliability, frequency of updates, and ease of accessing the information. The U.S. Census for South Dakota (<http://quickfacts.census.gov>) is recommended as the data resource for the passenger car unit cost values of time, because they provide a more complete representation of the average state income. The value represents mean income of every man, woman, and child over age 15, and includes employment wages as well as income sources such as Social Security Income (SSI), public assistance or welfare, and survivor or disability pensions. However, the accuracy of the value is debatable, because it is produced from five-year estimates. Moreover, the values available from the US Census for South Dakota are represented as mean money income per year, so there is a need to convert to an hourly rate. The U.S. Department of Labor (<http://sddot.com/business/contractors/docs/USDOLDBAWageDecision.pdf>) is the suggested source for the heavy truck unit cost value of time, because the values are used in projects to dictate the required federal wages and so are reassessed and updated on a regular basis, although the value must be converted to dollars per minute using Equation 5-47. The use of Vehicle Occupancy Factors (VOF) is also recommended to accurately represent the costs per vehicle by accounting for the average vehicle passengers. The current source of VOF has not been updated since its inclusion into the SD VOT cost calculations, so the 2009 NHTS VOF value of 1.67 is recommended. The South Dakota Occupational Wage Estimates provide wage values as a unit per hour, but the value does not include income from sources other than occupational employment, which excludes the elderly and residents with disabilities.

The American Automobile Association (AAA) is the recommended source to locate the vehicle operational unit cost values for passenger cars (<http://exchange.aaa.com/automobiles-travel/automobiles/gas-pricing>). The AAA average cost per vehicle includes fuel, maintenance, tires, insurance, licensing, registration and taxes, depreciation, and financing expenses. The American Transportation Research Institute (ATRI) is the recommended source for the vehicle operational unit costs of heavy trucks (<http://atri-online.org/atri-research/economic-analysis>). The ATRI average motor carrier cost per mile includes fuel and oil, truck/trailer lease, repair and maintenance, insurance, licensing and permits, tires, toll fees, and driver-based expenses such as driver wages and benefits.

Calculation of VOC for work zones can be accomplished by combining multiple methods that will improve estimation accuracy by including extra fuel consumption due to the speed change, speed cycle change, and additional travel distance because of detours. The AASHTO methods addressed the fuel change in consumption rates due to speed differentials. The current SDDOT usage of CPC tables

produces an adequate estimation of these effects, but component unit cost values may be updated using specific CPI values (fuel, oil, etc.) to produce more refined estimates.

Accident rates can be obtained from the SDDOT Highway Needs and Project Analysis Report: State Highway System Weighted Accident Rates or calculated directly. The necessary CMF values may be found in the Highway Safety Manual (HSM) or from the CMF Clearinghouse at <http://www.cmfclearinghouse.org/>, a website maintained by the FHWA Office of Safety. CMF values obtained from the CMF Clearinghouse include those found in the HSM, as well as values collected from published studies, but the complexity of the search requirements on the website may deter users. CMF values for project construction (work zone) analysis may be calculated using Equations 5-57, 5-58, and 5-59 with information for work zone length and project duration. Crash cost estimates by severity can be taken from the HSM for human capital costs and comprehensive costs. Because of the variability of CMF values due to changes in operational and physical characteristics of each project location, calculation of state specific values for roadways using historic trends may result in values that more accurately reflect local conditions. A summary of resources needed and update frequency is listed in Table 5.30.

Table 5.30 Summary of Resources Needed and Update Period

RUC Component	Current		Proposed	
	Planning	Project Construction	Planning	Project Construction
VOT	SD Occupational Wage Estimates (annually)	US Census (annually); US Dept. of Labor (bi-annually)	US Census (annually); US Dept. of Labor (bi-annually)	US Census (annually); US Dept. of Labor (bi-annually) AASHTO Redbook
VOC	SD Fleet and Travel Rates (annually)	AAA (annually) OOIDA (none) CPC* (annually)	AAA (annually) ATRI (annually)	US DOE (annually) CPC* (annually)
VOF	Auto	–	US Dept. of Energy	NHTS (2015)
	Truck	–	US Dept. of Energy	NHTS (2015)
AC	None	None	HSM; SDDOT needs book; CMF	HSM, SDDOT needs book; CMF

*updated when needed using CPI

The sensitivity analysis suggests that the contributions of RUC components in the planning and project construction analysis are different. The components for planning are ranked in order of monetary contribution as VOC, VOT, and AC, while the components for project construction are ranked as VOT, VOC, and AC. The difference can be primarily attributed to the selection of unit costs, which include both vehicle operating and ownership costs for the planning purpose, resulting in a higher value for VOC. The improvements to the methodology for project construction include provisions to account for operating costs due to fuel consumption and fuel efficiency caused by speed changes. The AC, in both planning and project construction, are based on the SDDOT equivalent PDO factor, which treats a fatal crash as 12 times the cost of a PDO accident and an injury crash 3 times that of a PDO. The SDDOT crash severity weights may undervalue the cost of accidents as compared with the FHWA accident costs, which use a multiple of 541 to account for fatalities and 21 to account for injuries. Further research may be warranted to determine a more precise rate of consumption based on new vehicle technology.

The contribution of individual variables such as Percent Trucks (P_T), VOF, and the K value were also evaluated. The truck percentage has insignificant impact on the overall user costs, because the difference in unit cost between vehicle classes is very small when VOF is included. VOF also has limited impact on the overall user cost, because it is only considered in the estimation of VOT to account for additional passengers present in automobile traffic. Increases to the K value, or route length, increase RUC substantially due to the inclusion of length in every component of the RUC calculation.

The case studies display the differences between the current methodology and the proposed methodology. The quantity of changes in value is attributed to changes in unit cost, changes to methodology, and the inclusion of AC. The planning analysis includes three examples for route removal, route addition, and a hypothetical case with AC. The first case shows that the proposed methodology almost doubles RUC compared with the current value, largely due to VOC increases. The second shows the savings to VOT that result from the addition of a route to a network and the third illustrates that AC constitutes a small fraction of total RUC if the SDDOT AR is used.

The project construction analysis includes six different case studies with multiple construction phases included. Overall, the increases in the VOT component can be attributed to the changes made to unit cost and VOF. The VOC component results show the variations in cost, compared with the current methodology. The change in methodology results in a more accurate view of the operating costs due to motorists because it makes use of unit cost values for fuel consumption and speed changes without including the additional costs due to vehicle ownership. In particular, the evident decrease in VOC values can be explained by the existence of detour routes with speeds that do not change or have increased compared with the existing route. Similar to the planning scenario, including AC in the calculation of RUC increases the cost for each case, but at an inconsequential rate if the SDDOT weighted AR is considered. Note that the current practice of rating the injury severity crash costs as equivalent to that of property damage only incidents substantially underestimates the cost of those accidents. A comparison can be seen using crash costs taken from the Highway Safety Manual and the equivalent points used by FHWA and the SDDOT (Table 5.17).

5.5 SD RUC Application

5.5.1 Overview of the SD-RUC Application

The SD-RUC Tool is intended to facilitate the calculation of Road User Costs for Project Planning and Project Construction uses within SDDOT. There are two available options for entering data, the RUC Wizard or the individual worksheet input pages, either of which can be used depending on the user's familiarity with the tool. The output is a quick report which contains the most pertinent data and is formatted to print in as condensed a page layout as possible. Additional options include the ability to save the quick report to a separate workbook for cataloging of project histories.

The tool uses the proven methodology for calculating RUC in this study and was designed to provide secured and convenient access for users. The built-in safety measures allow for the administrator to regularly update the values of RUC parameters using reliable sources in a controlled manner and which maintains consistent use of unit cost values in all estimations of RUC.

The RUC Tool was developed for use on a Windows® operating system (Windows Vista) using Microsoft Excel 2010. The programming of the RUC Wizard application was done using Visual Basic for Applications (VBA). This tool can be run as a stand-alone application with the file installed on a local computer, or in a multi-user configuration with the application installed on a server and used by several client computers.

The RUC tool has been tested on a range of Windows® operating systems and older versions of Microsoft Excel with no compatibility issues detected. Apple computer systems running Microsoft Office for Mac version 2004 or 2011 should not experience any problems with compatibility when using this tool. However, Apple computer systems running Microsoft Office 2008 for Mac will experience errors when using this tool because of the lack of VBA support included in that version of Office, which makes it impossible to execute macros programmed with VBA.

