Development of a Statewide User Cost Manual for Rural Work Zones

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LIST OF ACRONYMS

ADT	Average Daily Traffic
AC	Accident Cost
AASHTO	American Association of State Highway and Transportation Officials
FHWA	Federal Highway Administration
NJDOT	New Jersey Department of Transportation
QZ	Quick Zone
RUC	Road User Cost
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
UTL	Utah Traffic Lab
UDOT	Utah Department of Transportation
VOC	Vehicle Operating Cost
VOT	Value of Time
VDOT	Virginia Department of Transportation
WFRC	Wasatch Front Regional Council

EXECUTIVE SUMMARY

Over recent years, the number of reconstruction and rehabilitation projects has increased significantly due to increased travel demand and a need for maintaining highway infrastructures. With the increased road rehabilitation projects, reducing congestion and delay caused by work zones and improving mobility is more important than ever. Work zones are costly in the actual construction and user delay. Today, highway agencies quantify work zone related costs and investigate methods to reduce them, which is critical to successful work zone management. The Utah Department of Transportation (UDOT) has planned to develop a Statewide Road User Cost manual for work zones. Under current procedures, UDOT engineers construct a new cost estimation method each time a contracting clause is required. This practice devours skilled employees' time and leads to inconsistent results. A standardized method would enable personnel of varying skill levels to calculate appropriate user cost amounts quickly and consistently, saving the department both time and money. This would enable UDOT to quickly and efficiently determine the cost effectiveness of various alternatives including detours, temporary roadway or shoulder construction and off-peak hour day work.

The goal of this study is to develop the framework of the statewide road user cost manual for UDOT. This report documents the research underway at the Utah Traffic Lab (UTL) that will contribute to the development of the user cost manual. This study evaluates the impact of various work zone scenarios caused by roadway rehabilitation projects in Utah. The results for different scenarios are tabulated to construct the Road User Cost (RUC) look-up tables. These tables will assist UDOT for faster contracting and project delivery purposes.

Methodology

Utah's road system is divided into two groups: urban and rural. Upon consultation with UDOT, the rural roads are divided into three categories: rural freeways, heavy truck roads, and other road types. VISSIM micro-simulation tool is selected to model the road networks. Hourly traffic volumes (counts) are added as vehicle inputs in the simulation model. The simulation models are calibrated based on the traffic counts from the field. Different travel time sections are created in the model to estimate the time required to travel these segments. Two scenarios are tested, such as 'No Build' and 'Lane Closure' to estimate the travel time delays. Travel time delays are converted to monetary values (RUC) by multiplying with Value of Time (VOT) for different vehicle types. Analysis is done for weekdays, where traffic volumes for Tuesdays, Wednesdays and Thursdays are averaged, and separately for Mondays, Fridays, Saturdays and Sundays. Mean of the hourly traffic volumes for October 2008 and April 2009 are analyzed. A sensitivity analysis between average daily traffic and road user cost is studied. Findings indicate that there is a definite relationship between ADT and RUC for various lane closure scenarios. However, the rate of RUC increment with increase of ADTs is not uniform.

An outline of the proposed user cost manual is documented upon consultation with UDOT engineers. The outline is set forth for UDOT to follow, to apply user costs in a simple, defensible, and consistent manner throughout the department. However, decisions need to be made by UDOT in order to standardize it. UDOT needs to make various decisions with regards to user costs and should ensure that the value of time used is appropriate and justifiable. The department should ensure that the average percentages of cars and trucks in Utah are accurate for use in the user cost calculations.

1. INTRODUCTION

The highway community has been moving toward a new way of doing business as construction has intensified in recent years in an attempt to confront a two-fold problem. First, the United States highway infrastructure is aging. Much of it was built in the 1950s and 1960s and is in need of rehabilitation and replacement. Second, although highway capacity has increased little during the last two decades, traffic demand has grown to a large extent, causing high levels of congestion. Large construction projects designed to improve worn and outdated roads and bridges compound traffic problems during lengthy construction periods. Slower speeds in work zones increase travel times and create localized bottlenecks. User costs are those additional costs incurred by a driver having to drive slower, spend time in a queue, or take a detour. Road User Costs (RUCs) are essentially incurred by drivers due to reduced travel speed and capacity at work zones. RUCs include added vehicle operating costs and delay costs to highway users resulting from construction, maintenance, or rehabilitation activity. The RUCs are a function of the timing, duration, frequency, scope, and characteristics of the work zone (1). Today's motorists want high quality, longer-lasting highways, but they want any construction-related activity completed as quickly as possible. FHWA and AASHTO are working with state transportation agencies, industry, and academia to strengthen their long-standing partnership to better serve the customers, through rapid adoption of new technologies and innovative practices.

Typically, a state highway agency needs to have a plan or procedure to follow before beginning the process of charging a contractor for the user cost of a roadway. The reason for having a plan is stated by Gillespie (2) to the Virginia Department of Transportation (VDOT):

> "By following no standard procedure in calculating incentive/disincentive (I/D) amounts, VDOT may run the risk of seeing a tardy contractor challenge and invalidate the I/D clause in one of its contracts in court."

Under current procedures, UDOT engineers construct a new cost estimation method each time a contracting clause is required. This practice devours skilled employees' time and leads to inconsistent results. A standardized method would enable personnel of varying skill levels to calculate appropriate user cost amounts quickly and consistently, saving the department both time and money. The UDOT has proposed to develop a Road User Cost manual for the state of Utah. This will provide the department with a method to quickly analyze and quantify road user costs to the traveling public based on operating and time delays. The goal of the study is to develop the statewide road user cost manual for work zones in Utah. The research reported here details the work underway at the UTL that will contribute to the development of the user costs manual. The purpose of the research is to analyze the impact of lane closure scenarios due to reconstruction. A sensitivity analysis between the average daily traffic volumes (ADT) and RUC are studied to develop the RUC look-up tables. The tables will help UDOT engineers to quantify road user costs to be used as an incentive for contractors to achieve faster completion times. UDOT can determine the cost effectiveness of various alternatives such as detours, temporary roadway construction, off-peak hour work and various contracting alternatives (A+B, Incentive/Disincentive). A+B contracting strategy encourages contractors to minimize construction impacts by reducing construction time. Part A refers to the contractor's bid for items of work. Part B is the value of the total number of days bid to complete the project times the daily User Cost. The contract is awarded to the bidder having lowest result of:

$$A + (n \times \text{User cost}) \qquad (1)$$

where, n = # of days bid

The contractor's payment is based on both Part A and the actual number of days under part B. A+B is often used in combination with Incentive/Disincentive clauses. Using the road user costs as an incentive, the contractors are encouraged to formulate new and innovative construction methods that will complete the work in fewer days than by normal construction methods.

Moreover, the manual will familiarize analysts with work zone characteristics. It would explain the possible work zone related road user cost components that can occur and provide a step by step procedure to determine road user costs. This would ensure a fast and effective project delivery method. By understanding the major factors influencing road user costs, the analyst can take steps to minimize the effect of future rehabilitation activities on highway users. This would determine the appropriate capital investment on a project.

The goal of the study is supported by the following objectives:

- Examine how other states determine road user costs.
- Evaluate features that are desired by UDOT engineers for a simple method to determine user costs and develop a draft plan.
- Construct RUC look-up tables.