Because the RUC Tool uses VBA, it is important that the user's version of Excel permits the use of macros for the application to run properly. When opening the RUC tool, an Excel security warning may appear asking for permission to allow macros; this permission must be allowed.

5.5.2 RUC Modules

The RUC Application is separated into two distinct modules:

The **Project Planning** module is used for the analysis of several alternative routes on a network in which a route is being added or deleted.

The **Project Construction** module is used for the analysis of a work zone route with or without the presence of a detour.

5.5.2.1 Module Basics

This section covers the methods of navigating through the application for first time users. It describes how to use the home screen module options and finding and viewing project input information and viewing/printing Quick Reports.

When you open the RUC Tool you will be directed to the home screen. The home screen displays two module options, Project Planning and Project Construction. Two variable input choices are made available for either of the estimation procedures, the RUC Wizard or the input worksheets. The RUC Wizard is a walk-through process that guides the user to input variables using a series of dialog boxes and is recommended for first time users. The input worksheets are provided for experienced users of the tool and can enable a swifter inputting of variables and subsequent reporting output time.

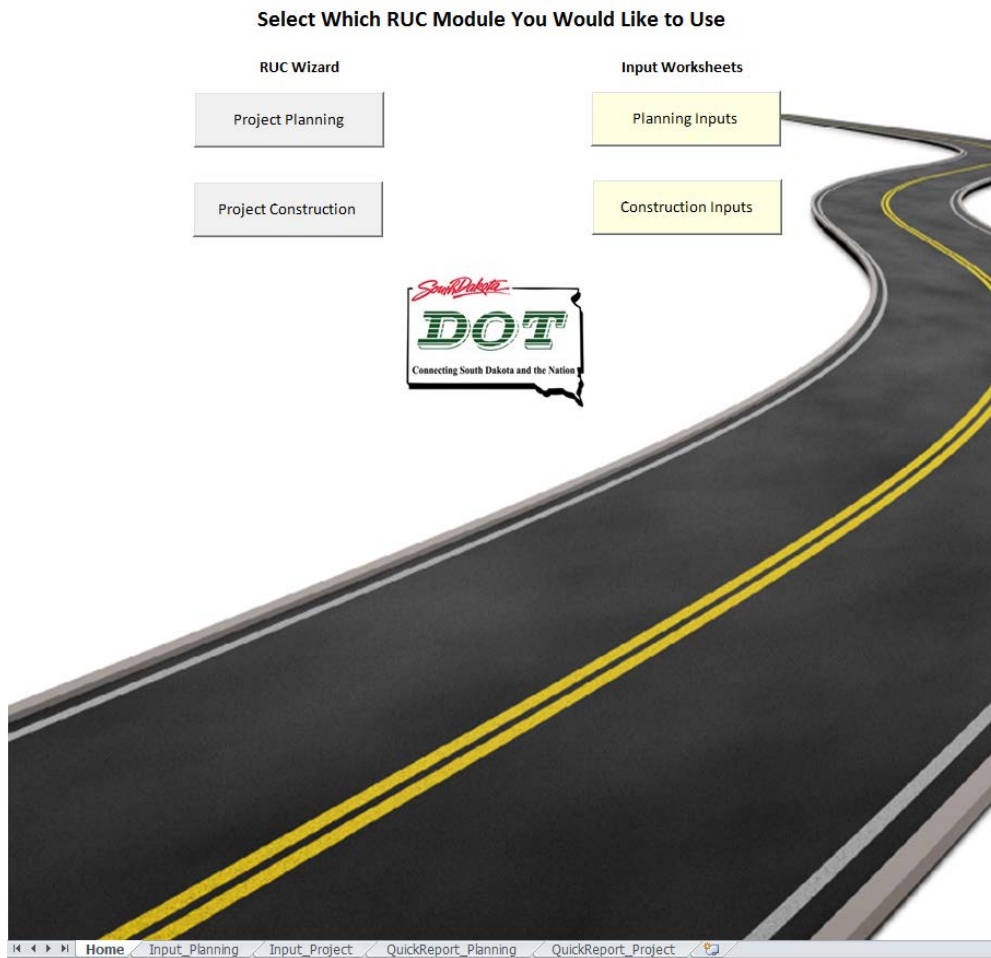


Figure 5.21 Home Screen

5.5.2.1.1 Selecting a Module

On the Home screen are two options for module selection: Project Planning and Project Construction. These modules are designed for use by the analyst of the individual department and should not be misused. The required variable inputs and outputs for each module will result in quite different cost estimates and they should not be cross used. The Project Planning modules result in present value estimations based on yearly RUC while the Project Construction modules result in a daily RUC value.

5.5.2.1.2 Worksheet Tabs

There are tabs available at the bottom of the screen that may be used for navigation of the tool. These tabs will direct you to the Home screen, Project Planning or Project Construction Input worksheets, and to the Project Planning or Project Construction Quick Reports.

Several worksheet tabs have been hidden from view and will be unavailable to all users except the administrator. These worksheets are for the storage of unit cost data and include the unit costs, fuel consumption rates, and speed cycle change tables. These worksheets are password protected and are only made available to the administrator for updating purposes at a time when they have deemed it necessary.

An additional worksheet is provided for logging update information, including the administrator’s name, date the update was applied, and the component(s) updated.

Table 5.31 Function and Display of each Worksheet

Worksheet name	Function	Display
Home	Home screen for selection of module	Visible
Input_Planning	Input page for Project Planning	Visible
Input_Project	Input page for Project Construction	Visible
QuickReport_Planning	Quick Report output for Project Planning	Visible
QuickReport_Project	Quick Report output for Project Construction	Visible
Unit Costs	Unit costs data (VOC, VOT, AC)	Hidden
SCC	Speed cycle change data (VOC)	Hidden
Fuel Consum.	Fuel consumption data (VOC)	Hidden
Update Log	Admin. Log for tracking unit cost updates	Hidden

5.5.2.2 Planning Analysis Module

The Project Planning RUC Wizard will guide the user through the inputting of variables that are relevant for a life cycle cost analysis. A series of dialog boxes will appear requiring information that will be used in the estimation of RUC. Most of the fields, aside from the project information windows, do not accept characters other than numerical values.

1. The first dialog window requests specific project information, including the Project Name, County, and Project Number. This information is used for organizational purposes and the window, or any fields therein, may be skipped if this information is not deemed necessary for the analysis.

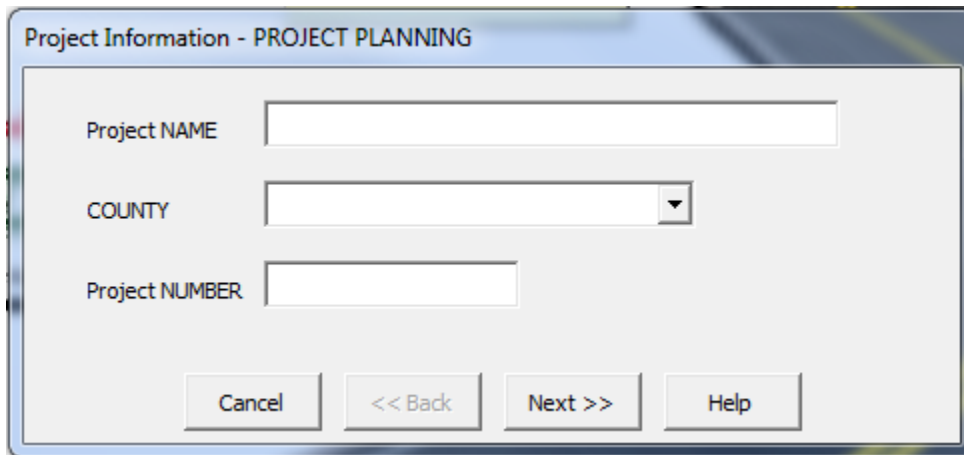


Figure 5.22 Project Information Screen (Project Planning)

2. The second dialog window determines the method of estimation based on the availability of traffic demand data that exist. If MPO travel demand data exist, the user will select the appropriate radio button to indicate the availability of the data and be taken to step 3. If the travel demand data are unavailable, then the user will select the appropriate button and be taken to step 5.