The report is organized as follows: A literature review on how various states' DOTs and researchers determine road user costs pertaining to work zones is described in Section 2. Section 3 provides the draft plan of the user cost manual after consultation with UDOT engineers. Research methodology is described in Section 4. Preliminary results are discussed in Section 5, followed by the conclusions drawn from the study in Section 6. Suggestions for future work are in Section 7.

2. LITERATURE REVIEW

There are many studies related to the estimation of user costs in a work zone. Different approaches and methods to compute user costs are reported in the literature. This section discusses the general procedures for deciding when user costs may be useful and methods to determine them. The methods used to estimate user costs in work zones are also described. Finally, a critical evaluation on the user cost estimation methods is discussed.

2.1 User Cost Estimation Plan

Daniel et al. (*3*) developed a plan to determine if and when user costs should be considered for use and how to apply that decision. Figure 2.1 shows the RUC estimating process developed by Daniels et al. (*3*).

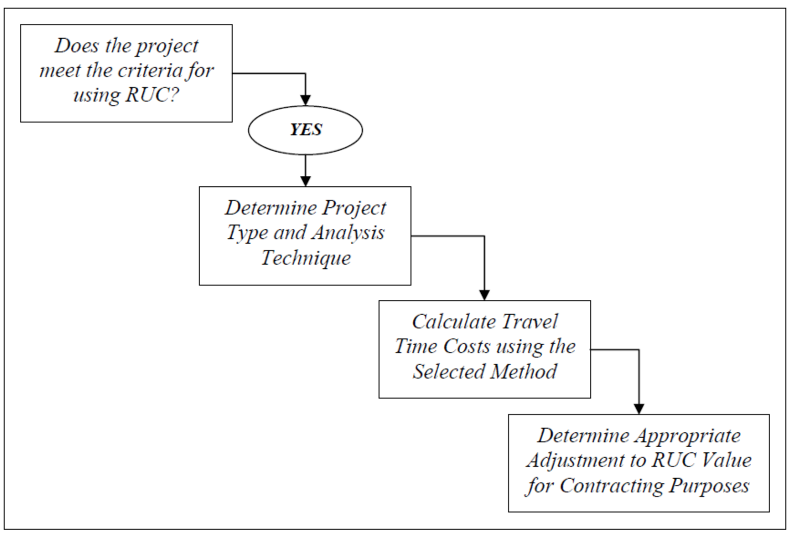

Figure 2.1 Procedure for Estimating RUC

According to Daniel et al (3), the criteria to apply user costs are 1. Capacity is added, 2. Economic impacts are expected, and 3. Rehabilitation in very high traffic areas. Further, Gillespie (2) emphasized the characteristics and properties that any state-wide method should entail, while correctly developing user cost estimates. These are:

- rigorous and accurate,
- easy to understand and apply,
- convenient by “piggybacking” on existing project activities and
- available data is applicable to a high proportion of cases.

2.2 User Cost Estimation Methods

A wide variety of approaches and methods address user costs in the literature. Ellis et al. (4) summarized six methods to calculate user costs: simple formulae, spreadsheets, high-level software, AASHTO red book method, flat rates, and no formal method.

Jiang et al. (5) developed a new microscopic computational model for estimating freeway work zone traffic delays and total work zone cost optimization using Boltzmann-simulated annealing neural network and optimization techniques to find the global optimum solution. The model takes into account various important factors such as lane closures, darkness factor and seasonal demand and is applicable to both short-term (less than a day) and long-term (more than a day) work zones. However, it does not take into account the impact of detours in the model. Recently, Chitturi et al. (6) determined a numerical methodology based on equations for computing delays and user costs in highway work zones.

Chien et al. (7) presented a simplified and useful model for estimating the delay cost using the ADT and finding the optimum work zone segment length in a four-lane freeway with one lane closure. They assume that if the work zone capacity is more than the ADT, no queue is formed. However, since traffic flow varies within a day, this assumption does not hold, at least during some parts of the day. Likewise, the starting time of the work zone in a day (work during the day versus evening) and seasonal demand factors were not addressed in the model. Jiang (8) developed a model for estimating the excess user costs at work zones. The model was based on traffic data from Indiana's freeways. He shows that during congestion at work zones, delay costs of vehicle queues contribute greatly to the total excess user costs. His results show that excess running costs due to speed changes have negative values, indicating that reduced speeds at work zones actually reduce the vehicle running costs.

In an attempt to determine the user delay costs for a typical Ontario work zones, Huen et al. (9) evaluated the significance of delays and associated delay costs for a construction zone using predetermined models. Results show that the magnitude of delay, both cost and time, is directly related to the volume of daily traffic and the number of lanes in the facility.

Memmott et al. (10) studied the effects of different lane closures strategies (one-, two-, or three-lane closures) in one or both directions of travel and the additional costs to users traveling in a highway work zone. They used a computer model, Queue and User Cost Evaluation of Work Zones (QUEWZ). Memmott et al.'s results indicate that accuracy of cost calculations increases by using hourly instead of daily traffic volume compared to previous models. In an attempt to review available software and computer programs, Saito et al. (11) compared four computer tools that determine user costs such as MicroBENCOST, QuickZone (QZ), Delay enhanced (Delay E), and DUCK (Delay User Costs and is a simple Excel spreadsheet). They recommended that DUCK and Delay E should be used for user cost calculations under specific conditions, such as, DUCK is to be used for projects where the delay is caused by a reduction in speed, while Delay E is to be used for projects where the source of delay stems from queues forming due to the demand greater than the capacity of the facility.

2.3 Statewide Manuals for Road User Cost Estimation

2.3.1 Texas Department of Transportation

TxDOT developed a manual technique for determining RUC for typical added-capacity and highway rehabilitation projects. The first step involves defining general categories of projects and the suggested analysis technique for estimating RUC. Projects were categorized as 'Phase-by-Phase,' 'Before versus After,' and 'During Construction versus After' as shown in Table 1. Different solution techniques are attributed to different project categories. These techniques are classified either as simulation models (such as the FREQ and PASSER series of programs) or by manual technique (such as tables, graphs, or hand calculations).

Table 2.1 Categories of Projects for RUC Application

Table 1-1. Categories of Candidate Projects for Application of RUC

Category	Description of Projects	Setting	General Analysis Approach	Technique	Reference Guide
I	**High Impact Urban Freeway Construction or Rehabilitation** • Severe capacity reduction during construction • Phase completion time critical • Interaction with other freeway or arterial projects	Urban	Phase-by-Phase or Before vs. After	FREQ, CORSIM, or HCS models	1
II	**Urban Arterial Roadways** • Signalized intersections • Diamond interchanges	Urban	Before vs. After	PASSER models	1
III	**Other Added Capacity Projects** • Highway widening projects not classified as I or II above (rural highways, suburban arterials, urban freeways) • New facility construction	Urban or Rural	Before vs. After	Manual Technique	1 and 2
IV	**Rehabilitation and Other Non-Capacity-Added Projects** • Paving projects (no capacity increase) • Bridge replacements • Detour routing	Urban or Rural	During Construction vs. After	Manual Technique	1 and 2

Reference 1: *A Short Course on Techniques for Determining Construction Related Road User Costs*
Reference 2: *Techniques For Manually Estimating Road User Costs Associated With Construction Projects*

The objectives of the TxDOT manual include the following:

1. To develop a manual technique for determining RUC for typical added-capacity and highway rehabilitation projects,
2. to develop implementation guidelines that define the appropriate technique, given the project type, for calculating RUC and determining the ultimate value to be used for contracting purposes,
3. to review and evaluate the value of time used by TxDOT in determining delay savings and recommend appropriate values to use in RUC calculations, and
4. to review and evaluate the practice of discounting of RUC values to 25%.

The manual technique is formulated using look-up tables approach both for added capacity and rehabilitation projects. To cover the greatest possible range of added-capacity project types, separate tables are available for 10 different project types. Each table provides the values of daily RUC per unit length (in $/day per mile) of an individual facility for a range of average daily traffic volumes (ADT) and percentage of trucks. The value selected from the table that represents the "after" condition is subtracted from the value selected from table for the "before" condition. The difference of both values gives the delay savings.

A MicroBENCOST (a planning-level economic analysis tool developed by TTI under NCHRP Project 7-12) model was selected to calculate RUC values for the various tables. This tool can handle the option of trucks percentages and vehicle-mix. The equation by used to calculate the RUC is given by:

$$RUC = VOC + AC + VOT \quad (2)$$

where,

RUC = road user cost
VOC = vehicle operating cost
AC = accident cost
VOT = value of time

2.3.2 New Jersey Department of Transportation

The approach of the NJDOT user cost manual is dependent on different Road User Components. New Jersey (*1*) defines a list of various values and costs that may be used to the total user cost:

1) Unrestricted Flow (Demand < Capacity):
   a) Speed Change with VOCs
   b) Speed Change Delay
   c) Work Zone Delay

2) Forced Flow (Demand > Capacity):
   a) Stopping VOC
   b) Stopping Delay
   c) Queue Delay
   d) Queue Idling VOC

3) Circuitry:
   a) Circuitry VOC
   b) Circuitry Delay

4) Crashes:
   a) Crash Costs

New Jersey uses five of the previously listed delays and costs because they account for the greatest percentage of all costs. These are:

1) Work zone delay
2) Queue delay
3) Queue idling VOC
4) Circuitry delay.
5) Circuitry VOC

The work zone delay is the value of the time lost by drivers traveling through a work zone that has a slower speed limit than the normal speed limit. The queue delay results from time lost when drivers are stopped and waiting in the queue itself. The queue idling VOC is the VOC due to idling for the length of time spent in the queue. The circuitry delay is the difference in time from the normal travel time and the time taken to travel along a detour or bypass route. The circuitry VOC is the difference in VOC of driving through a detour rather than the work zone or normal route. Once the individual work zones have been identified, each can be evaluated separately. Next, individual road user cost components are quantified and converted to dollar cost values. Finally, worksheets are developed to aid in organizing and calculating the necessary data. It is recommended that these worksheets be used for the actual computations.

2.4 User Cost Methodology Used in UTL

Previously, the Utah Traffic Lab (UTL) conducted several research projects for UDOT to evaluate the impact of highway construction on road users. Each of these projects dealt with the impact of the various construction scenarios on travelers. The impacts were measured as hours of delay, percentage of congested roads, and monetary values.

General UTL Methodological steps include the following:

1) Model the road network in VISUM
2) Update the geometry of study area using Google Earth and TerraServer
3) Develop networks for each diurnal period from base model
4) Add traffic volumes to the model
5) Upload UDOT's Traffic signal timings from SYNCHRO (VISSIM used as an
6) intermediate step for signal timings transfer).
7) Calibrate VISUM model by TFlowFuzzy and Traffic Assignment
8) Develop different scenarios for each diurnal period
9) Run VISUM
10) Obtain delays for each scenario
11) Convert delays to user costs

2.5 Evaluation from Literature

The review of existing literature shows there is a wide variety of studies dealing with the evaluation of user costs related to work zones. Approaches vary from focusing exclusively on the work zone delay and user costs to the evaluation of computer models. Generally, most studies dealing with the estimation of user costs attempt to compute the magnitude of delay and user costs on freeway work zones using different computational models (4-10). However, each model has its own limitations and assumptions that are inherent to the model's computational technique. Studies of software tools show that different software packages work under specific conditions (11). Some of these models have no option to reduce the capacity on the links due to speed limit reduction.

The TxDOT user cost methodology depends on the accuracy of the results obtained from the MicroBENCOST model. The advantage of this method is that once the RUC tables are formulated, projects can be finished in less time. However, MicroBENCOST is most sensitive to the volume of traffic. At lower volumes of traffic, minor variations in the input variables have minimal impact on the final outcome. As traffic volumes increase, all variations in the input data should be considered important. Geometric data such as lane width, median width, and shoulder width have less impact on the output than percentage of trucks unless they fall out of normal ranges. Wide variation in the 24-hour distribution of traffic, average vehicle occupancy, or distribution of vehicle types over that used in the development of the tables should lead to reconsideration of the use of the tables in estimating RUC. Detour condition is not considered in tables. If detour condition exists, then simulation in MicroBENCOST specifically for an individual project is required. However, MicroBENCOST can only calculate long term costs over many years but not short term costs. Further, this tool has many inputs, is DOS-based, and is difficult to work with because there is no visual diagram or layout of the system on the monitor. Also, because this program is not easy to use, it is probably not well suited for use by UDOT.

The New Jersey user cost manual emphasizes different road user cost components and the delay associated with each of the components. Detour condition has been taken into account. Several worksheets need to be completed to compute the user cost. However, no distinction of the project types (added capacity or rehabilitation) has been incorporated.

The methodology followed by UTL researchers is quite standard for most of the user cost projects. However, it is inefficient, especially for larger networks. Thus, UDOT commissioned a study to develop a statewide user cost manual, which would guide analysts through a step-by-step procedure for solving user cost in work zones. UDOT proposed the standard method to be rigorous and accurate in order to be upheld in court, if needed. The method must provide both the state and the contractor an understanding of how the agreed-upon user cost has been formulated. UDOT has requested a simple method that the engineers in any regional office may use and will provide a value that is reasonable and justifiable in a legal disagreement. UDOT engineers should understand the basic concepts behind the method and know how to determine the user cost estimate quickly and easily. Any chosen method should be applicable to a high proportion of projects for ease of use and to provide consistent results throughout the state.

3. DRAFT USER COST MANUAL

3.1 Outline of User Cost Manual

A draft outline of the road user cost manual was developed from information gathered by UDOT personnel about what they expect from such a system. A flow chart has been provided by UDOT to assist in developing the statewide user cost manual. Figure 3.1 shows UDOT's flowchart.