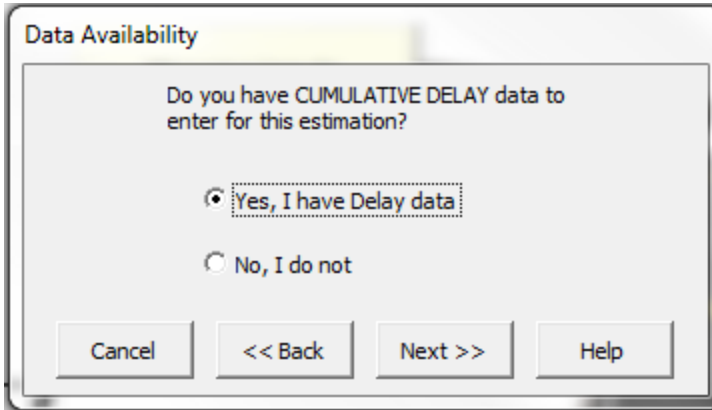


Figure 5.23 Data Availability

3. If data are available from an MPO traffic demand model, the user is directed to input the data for the existing ADT, Percent Trucks, and Cumulative Delay from the model. The user is also required to input the number of Alternatives that they would like to compare against the existing conditions.

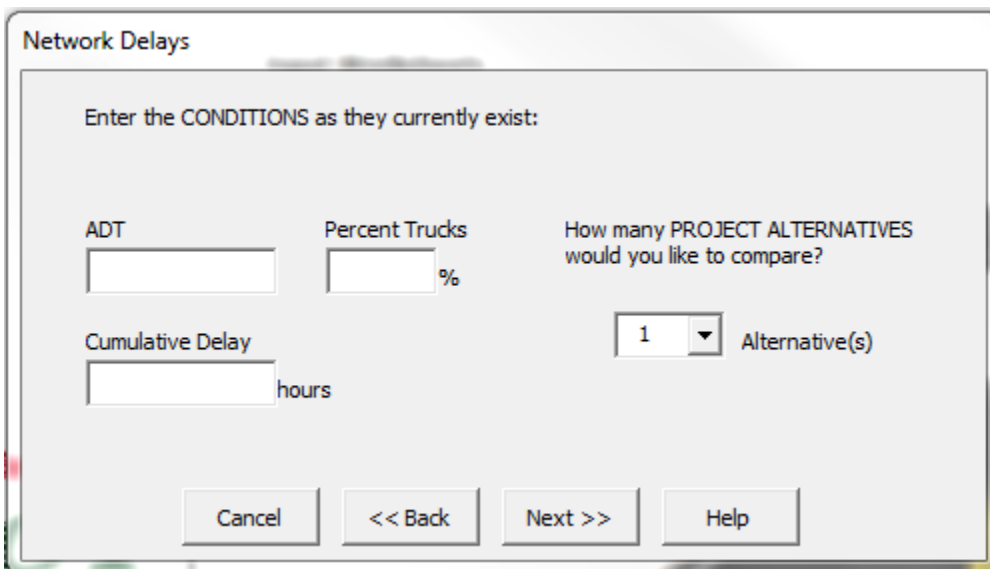


Figure 5.24 Existing Conditions for Network Analysis

4. The next dialog window requires the user to name each Alternative that was selected in the previous step and input the Cumulative Delay information that was provided through the MPO network traffic demand model. After this information has been entered in full, the user will be directed to step 9.

Network Delays

Alternative 1
Enter a NAME for this Alternative: Cumulative DELAY hours

Alternative 2
Enter a NAME for this Alternative: Cumulative DELAY hours

Cancel << Back Next >> Help

Figure 5.25 Alternative Conditions from Network model

5. If data are unavailable from an MPO traffic demand model, the user is directed to input the data for the Existing Conditions. This information includes the ADT of the route, the Percent Trucks that are currently using the route, the Operating Speed Limit of the route (in multiples of 5 mph), the Project Length, and the Accident Rate. The fields for Operating Speed Limit and Accident Rate are provided in drop-down menu form for ease of use. The Operating Speed Limit menu displays a speed range from 5 to 75 mph. The Accident Rate menu displays a compiled list of weighted accident rates for the South Dakota highway system taken from the South Dakota Highway Needs Book. If an accident rate for a specific route section is required, it may be entered directly into the Accident Rate field.

Existing Conditions

Enter the CONDITIONS as they currently exist:

ADT Posted Speed Limit mph

Percent Trucks % Project Length miles

Accident Rate

Cancel << Back Next >> Help

Figure 5.26 Existing Conditions Screen

- The next dialog window requires the user to input the number of Project Alternatives that they would like to compare against the Existing Conditions. There are also input requirements for the Traffic Growth Factor and the Discount Rate. The values of these fields appear as the default rates of 2% and 4% respectively.

Number of Alternatives

Enter the number of ALTERNATIVES you would like to evaluate based on the EXISTING CONDITIONS

How many PROJECT ALTERNATIVES would you like to compare? 1

Traffic GROWTH Factor 2.000 %

DISCOUNT Rate 4.00 %

Cancel << Back Next >> Help

Figure 5.27 Alternative Selection Screen

- The fourth window guides the user through the inputs required for each Alternate Route(s), chosen in step 3 that is being considered against the Existing Conditions input in step 2. The required fields include a Name for the alternative, the number of Segments included in the alternate route, the number of Intersections included in the alternate route, the Life span of the alternative, and accident cost information, which may be a crash modification factor (CMF) or an Accident Rate.

Figure 5.28 Alternate Route Screen

8. The next two windows require the user to input the Posted Speed Limit (in multiples of 5 mph) and Length of any segments that are being considered in the alternate route, along with the intersection information along the route, including the presence of Signalization, the Level of Service (LOS) of that intersection, and the ADT through the intersection. These windows will repeat until the number of alternatives selected in step 3 is reached.

The image shows two overlapping windows titled "Alternative Routes". The top window displays data for two segments:

Segment	Speed	Length
1:	45 mph	miles
2:	45 mph	miles

The bottom window displays data for two intersections:

Intersection	Signalization	LOS	ADT
1:	<input checked="" type="radio"/> Yes <input type="radio"/> No	A	543
2:	<input checked="" type="radio"/> Yes <input type="radio"/> No	A	543

Both windows include a header "ALTERNATIVE 1 of 1" and a footer with buttons: Cancel, << Back, Next >>, and Help.

Figure 5.29 Alternate Route Screen for Segments/Intersections

9. When all required data have been entered, the Application will direct the user to the input worksheet to review the inputs and make any changes that may be necessary. When the user is satisfied with the inputs, he or she may hit the Calculate button, which constructs an estimate from the variables present.

Once the values have been calculated, the user may select the Quick Report button, which directs the user to choose three or fewer alternatives for comparison that will be included in the Quick Report. Once the selections have been made, the user must press the Generate button to produce a Quick Report. Quick Reports may be printed using the Print button or saved to an external file using the Save button.

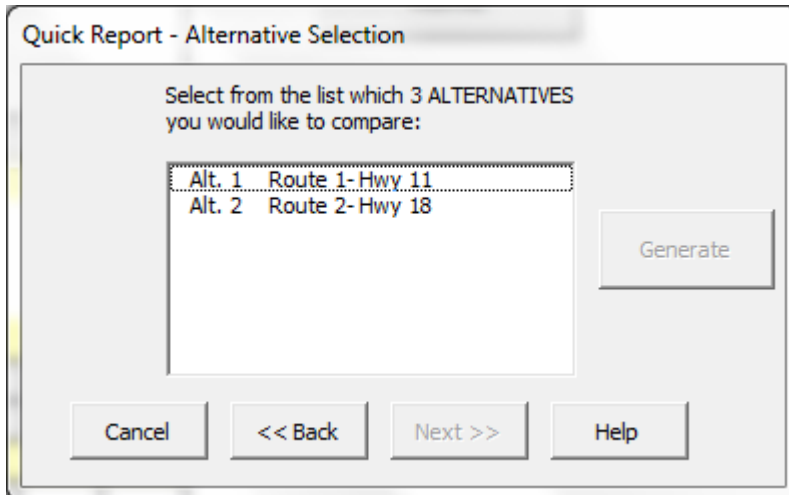


Figure 5.30 Project Planning Quick Report Alternatives Screen

5.5.2.3 Project Construction Analysis Module

The Project Construction RUC Wizard will guide the user through the inputting of variables that are relevant for a work zone analysis. A series of dialog boxes will appear requiring information that will be used in the estimation of RUC. Most of the fields, aside from the project information windows, do not accept characters other than numerical values.

1. The first dialog window requests specific project information including the Project Name, County, and Project Number. This information is used for organizational purposes and the window may be skipped if this information is not deemed necessary for the analysis.

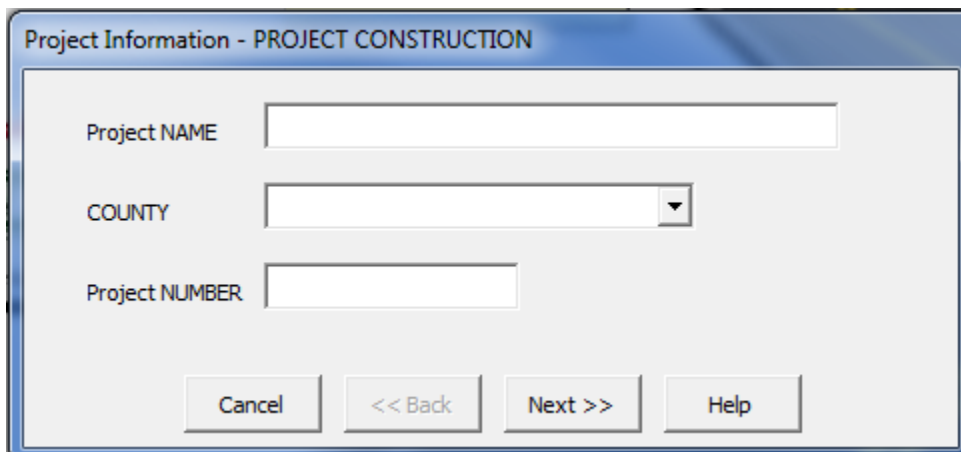


Figure 5.31 Project Information Screen (Project)

2. The second dialog window requests information for the number of Construction Phases that the user would like to evaluate. The evaluation of Construction Phases is limited to 10 or fewer.

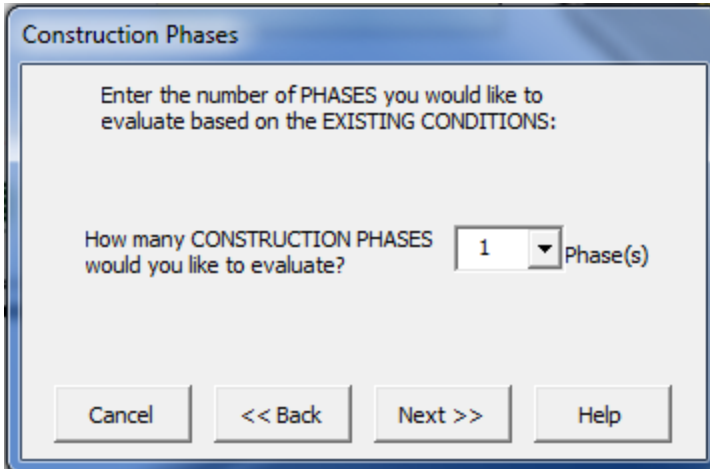


Figure 5.32 Phase Selection Screen

3. The third window guides the user through the inputs required for each Construction Phase, chosen in step 2 that is being considered. The required fields include a Name for the phase and the conditions as they currently exist. This Existing Condition information for each phase includes the ADT of the route, the Percent Trucks that are currently using the route, the Posted Speed Limit of the route (in multiples of 5 mph), the Project Length, and the Accident Rate. The fields for Posted Speed Limit and Accident Rate are provided in drop-down menu form for ease of use. The Posted Speed Limit menu displays a speed range from 5 to 75 mph. The Accident Rate menu displays a compiled list of weighted accident rates for the South Dakota highway system taken from the South Dakota Highway Needs Book. If an accident rate for a specific route section is required, it may be input directly into the Accident Rate field.

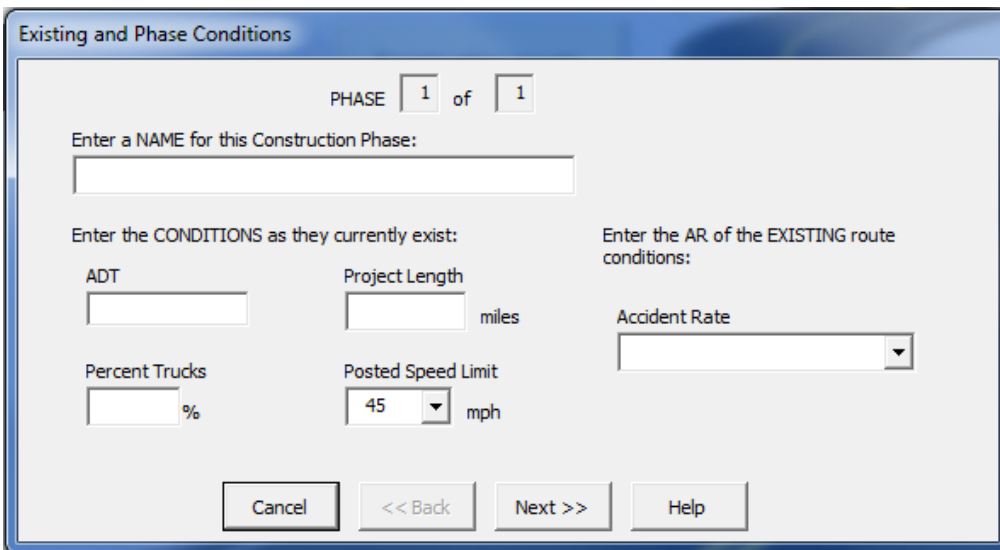


Figure 5.33 Phase Conditions Screen for Existing Conditions

4. The next window requires information for the Work Zone conditions. This includes the reduced Posted Speed Limit through the work zone, the number of Segments included in a detour (select 0 if no detour will be used), the Percentage of vehicles expected to use the detour, the Duration of the project, and the crash modification factor (CMF) of the construction project.

Existing and Phase Conditions

PHASE 1 of 1

Enter the WZ PHASE CONDITIONS:

Enter the reduced SPEED LIMIT through the Work Zone: 25 mph

DURATION of this Project Phase: 1 days

Enter the SEGMENTS included in this Detour Route: 1

Enter the CMF of this Project Phase:

Enter the PERCENTAGE of vehicles expected to use the DETOUR: 50 %

CMF: 1

Cancel << Back Next >> Help

Figure 5.34 Phase Conditions Screen for WZ Conditions

- The following window will require the input of detour segment information, including the Posted Speed Limit (in multiples of 5 mph) and length of any Segments that are being considered in this construction phase. These windows will repeat until the number of alternatives selected in step 3 is reached.

Existing and Phase Conditions

PHASE 1 of 1

Segment	Speed	Length
1:	25 mph	miles

Cancel << Back Next >> Help

Figure 5.35 Phase Conditions Screen for Segments

- When the total number of Construction Phase(s) is reached the Application will direct the user to the Input worksheet to review the inputs and make any changes that may be necessary. When the user is satisfied with the inputs, he or she may hit the Calculate button, which constructs an estimate from the variables present.

Once the values have been calculated, the user may select the Quick Report button, which directs the user to choose five phases for comparison that will be included in the Quick Report. Once the selections have been made, the user must press the Generate button to produce a Quick Report. Quick Reports may be printed using the Print button or saved to an external file using the Save button.