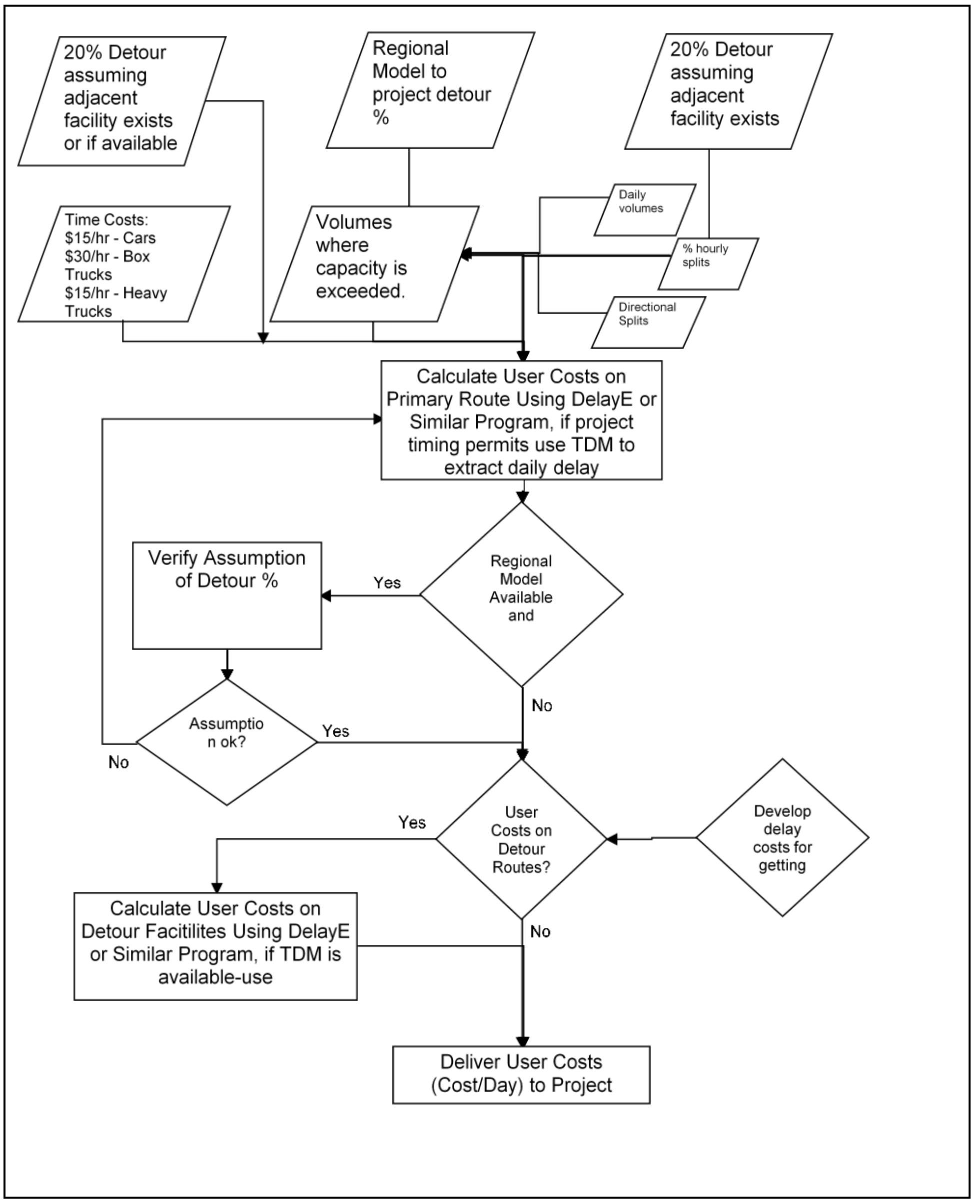

Figure 3.1 Developments of User Costs

Based on the above flowchart and discussion with UDOT engineers, an outline of the Road User Cost manual was formulated. Rehabilitation projects are the primary focus of the manual. The outline shows the chapters that belong to the manual and contents of each chapter and is described below:

EXECUTIVE SUMMARY

Chapter 1

INTRODUCTION

Chapter 2

DATA COLLECTION

Traffic Control Plan

- Existing project layout.
- Layout of project sequencing.
- Roadway lane information:
  - number of lanes;
  - lane widths;
  - lateral restrictions;
  - turn restrictions; and
  - special traffic control operations (if any)
- Detours if any (for total roadway closure):
  - times of detours;
  - available detour % and
  - proposed detour routing

Other factors are adjacent traffic generation (e.g., shopping centers, sports venues, schools, etc.), time of year constraints, and special events.

Traffic Volume Data

Current traffic data includes: hourly volumes, peak period traffic counts, travel time studies within the limits of the construction project. Also, traffic volume on roads outside the area of construction may be needed if road closures and/or extensive detouring are expected. The importance of having current and accurate traffic volume data is critical to RUCS.

Chapter 3

SELECTION OF ANALYSIS TECHNIQUE

The next step in completing a road user cost study is to select the most appropriate technique to estimate the roadway delays. The availability of a traffic control plan, traffic volume data and type of project can influence which technique is used for the study.

• Layout Overall Approach for Analyses

Description of the approach/plan of attack

• Traffic Demand Model Selection

• Design Scenarios

Lane closures and/or restriction in lane width that leads to reduced capacity of road.

• Determine Delays

Travel time (with construction activity) – Travel time (before) = Delay

VHT needs to be determined also

30 mph travel speed for diversion

Chapter 4

THE METHODOLOGY

What is the Project Type?

Urban or Rural

If, Urban then:

Does Regional Travel Demand Model Exist?

If yes, then follow the steps:

1. update highway network/study area based on Google Earth and TerraServer
2. add daily traffic volumes to the models
3. adjust for traffic signals if necessary
4. calibrate the model
5. adjust the model to reflect construction scenarios
6. run the model and review the output (delay in travel time)

If no,

do alternative routes exist?

If yes, then go for micro simulation (Dynamic Assignment) considering detour % and calculate daily delay (diversion)

If no, does demand exceed capacity (queue is formed)?

If yes, model the network in DelayE and calculate delay in travel time

If no, go for QuickZone to calculate daily delay

If rural, look for any detour available

1. If yes, then go for micro simulation and calculate delay (diversion) time
2. If no, model the network in DelayE if queue is expected otherwise use QuickZone to calculate daily delay
3. Convert Vehicle Delay to Monetary value: the value of time is multiplied by the time delay to determine the user costs

<u>Consider current Value of Time</u>

$15/hr – Passenger Car

$ 40/hr – Box Trucks

$70/hr –Truck Trails

Calculate daily user cost (Cost/Day)

Chapter 5

CALCULATION OF USER COSTS

Deliver User Costs (Cost/Day) to project time duration

Chapter 6

DOCUMENTATION

Documentation of the work is required to ensure a consistent user cost methodology for the potential users. It is also important for dealing with any legal issues about the validity of the study. This would help in case of any challenge. The topics needed to be documented are traffic data sources, modeling approach, scenarios studied, delay calculations, value of time used and project specific items. Any assumption considered in the study should be documented as well.

3.2 RUC Look-up Tables

Following the review of several possible manual techniques (1,3), it was decided to construct look-up tables that provide RUC values based on a minimal number of project attributes. The attributes are project area type, type of road, number of lanes and the corresponding user costs on lane closures. To cover the greatest possible range of rehabilitation project types, separate tables were developed for different project types (rural freeway, heavy truck and other road types). Each table provides the values of daily RUC per unit length of an individual facility for a range of Average Daily Traffic volumes (ADT).

3.3 Decisions for UDOT

The proposed user cost manual outline is the procedure set forth for UDOT to follow to apply user costs in a simple, defensible, and consistent manner throughout the department at each of the regional offices. However, some decisions need to be made by UDOT in order to use it. UDOT must make various decisions in regard to user costs and should ensure that the value of time used is appropriate and justifiable. The department should also ensure that the average percentages of cars and trucks in Utah are accurate for use in the user cost calculations.

4. RESEARCH APPROACH

4.1 Derivation of Road User Cost Values

A model is needed to calculate RUC values for the tables. A sensitivity analysis is needed to see the effect of lane closures on the user cost based on average daily traffic (ADT) volume. The two characteristics that are important in selecting the analysis technique are (1) the model should be consistent with the scale of analysis, and (2) the model should be easy to use, but based on sound traffic flow and economic theory.