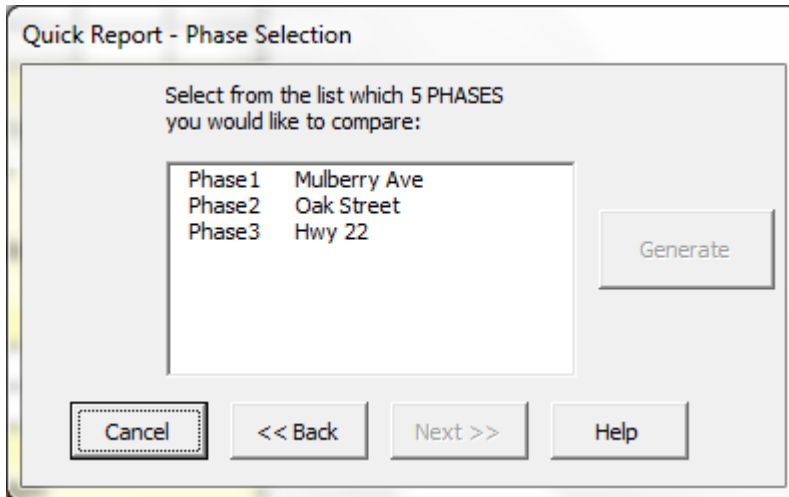


Figure 5.36 Project Construction Quick Report Phase Selection Screen

5.5.2.4 Using the Input Worksheets

The Input worksheets are provided for experienced users who wish to input the variables directly into the spreadsheet instead of using the RUC Wizard. The Input worksheets may be accessed from the home screen using the Input Worksheet button for the module of the analysis method being considered or using the tabs located at the bottom of the screen. Accessing the input worksheets through the home screen button will erase all data stored within the fields on these pages.

5.5.2.4.1 Project Planning Analysis

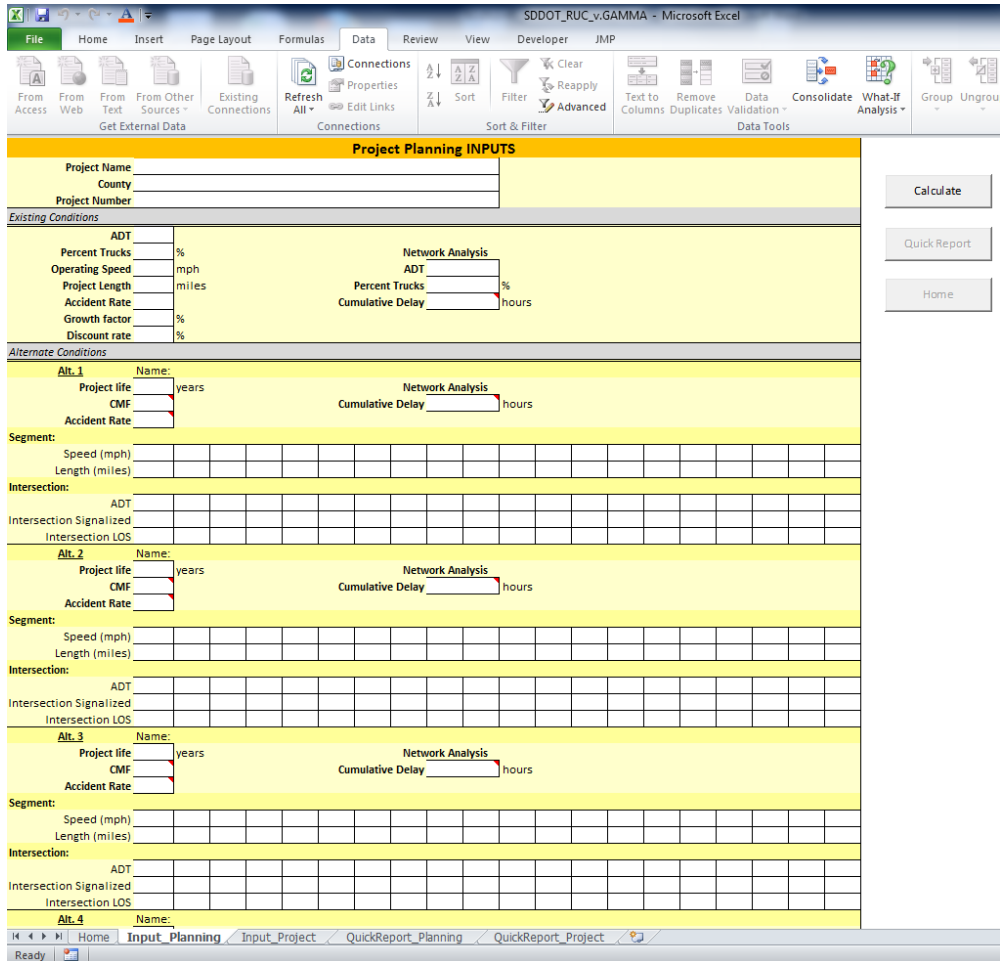


Figure 5.37 Project Planning Input Screen

The Project Planning Input worksheet provides the user with fields for inputting any variables required for a complete analysis of the project. These input fields prompt the user with input requirements and are data validated to only accept specific numerical characters and ranges.

The Project Planning Input worksheet provides the user with fields for project identification, including Project Name, County, and Project Number. These three fields may be entered with any variety of alphanumeric characters that may be necessary for identification purposes.

The Existing Conditions require ADT, Percent Trucks, Operating Speed, Project Length, Accident Rate, Growth Factor, and a Discount Rate. The operating speed may be selected from a drop-down menu for ease of input. These variables represent the base case scenario, and it is important to note that all these variables must be entered to assure that the estimation outputs are accurate.

The following fields pertain to the Alternatives and include fields for an Alternative Name, the Project life, CMF or Accident Rate (it is important to note that only a CMF or Accident Rate may be entered here, never both), information relating to the segments that include the Speed and Length, and information relating to the intersections that include the ADT, Intersection Signalization, and the

Intersection LOS. There are a total of 10 Alternative Condition fields available for analysis with placeholders for 20 segments or intersections.

Once all variables have been input, the user hits the Calculate button, which constructs an estimate from the variables present. Once the values have been calculated, the user may select the Quick Report button, which directs the user to choose three alternatives for comparison that will be included in the Quick Report. Once the selections have been made, the user must press the Generate button to produce a Quick Report. Quick Reports may be printed using the Print button or saved to an external file using the Save button.

5.5.4.2.2 Project Construction Analysis

The screenshot displays the 'Project Construction INPUTS' worksheet in Microsoft Excel. The worksheet is organized into sections for project identification and four construction phases. The 'Project Identification' section includes fields for Project Name, County, and Project Number. Each of the four phases (Phase 1 through Phase 4) contains a set of input fields: Name, ADT, Percent Trucks, Operating Speed, Project Length, Accident Rate, Work Zone Speed, Detour Percentage, CMF, and Project Duration. Below each phase is a 'Detour Segment' section with Speed (mph) and Length (miles) fields. To the right of the worksheet, there are three buttons: 'Calculate', 'Quick Report', and 'Home'. The Excel interface shows the Data tab selected in the ribbon.

Figure 5.38 Project Construction Input Screen

The Project Construction Input worksheet provides the user with fields for inputting any variables required for a complete analysis of the project. These input fields prompt the user with input requirements and are data validated to only accept specific numerical characters and ranges.

The Project Construction Input worksheet provides the user with fields for project identification, including Project Name, County, and Project Number. These three fields may be input with any variety of alphanumeric characters that may be necessary for identification purposes.

The Work Zone Conditions has fields for each phase name and requires information for the existing conditions of each phase, including ADT, Percent Trucks, Operating Speed, Project Length, and Accident Rate. There are also required fields for the Work Zone Speed Limit, Detour Percentage, CMF, and Project

Duration. Information for the detour segments includes the Speed and Length. The posted speed may be selected from a drop-down menu for ease of input. There are a total of 10 Work Zone Phase fields available for analysis with placeholders for 10 detour segments.

Once all variables have been input, the user hits the Calculate button, which constructs an estimate from the variables present. Once the values have been calculated, the user may select the Quick Report button, which directs the user to choose five phases for comparison that will be included in the Quick Report. Once the selections have been made, the user must press the Generate button to produce a Quick Report. Quick Reports may be printed using the Print button or saved to an external file using the Save button.

5.5.3 RUC Data Preparation

This section addresses the collection and preparation of data that are required for an analysis. The data requirements are detailed below for project planning and project construction.

5.5.3.1 Project Planning Data Inputs

The required data for a project planning analysis depend on the availability of data from a traffic demand model. If the project is within an MPO, they can provide a traffic demand model that may be used in the analysis of the network with and without the addition/subtraction of a route.