Every roadway section that is traveled has motorist costs associated with it. To drive a given length of roadway, motorists will experience costs: the value of the motorists' time to travel that section, the expenses to operate the vehicle over that section, and, in the aggregate, accident costs for the roadway section based on a rate of accident type per vehicle-miles of travel. Since delay costs are the most significant of other cost components, only motorists delay cost is considered. Delays are experienced as the travel speed drops, due to capacity, geometric, and operational constraints.

The first step in developing the RUC tables is to divide Utah's roads into two groups: urban and rural. The rural roads are further divided into three categories: rural freeways, heavy truck roads, and other roads. VISSIM micro-simulation software is used to model these road networks and find the travel time delays. The outline of the user cost manual describes the usage of different traffic simulation tools for different types of project. However, Delay E was unavailable, so VISSIM was used to model simple networks also.

All simulations are run for "before" and "after" conditions to calculate the delays. The "before" scenario assumes all lanes are open to traffic and the "after" scenario assumes one or more lanes are closed to traffic when the construction work is underway. The absolute difference between the travel times of the two scenarios gives the delay in travel time. Road user cost is calculated by multiplying the delay with VOT of respective vehicle types to arrive at a dollar value of motorist time costs. This process is repeated for peak and off-peak days of the week. In this way, a RUC table is developed which provides a sensitivity analyses between ADT and RUC.

4.2 Modeling of Rural Freeway Network

A VISSIM model simulating the rural freeway network of Utah was developed. Figure 4.1 shows the VISSIM model for the same.

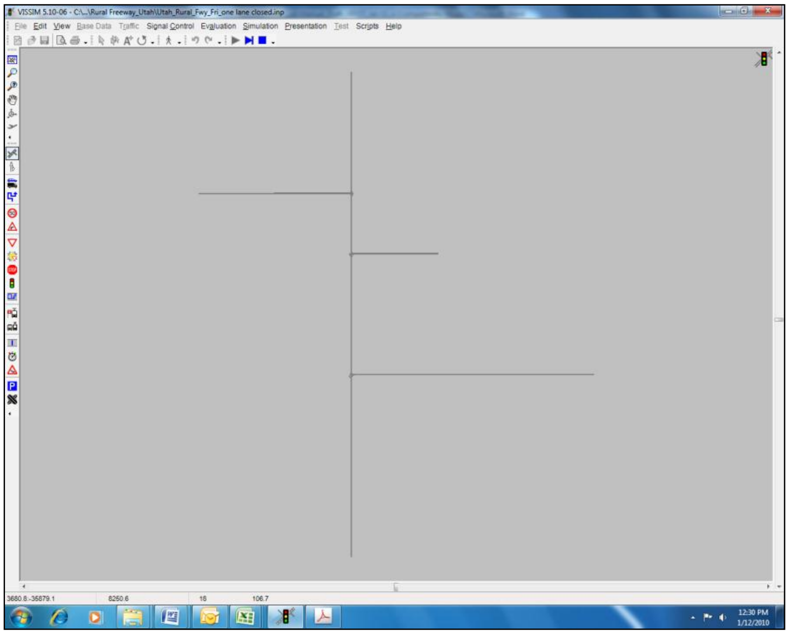

Figure 4.1 VISSIM Model Simulating Rural Freeway of Utah

Most of Utah's rural freeways are four-lane facility; hence all links in the model are constructed with two lanes in each direction. These freeway sections included in this analysis do not include interchanges or ramps. The unit of length used for applying RUC values is one mile, meaning the table values represent RUC per day per mile. Mean hourly traffic data of October 2008 and April 2009 are used in the simulation. Two sets of traffic volumes are tested. One set is for Tuesdays, Wednesdays, and Thursdays together, and the other set is for Fridays. Several travel time sections are defined to derive the travel time required by motorists to travel that particular stretch of road. All simulations are run with a "No Build" condition with all lanes open. Next, the lane closure scenario is modeled. Here, one lane in every link is closed and the simulation is run to see the increased travel time, if any, in the travel time sections. Figure 4.2 shows the queue building up when the left lane of the link is closed to all types of traffic. Finally, a table is developed to see the effect of lane closure versus ADT for each link.

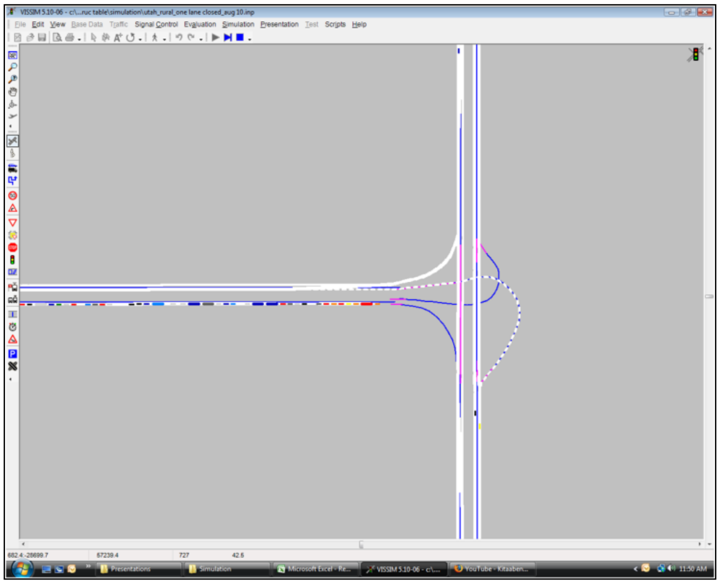

Figure 4.2 Queue Building Up in a Link with One Lane Closed

4.2.1 Calibration of the Rural Freeway Model

Calibration of the model for the rural freeway routes is based on the traffic counts. Differences between some of the volumes have proven that flow variations on some of the links are not substantial. Calibration of the assignment performance is done for the whole day. Figure 4.3 shows the results of the calibration. The coefficient of determination (R^2) is 0.96. This shows that modeled and counted volumes are highly correlated.

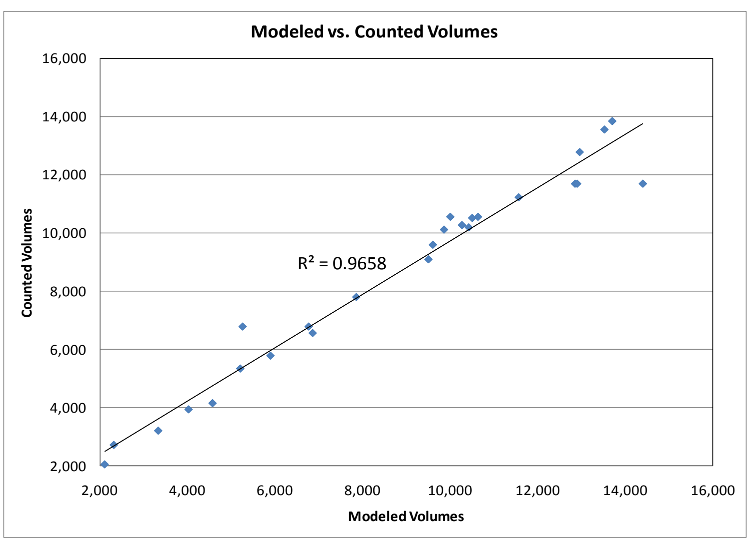

Figure 4.3 Calibration Results for Rural Freeway Network

4.3 Rural Heavy Truck Routes

A VISSIM model was developed for the counties in Utah, bordered by I-15 in the West side and I-70 on the South side near the Price city (counties Cache, Wasatch, Duchesne, Utah, Emery, Carbon, Juab, Piute, Kane, Grand and San Juan). Figure 4.4 shows the VISSIM model for the rural heavy truck routes.

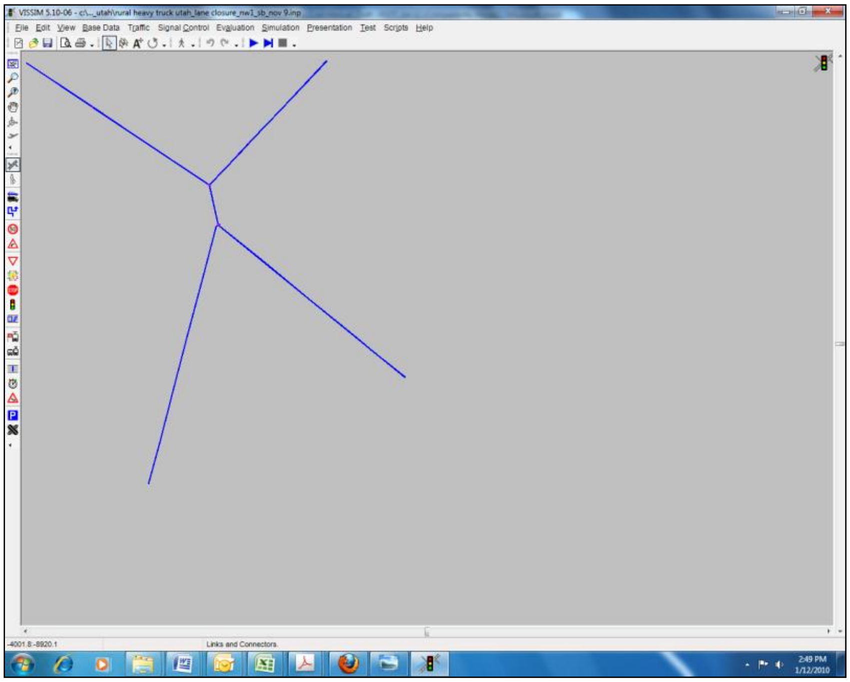

Figure 4.4 VISSIM Model of Rural Heavy Truck Route

The heavy truck routes in this study area are primarily two lanes; hence two lane links are constructed in the model. Several travel time sections are built to calculate the time required to travel the section of road. Simulation was run for "No Build" condition when all lanes are open to traffic for 24 hours. The next step is to simulate the lane closure scenario. To simulate lane closure, virtual traffic signals are imposed on both NB and SB directions to regulate the traffic flow. Alternating directions in detour zones are controlled by traffic signals, with 120 seconds of green in each direction, plus clearance time. This scenario simulates the traffic control done by a worker in a work zone. Figure 4.5 shows a three-mile section of the NB link temporarily closed to traffic and the traffic diverted to ensure mobility. Simulation of the lane closure section by section gives the increase in the travel time required to traverse the sections. The absolute difference between the "No Build" and "Lane Closure" scenarios gives the delay in travel time. This delay is multiplied by the VOT to arrive at a dollar value.

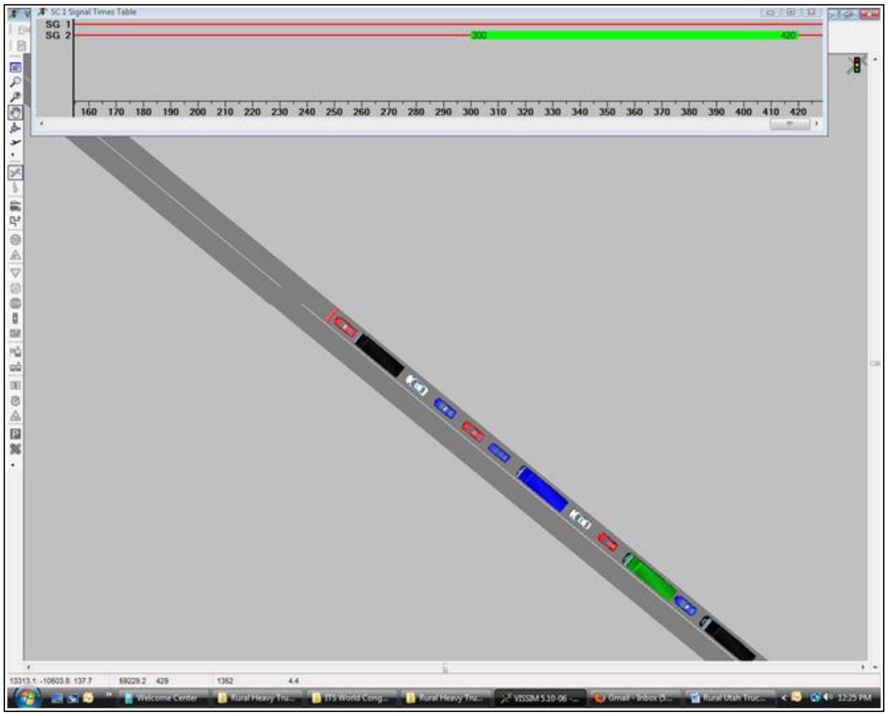

Figure 4.5 Traffic Around Work Zone Area Regulated by Traffic Signals

4.3.1 Calibration of the Rural Heavy Truck Model

Calibration of the model for the rural freeway routes is based on the traffic counts. Differences between some of the volumes have proven that flow variations on some of the links are not substantial. Calibration of the assignment performance is done for the whole day. Figure 4.6 shows the results of the calibration. The coefficient of determination (R^2) is 0.98. This shows that modeled and counted volumes are highly correlated.

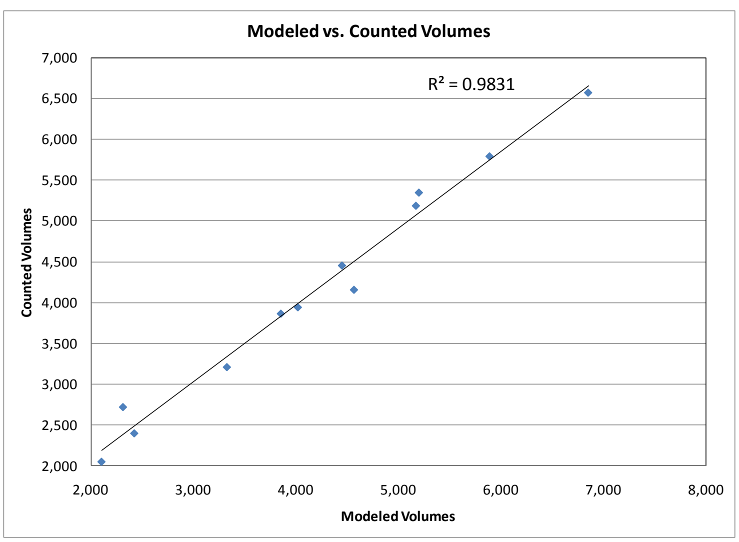

Figure 4.6 Calibration Results for Rural Heavy Truck Route

4.4 Other Rural Road Types

A VISSIM model was developed for South-Eastern counties in Utah, bordered by I-70 in the north side and I-15 on the west side (counties Sevier, Emery, Grand, Piute, Wayne, San Juan, Garfield and Kane). Figure 4.7 depicts the VISSIM model that represents the other rural roads in Utah. User delays are analyzed for nine state roads in this part of the state, where traffic recording stations were located. User delays and cost are analyzed for one-mile lane closures near each station. Alternating directions in detour zones are controlled by traffic signals with 120 seconds of green in each direction, plus clearance time.