The data necessary for a network analysis include, existing condition:

- ADT
- Percent Trucks
- Cumulative Delay

And alternative condition:

- Cumulative Delay

If user cost estimation is desired and traffic demand models are unavailable, the following data are required for the existing condition:

- ADT
- Percent Trucks
- Operating Speed
- Project Length
- Accident Rate
- Growth Factor
- Discount Rate

And alternative condition:

- Project Life
- CMF or Accident Rate
- Segment Data
 - Speed
 - Length
- Intersection Data

- ADT
- Presence of Signalization
- Level of Service

5.5.3.2 Project Construction Data Inputs

The required data for a Project Construction analysis include values for each construction phase, including:

- ADT
- Percent Trucks
- Operating Speed
- Project Length
- Accident Rate
- Work Zone Speed
- Traffic Detour Percentage
- CMF
- Project Duration
- Detour Segment Data
 - Speed
 - Length

5.5.4 Default Values, Limitations and Updating Procedures

This section provides a reference for any default values, limitations within the range of values allowed, and the procedures to follow when updating unit cost data.

5.5.4.1 Default Values

Within the RUC estimation Application tool there are several value limitations given to certain variables as well as default values that are given upon initialization. The default values that are universally set in both modules include the speed limit of 35 mph for any Posted Speed fields. Other default values can be seen in Table 5.32.

Table 5.32 Default Values

Project Planning		
Operating Speed	45	mph
Project Alternatives	1	
Growth Factor	2	%
Discount Rate	4	%
Project Life	1	year
CMF	1	
Segments	3	
Intersections	0	
Intersection ADT	existing ADT	

Project Construction		
Operating Speed	45	mph
Project Phases	1	
Reduced Work Zone Speed	25	mph
Detour Percentage	50	%
Detour Segments	1	
Project Duration	1	day
CMF	1	

5.5.4.2 Value Limitations

Value limitations and data validation that have been set within the application have been done so to reduce the chances for user error. These limitations were selected with ranges that ensure most any estimation performed in the state will be possible while limiting the probability of user input errors. Any value limitations found within the RUC Tool can be seen in Table 5.33.

Table 5.33 Limitation of Values

Project Planning		
ADT	0	250000
Operating Speed	0	75 <i>multiples of 5</i>
Project/Segment Length	0	50000
Project Alternatives	1	10
Growth Factor	0	99
Discount Rate	0	500
Project Life	0	100 years
CMF	0	20
Accident Rate	0	200
Segments	1	20
Intersections	0	20
Intersection ADT	0	250000

Project Construction		
ADT	0	250000
Operating Speed	0	75 <i>multiples of 5</i>
Project/ Segment Length	0	50000
Project Phases	1	10
Project Duration	0	1000 days
CMF	0	20
Accident Rate	0	200
Detour Segments	0	10

5.5.4.3 Update Procedures

Procedures for updating apply to the administrator only and must be done in a way in which the updates are applied to all copies of the RUC Tool that are to be used in future estimations. Failure to apply updates consistently will result in estimations that do not use the most recent unit cost data and may result in estimations that undervalue the current user costs. An update log is supplied with the RUC Tool in which all updates should be documented by the administrator at the time they are applied.

The worksheets for Unit Costs, SCC, Fuel Consumption, and the Update Log are hidden and password protected. Sources for unit cost data and the procedure for updating each component of unit costs are outlined on each of these worksheets. A timeline depicting known update frequency can be seen in Figure 5.39 and the availability of update data for each unit cost component can be seen in Table 5.34.

Hyperlinks are provided in Table 5.34 and within the RUC Tool worksheet for Unit Costs, which provide a convenient path to each source. However, it should be noted that over time these links may become disconnected and the administrator may need to locate the source tables directly.

Recommended procedure for updating unit cost data is to review the update log periodically and make updates annually at a minimum. When updates are determined to be necessary, the administrator must first unhide the unit cost worksheets. The procedure to unhide a worksheet is to select the **Home** tab, click on **Format** in the **Cells** group and then under **Visibility**, select **Hide & Unhide**, then **Unhide Sheet**. To unlock the worksheet select the **Review** tab from the menu, select **Unprotect Sheet** from the **Changes**

group, then input the password. The specific method for updating the Unit Cost, SCC, and Fuel Consumption worksheets are documented within each worksheet along with any relevant source data, including hyperlinks and availability of updates. The administrator should log the components that were updated in the Update Log, including the name of the administrator performing the update and the date that the update was applied. When all updates have been applied, the administrator must lock the worksheets by selecting the **Review** tab from the menu, select **Protect Sheet** from the **Changes** group, and then input the password. This ensures that these values remain unaltered by other users.

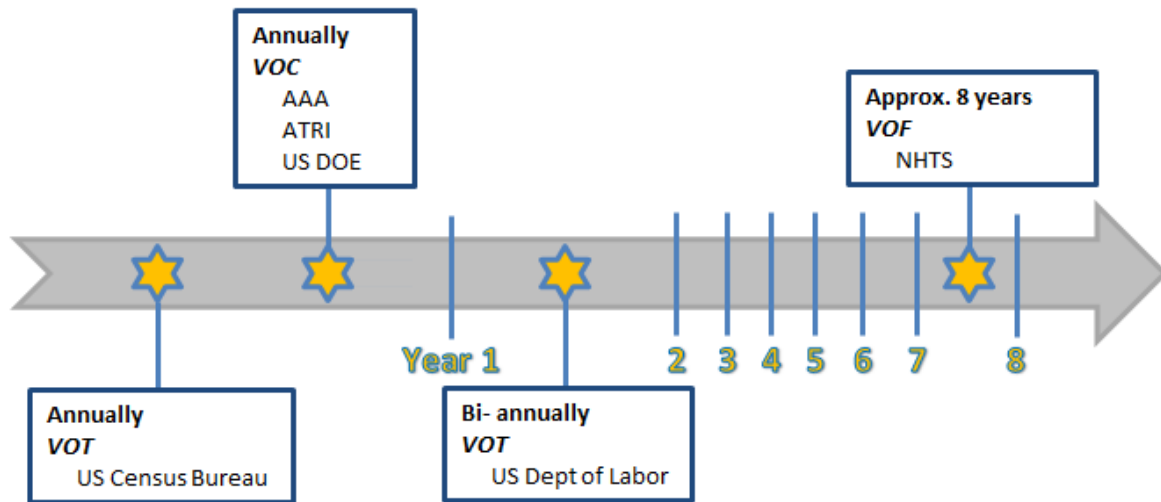


Figure 5.39 Timeline of Update Source Availability

Table 5.34 Update Sources and Availability

VOT	
<i>Auto</i>	<p>US Census Bureau -State and County Quick Facts <i>Per capita money income in past 12 months</i> http://quickfacts.census.gov/qfd/states/46000.html convert to cost per minute: $(1/52)*(1/40)*(1/60)$ Availability: Annually</p>
<i>Truck</i>	<p>US Dept. of Labor- Wage and Hour Divisions for SD SDDOT -Defined Work Classification and Wage Requirements <i>TRUCK DRIVERS Group GT2</i> convert to cost per minute: (1/60) http://sddot.com/business/contractors/docs/USDOLDBAWageDecision.pdf Availability: Bi-annually</p>
VOC	
<i>Auto</i>	<p>AAA -Your Driving Costs <i>Composite Average for 15,000 miles</i> http://exchange.aaa.com/automobiles-travel/automobiles/gas-pricing Availability: Annually</p>
<i>Truck</i>	<p>ATRI -Operational Costs of Trucking <i>Average Carrier Costs per Mile</i> http://atri-online.org/atri-research/economic-analysis Availability: Annually</p>
<i>Fuel Prices</i>	<p>US DOE -Annual Energy Review <i>Retail Motor Gasoline and On-Highway Diesel Fuel Prices -US City Average</i> http://www.eia.gov/petroleum/data.cfm#prices Availability: Annually</p>
<i>Intersection Delay</i>	<p>Highway Capacity Manual 2010 <i>LOS Criteria for Intersections</i></p>
<i>Fuel Consumption</i>	<p>AASHTO Redbook -User and Non-user Benefit Analysis for Highways Table 5.5</p>
<i>Speed Change Cycle</i>	<p>Bureau of Labor Statistics - Consumer Price index <i>US City Average - All Items</i> http://www.bls.gov/cpi multiply by ratio of appropriate CPI</p>
Accident Costs	
	<p>Highway Safety Manual 1st Edition, Table 7-1 <i>Societal Cost Estimates by Crash Severity - PDO</i></p>
VOF	
	<p>National Household Travel Survey - Summary of Travel Trends <i>Average Vehicle Occupancy by Trip Purpose</i> <i>All Purposes</i> http://nhts.ornl.gov/2009/pub/stt.pdf Availability: periodically, approx. 8 years, last publication 2009</p>