4.4.1 Calibration of the Other Rural Road Types Model

The simulation model for the other rural roads is based on the traffic counts. Calibration of the assignment performance is done for the whole day. Figure 4.8 shows the results of the calibration. The coefficient of determination (R^2) is 0.98. This shows that modeled and counted volumes are highly correlated.

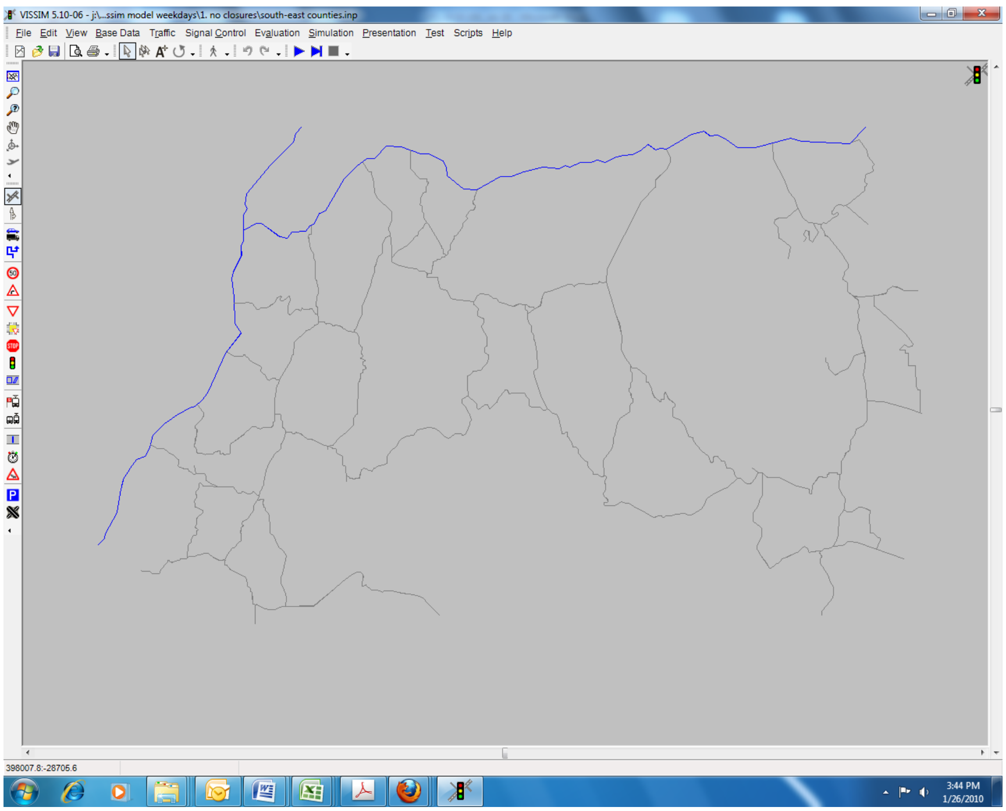

Figure 4.7 VISSIM Model for Other Rural Road Types

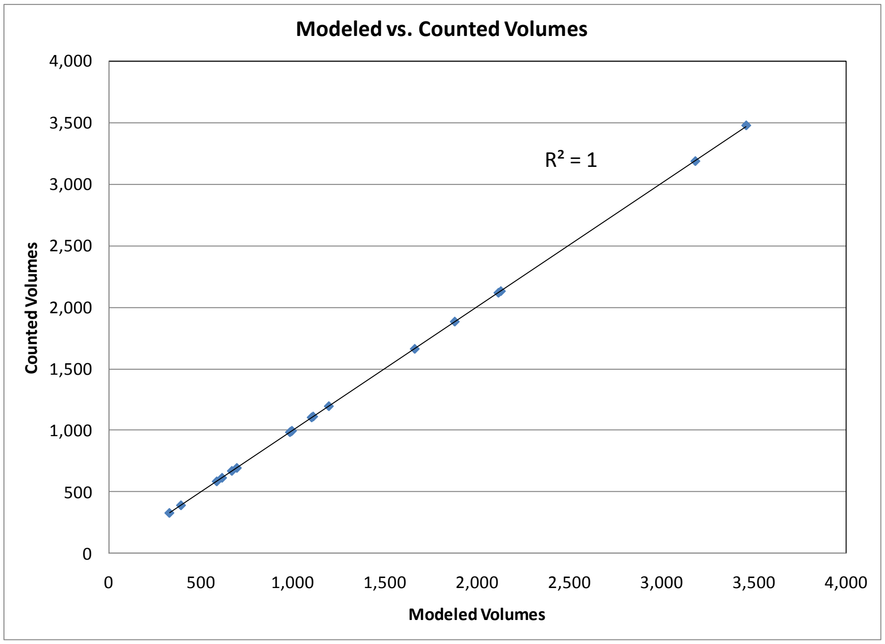

Figure 4.8 Calibration Results for Other Rural Road Types

4.5 Format for RUC Tables

The values provided in the tables are the estimated daily user benefits that are being lost while rehabilitation work is underway. Figure 4.9 provides an example of the procedure for estimating RUC for a rehabilitation project.

One lane closed in one direction			**Example problem:** A rural highway rehabiliation project with
Road Type	**ADT**	**$/day/mile**	an ADT of 15,000 propose to close one lane in one direction.
			What is the RUC?
1	5000	0	
2	10000	100	RUC from table:$150/day
3	15000	150	
4	20000	200	
5	40000	400	

Figure 4.9 Example of RUC Table and Its Application

5. DATA COLLECTION

Hourly traffic counts were collected from UDOT's website for the months of October 2008 and April 2009. These counts were inputted by the WFRC and taken as regular UDOT counts. The traffic counts for the required traffic recording stations were collected for this study. Mean hourly counts between October 2008 and April 2009 have been used as vehicle inputs in the simulation. Analysis is done separately for weekdays, where traffic volumes (counts) for Tuesdays, Wednesdays and Thursdays were averaged, and separately for Mondays, Fridays, Saturdays and Sundays. Table 5.1 provides a sample of the hourly traffic counts for October 2008 for a station (403) along I-15 used in the analysis.