6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The South Dakota Department of Transportation (SDDOT) uses road user costs (RUC) to calculate incentive or disincentive compensation for contractors, quantify project-specific liquidated damages, select the ideal sequencing of a project, and forecast the long-term effects new construction will have on the traveling public. The currently used road user cost calculations were initially set by the research project SD1995-07, *Criteria and Guidelines for Innovative Contracting*, in 1996 and have undergone little updating aside from unit cost values. Since the last research project, the two offices that depend on road user costs have updated these values to keep up with inflation, but have done so independently. Currently, they use different worksheets with similar fields, but the values used to calculate road user costs are substantially different.

Maintaining the most up-to-date RUC is extremely important to SDDOT, as underestimation of road user costs results in increased costs to the traveling public, while overestimation results in SDDOT overpaying on incentives for early completion of construction projects. Obtaining proper RUC also helps to justify the deployment of new technologies that can accelerate the construction process for pavement and bridges. Calculated RUC in South Dakota are currently much lower than those of surrounding states, in part due to infrequent updates. As a result, construction projects within the state may be given less priority during construction by the contractor compared with surrounding states with greater incentive/disincentive values.

Following a comprehensive review of the state-of-the-practice RUC methodologies, this research aims to update the current RUC methodology and unit costs used by SDDOT and deliver a worksheet tool that can evolve over time to adjust for changing user costs and facilitate future RUC estimations. A user manual to accompany the worksheet will provide users with instructions on using the tool as well as procedures on how and when to update the unit cost values to ensure that RUC estimations remain consistent in all offices.

The monetary impacts to road users due to new construction, reconstruction, rehabilitation, restoration, resurfacing, and other miscellaneous highway maintenance activities directly affect project development and can be estimated through the vehicle operating costs (VOC), value of road users' time (VOT), accident costs (AC), vehicle emission costs, and others. The literature review indicates a variety of methods applied at state DOTs as well as recommended by FHWA and in the AASHTO Redbook. Results of a survey sent to surrounding state DOTs revealed the similarities and differences between each agency's approaches to RUC. While most responding agencies use simplified calculations and spreadsheets, the components included in these calculations as well as the sources used for unit cost are diverse. The available frequencies of updating unit costs are dependent on the selected source. Most agencies have selected AASHTO or FHWA recommended sources, while others rely on local data to determine unit costs. Based on the extensive review of the state-of-the-practice RUC methodologies, AASHTO and FHWA guidelines, solicited expectations from SDDOT, as well as the feedback from other state DOTs in the region, the current SDDOT RUC procedures have been modified and improved to provide a more accurate and reliable RUC estimation under various planning and project construction situations.

The evaluation of the proposed methodology involved a sensitivity analysis and case studies. The sensitivity analysis determined the contribution that variations to each significant variable will have on the overall RUC estimation. Case studies were conducted to evaluate and compare the current methodology used by SDDOT with the changes recommended in this study.

The proposed methodology was implemented in a Microsoft Excel-based worksheet that allows users to calculate the RUC for design alternatives for both planning and project construction to maximize its application to SDDOT. The tool uses the proven methodology for calculating RUC in this study and was designed to provide secured and convenient access for users. The built-in safety measures allow for the administrator to regularly update the values of RUC parameters using reliable sources in a controlled manner, which maintains consistent use of unit cost values in all estimations of RUC.

6.2 Conclusions

Based on the results of the analytical studies covered in this report, the following conclusions can be drawn.

6.2.1 Project Planning

1. RUC analysis for project planning includes the addition or removal of routes to a network.
2. New methodology was proposed to include accident costs in future calculations
3. Sources of unit costs were reevaluated and updated
4. VOT unit costs include the wage rates for South Dakota workers
5. VOC unit costs include operating and ownership costs
6. AC unit costs use the property damage equivalent weighted accident rates calculated for South Dakota and the recommended PDO value from AASHTO

6.2.2 Project Construction

1. RUC analysis for project construction includes the work zone and any detour conditions due to the work zone
2. New methodology was proposed that made changes to VOT and VOC and includes AC in future calculations
3. Source of unit costs were reevaluated and updated
4. VOT unit costs include the wage rates for South Dakota workers
5. VOC unit costs are dependent on components for the cost of vehicle to slow to construction speeds and accelerate to operating speeds, fuel consumption costs, and the price of fuel
6. AC unit costs use the property damage equivalent weighted accident rates calculated for South Dakota and the recommended PDO value from AASHTO

6.3 Implementation and Recommendations

In this study, the current RUC methodology and associated unit costs were evaluated. Changes were implemented to the methodology to allow for a more complete analysis that aligns with the needs of each department and their use of RUC. The methodology was used to construct a worksheet that allows users to calculate the RUC for both stages of project planning and development in which it is currently being calculated for.

Based on the results of this research effort, the following recommendations can be made.

1. The South Dakota Department of Transportation implements the new worksheet in any future RUC estimation practices when appropriate. The RUC worksheet tool is designed for the office of Project Development to estimate the changes to user costs for the purpose of establishing

incentive or disincentive compensation for contractors, quantify project-specific liquidated damages, select the ideal sequencing of a project, and forecast the long-term effects new construction will have on the traveling public.

2. It is recommended that SDDOT designate an administrator to preside over the unit cost updates within the worksheet to ensure that all calculations done at SDDOT use consistent unit cost figures. The unit cost sources that have been identified and recommended for use have been provided in the RUC User Manual along with the dates when the updates become available. An update log is provided within the RUC worksheet tool for the administrator to record and track the date unit cost updates were applied.

Future research may be warranted to increase the precision of RUC calculations. Increased traffic volumes due to population growth and the subsequent traffic congestion demand more complex estimations and more accurate estimations of hourly vehicle demand and capacity to account for work zone delay and vehicle emissions. In the future, it may be necessary to review the RUC methods recommended here to determine if all project development needs are being met.

Recommendations to improve upon future RUC calculations include the following.

1. Vehicle efficiency rates may be constructed based on modern vehicle technology for the consumption of fuel, oil, tires, etc. to allow for the most accurate possible rates. The rates of consumption that form the basis for many vehicle operating cost models have not been sufficiently reexamined since original research set these values.
2. Accurate traffic volume, especially diverting traffic, may be estimated using travel demand forecasting models or other methodologies. Furthermore, more precise maximum capacity estimations based on work zone operations and configurations specific to South Dakota will enhance RUC estimations.
3. Crash unit cost by injury severity should be more consistent with FHWA criteria. Aligning SDDOT weighted accident rates with the FHWA weighted rates will ensure that South Dakota maintains crash costs that are compatible with the national standards. This issue should be reviewed and a determination should be made at the department level to change these rates.
4. Work zone crash rates and CMFs can be estimated using South Dakota work zone crash data. By formulating crash rates and CMFs specific to work zones in South Dakota, the statistically acceptable CMF values for the state will be provided and the accuracy of estimates will be increased.

7. RESEARCH BENEFITS

The research project satisfies the FHWA strategic outcomes of 1) state of good repair; 2) safety, and 3) economic competitiveness. Incorporating road user cost into the road project decision-making process will ensure that SDDOT proactively maintains its critical transportation infrastructure in a state of good repair without compromising traveler safety and costs. It helps to develop win-win strategies for both road users and road managers, and it helps to maximize economic returns on South Dakota transportation investment from a system perspective.

The potential benefits presented by this research include significant cost savings by balancing construction costs with existing costs of delay to travelers and freight. These savings are dependent on the rate of construction in a given season and are difficult to quantify. Additional benefits include ensuring that RUC methodologies and unit costs are consistent with the practices used in nearby agencies, which ensures that contractor incentives/disincentives remain competitive, giving increased motivation for contractors to finish road projects within South Dakota borders in a timely manner.

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APPENDIX A: SDDOT SURVEY

Review and Development of Road User Costs (RUC) and Methods



Project SD 2011-05

Task 3: Survey

Please provide us with the following contact information:

Name: _____
Title: _____
Division: _____
Department: _____
Phone: _____
Address: _____
E-mail: _____

Please answer all questions as completely as possible. If a question does not apply to you, or your department, you may leave it blank.

Section 1: general questions

- 1) Does SDDOT include RUC in the *Planning* or *Project Selection* stage?
 - *Planning* is for project alternative selection using LCCA, BCA, or other economic analysis techniques under a multi-year timeframe.
 - *Project Development* is primarily for designing work zone staging, phasing, timing, and determining project delivery methods.

- 2) Does SDDOT use the current RUC method in every project or does it use any criteria to determine when applicable? For example, the scale and scope of project or project type: new construction, reconstruction, 3R (restoration, rehabilitation, resurfacing), and maintenance.

- 3) What do you consider the most critical factors in addressing the RUC method? Please rank the boxes in order of importance. (Rank with 1 being the most critical)
 - Vehicle Operating Cost
 - Value of Time

- Accident Costs
- Vehicle Emissions
- Local Impacts
- Other: _____

4) Did the DOT implement any changes to the RUC procedure recommended by Trauner Consulting Services (TCS) in report SD Study 95_07 “*Criteria and Guidelines for Innovative Contracting*”?

- Accident Costs
- Vehicle Occupancy Factor
- Vehicle Operating Costs due to speed changes
- None
- Other: _____

5) For work zone project development, what contracting method is most utilized:

- Incentive and Disincentive (I/D)* -provisions for Early Completion are provisions which compensate the Contractor a daily amount for completing the work ahead of the I/D completion date or assess a daily amount for finishing later than the I/D completion date.
- A+B bidding* -a cost-plus-time bidding procedure, selects the low bidder based on a monetary combination of the Contract bid items (A) and the time (B) needed to complete the project or a critical portion of the project.
- Lane Rental* -provisions assess the Contractor daily or hourly rental fees for each lane, shoulder, or combination of lanes and shoulders taken out-of-service during a project to minimize the time that roadway restrictions impact traffic flow.
- Others* _____

6) For your answer to question 5, based on what criteria are the contracting methods chosen?

Section 2: objectives for RUC

- 7) Is the focus of the state RUC needs on rural highways or urban freeway and interstates?
- 8) Do urban construction projects currently require an hourly value for lane closures, i.e. lane rentals? If not, is that something that will be utilized in the future?
- 9) Do you consider *Vehicle Emissions* to be a critical issue on SD roadways?
- 10) Do you consider *Accident Costs* to be a critical issue in SD work zones?

Section 3: methodologies (policies, processes, and procedures)

11) What methods are used to estimate traffic demand for a project area?

12) What method(s) are currently being used to estimate WZ capacity? (multiple choice)

- HCM based
- Field experience, engineering judgment
- Regression models
- None
- Other: _____

If it varies by work zone type or application, please specify:

13) What formula/software tool(s) are currently being used to estimate WZ capacity? (multiple choice)

- QUEWZ
- QuickZone
- CA4PRS
- VISSIM
- None
- Other: _____

If it varies by work zone type or application, please specify:

Section 4: data requirements

14) Is any hourly traffic demand data available for the state road network or is only ADT available?

15) Is peak hour demand data or hourly traffic demand data available for use in urban RUC calculations?

16) Is the percentage of truck volume for the state road network available?

17) Is information regarding WZ location, configuration, traffic control strategy, number of work days, work activity time of day and detour information available?

18) Is state work zone crash rate(s) information available?

19) Does your office currently maintain any unit cost related data, i.e. unit crash costs by injury severity, unit cost of personal/business/freight travel?

Section 5: data storage and updates

20) What resources are currently used to update unit cost data?

21) How often is unit cost data updated?

22) Who is responsible for updating unit cost information?

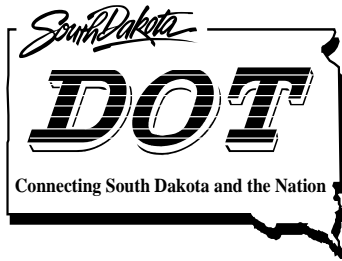
23) Do you currently have a centralized location to log data (RUC relevant data and calculations), such as traffic demand or vehicular crashes, and to allow for a periodic update?

24) If you need data from other data sources to calculate or estimate RUC, what method is currently being used to exchange files or data amongst the different departments?

Thank you.

The sharing of your time and knowledge is greatly appreciated!

APPENDIX B: REGIONAL DOT SURVEY



Department of Transportation
Division of Planning & Engineering
Office of Research
700 E Broadway Avenue
Pierre, South Dakota 57501-2586
605.773.3292 FAX: 605.773.4713

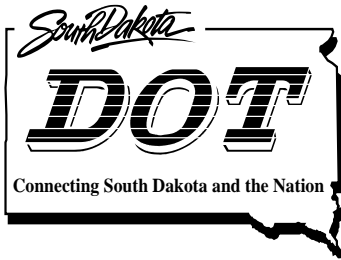
Dear Recipient:

South Dakota State University (SDSU) is conducting research to review and evaluate the current Road User Cost (RUC) methods employed by the South Dakota Department of Transportation. As part of this research effort, we are distributing a short survey of questions to surrounding state DOTs to collect information regarding the current RUC methods used in work zone and planning calculations.

The enclosed questionnaire is intended to be completed by DOT personnel who make use of RUC in either planning estimations or operational work zone calculations. We would appreciate if you assisted us in forwarding this to the relevant parties within the respective departments. It would be appreciated if you can respond to the survey before October 21, 2012 via mail or email to Dr. Xiao Qin at SDSU. If you have any questions, please feel free to contact Dr. Qin at (605) 688-6355, xiao.qin@sdstate.edu or Mr. Aaron Breyfogle at (605) 773-3871, aaron.breyfogle@state.sd.us.

Thank you for your cooperation,

Xiao (Shaw) Qin (Chin), Ph.D., PE
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Brookings, SD 57007
Phone: (605)6886355
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Pierre, South Dakota 57501-2586

605.773.3292 FAX: 605.773.4713

Review and Development of Road User Costs (RUC) and Methods Project SD 2011-05

Please provide us with the following contact information:

Name: _____

Title: _____

Division: _____

Department: _____

Phone: _____

Address: _____

E-mail: _____

Please answer all questions as completely as possible. If a question does not apply to you, or your department, you may leave it blank.

1) Are different RUC methods used for *Planning* and *Project Development*? If the answer is yes, please indicate which you are responsible for. If RUC is being utilized in other ways, please list and explain in "Other".

Planning is for project alternative selection using LCCA, BCA, or other economic analysis techniques using a multi-year timeframe.

Project Development is primarily for designing work zone staging, phasing, timing, and determining project delivery methods.

Both

Other: _____

2) Are districts within the state using a standardized technique for RUC?

3) What criteria do you use to establish the need for conducting RUC analysis?

4) What components are considered in your RUC calculation? (check all that apply)

- Value of Time
- Vehicle Operating Costs
- Accident Costs
- Emissions Costs
- Impacts to Local Business
- Other: _____

5) How do you estimate the Road User Costs at work zones? (check all that apply)

- A) Software
- B) Spreadsheet(s)
- C) Hand Calculations
- D) Other: _____

If you answered with 'A', what tools/software are you currently using to estimate RUC? Please list: e.g. QuickZone, QUEWZ, etc.

If you answered with 'B', can you share with us the spreadsheet information, including data input requirements and any equations used?

6) What methods/resources are used to update unit cost data and at what frequency?

COMPONENT	UPDATING METHOD/RESOURCE	FREQUENCY OF UPDATE
Vehicle Operating Costs		
Value of Time		
Accident Costs		
Vehicle Emissions		
Business Impacts		
Other: _____		

7) If there is anything you feel is lacking in your current RUC method, please specify:

The sharing of your time and knowledge is greatly appreciated!