Table 5.1 Hourly Traffic Volume for Station 403

Utah Department of Transportation

Neg Dir, Monthly Hourly Volume for October 2008

Site Names: -0403, 0015-112.432-
County: Beaver
Funct. Class: Rural Principal Arterial - Interstate
Location: 0.5 MILES NORTH OF NO BEAVER MP 112.43 FC 01

Seasonal Factor Group: 403
Daily Factor Group: 403
Axle Factor Group: 403
Growth Factor Group: 403

	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	Total
01	106	68	68	57	51	93	93	185	263	302	351	467	527	505	541	506	510	513	515	377	331	291	226	159	7105
02	114	95	59	65	65	82	109	176	288	384	454	557	587	637	700	665	724	667	541	564	469	443	296	209	8950
03	155	126	87	85	85	87	115	187	324	391	458	545	800	924	950	1,063	1,094	1,003	855	619	614	576	343	210	11696
04	179	112	100	65	67	84	121	158	241	322	397	498	562	525	520	495	512	461	367	286	252	202	166	133	6825
05	76	81	58	46	53	70	74	135	207	358	491	586	698	763	762	816	951	835	562	610	737	702	329	199	10199
06	99	78	66	57	38	72	142	194	270	320	468	486	542	619	570	561	550	471	427	306	259	243	210	124	7172
07	87	72	51	41	48	66	80	120	214	283	351	398	396	441	451	496	453	419	375	331	257	203	164	129	5926
08	84	81	67	55	50	80	95	147	266	297	347	448	500	497	517	527	572	532	449	346	295	268	200	136	6856
09	114	79	89	78	55	83	99	172	269	318	437	522	626	544	625	640	631	649	569	530	418	394	283	200	8424
10	148	121	93	88	78	100	122	186	254	349	466	589	632	697	697	803	817	773	787	639	568	485	347	239	10078
11	139	101	87	60	57	73	109	157	251	342	429	530	570	565	568	506	459	390	404	327	254	170	220	228	6996
12	104	65	55	38	35	34	68	90	200	305	409	510	604	604	635	711	675	712	582	541	423	321	211	129	8061
13	84	73	54	67	56	65	118	172	245	333	438	458	561	496	541	539	529	471	391	330	261	190	190	118	6780
14	70	80	55	52	40	74	111	155	209	308	359	420	461	488	483	522	523	470	485	380	297	295	166	151	6654
15	101	88	74	46	54	84	90	195	269	413	439	496	496	659	673	672	692	760	1,145	808	738	696	408	243	10339
16	164	99	87	62	75	76	121	223	389	589	714	804	812	828	1,001	1,093	1,112	1,395	1,019	683	556	539	382	252	13075
17	193	105	105	73	81	85	130	180	275	428	593	716	685	696	833	850	1,087	1,000	661	583	551	434	291	181	10816
18	159	92	71	66	59	67	89	162	212	321	400	504	511	501	536	473	469	483	419	408	291	248	190	127	6858
19	106	78	76	50	57	52	73	165	254	344	454	519	616	627	697	701	767	706	652	582	412	356	272	132	8748
20	114	66	55	44	63	61	110	160	207	273	392	496	538	592	558	585	578	515	564	428	380	305	214	141	7439
21	94	75	63	46	50	70	87	138	226	316	332	404	454	514	495	502	430	433	382	304	260	217	178	118	6188
22	87	74	58	56	54	62	100	149	236	321	386	459	443	509	476	539	580	512	446	364	305	264	209	160	6849
23	101	83	61	61	56	84	109	190	262	312	393	465	529	563	581	589	605	597	517	451	438	328	272	187	7834
24	141	94	87	72	61	88	127	171	242	325	427	573	692	658	726	828	778	804	695	517	523	369	257	163	9418
25	106	162	81	69	62	64	114	135	258	306	390	448	480	395	571	499	425	467	466	425	295	226	178	150	6772
26	90	77	61	48	51	65	84	121	215	332	404	507	576	621	666	647	666	568	488	455	468	348	229	129	7916
27	96	63	45	52	46	72	119	165	222	298	346	437	456	480	444	463	454	436	368	246	236	217	152	122	6035
28	96	64	59	24	54	73	89	120	217	272	301	360	470	454	464	419	455	409	359	279	217	212	166	98	5731
29	102	83	64	47	77	60	108	140	216	334	355	419	500	555	530	495	465	522	412	332	262	228	200	123	6629
30	117	80	79	64	55	86	103	189	271	343	406	514	597	553	617	636	626	594	551	483	359	356	225	161	8065
31	128	136	82	69	67	91	124	168	258	339	426	500	520	621	656	687	662	645	527	389	342	297	203	158	8095

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6. RESULTS

Preliminary results obtained for the development of the RUC tables for work zone projects are discussed here.

6.1 Rural Freeway Routes

Table 6.1 provides the results obtained from the simulation for rural freeway routes. RUC is calculated as dollar per day per mile. The table shows that as ADT increases, the RUC also increases, however this is not systematic. However, there is no pattern in the rate of increase of RUC with the increase of ADT.

Table 6.1 RUC Table for Rural Freeway

One lane closed in one direction		
Rural Freeway	**ADT**	**$/day/mile**
1	1748	45
2	1956	51
3	1970	51
4	2050	47
5	2312	60
6	3005	78
7	3489	85
8	4036	105
9	4674	122
10	4766	125
11	5330	92
12	5384	143
13	5509	150
14	5655	152
15	5957	156
16	5970	160
17	6108	162
18	6186	169
19	6250	172
20	6620	177
21	6789	182
22	6870	187
23	6873	190
24	7819	207

6.2 Rural Heavy Truck Routes

Table 6.2 provides the results obtained from the simulation for rural heavy truck routes. The table shows that there is a definite relationship between ADT and RUC values. As ADT increases, so does the RUC values, however the increase is not uniform. This data is useful for estimating RUC associated with a rehabilitation project.

Table 6.2 RUC Table for Rural Heavy Truck Route

One lane closed in one direction		
Rural Heavy Truck Route	**ADT**	**$/day/mile**
1	1140	692
2	1434	840
3	1449	849
4	1494	881
5	1567	919
6	2808	1645
7	2815	1660
8	3040	1781
9	3161	1865
10	3729	2189
11	3862	2216
12	4352	2553
13	4358	2555
14	4455	2620
15	4759	2731
16	4987	2926
17	5094	4012
18	5185	4082
19	5828	4600

6.3 Other Rural Road Types

Table 6.3 shows the results from the simulation of other rural roads types. The table shows there is a definite relationship between ADT and RUC values. As ADT increases, so does the RUC values; however, the rate of increase is not uniform. This data is useful for estimating RUC associated with a rehabilitation project.

Table 6.3 RUC Table for Other Rural Road Types

One lane closed in one direction			
ADT	**$/day/mile**	**ADT**	**$/day/mile**
278	194.85	935	953.29
305	196.33	943	990.82
312	228.42	1041	1073.34
341	232.53	1123	1120.22
357	250.85	1152	1116.68
372	275.43	1491	1461.66
453	324.23	1504	1491.70
500	364.71	1583	1582.96
507	370.53	1685	1723.25
525	414.47	1735	1733.55
575	419.55	1775	1829.44
577	471.17	1808	1845.59
591	474.15	2001	2038.77
637	474.59	2095	2121.60
639	492.49	3071	2288.55
680	549.68	3243	2400.59
694	645.82	3333	2513.68
732	691.34	3682	2765.52
774	696.67	4052	3138.34
882	817.36	4079	3207.72
889	863.25	4824	5157.74

7. SUMMARY OF FINDINGS

The goal of the study is to develop a statewide rural road user cost manual that will provide UDOT with a method to quantify road user costs to the traveling public, based on operating and time delays. This study has provided simplified manual techniques for calculating RUC and clarified the process for determining appropriate values to be used in construction contracts. An outline of the user cost manual was developed upon consultation with UDOT engineers. The researchers decided to construct the RUC look-up table to study the sensitivity between ADT and RUC for different road types. Simulation models were developed in VISSIM for different state road networks. Findings suggest that with the increase of ADT, the RUC values increases. Results show a systematic variation between ADT and RUC for lane closures during construction. However, the rate of increase of RUC does not follow any definite pattern. The concept of developing the RUC look-up table will be a useful guide for estimating user costs for any type of rehabilitation projects involving lane closures. This will enable engineers to quickly calculate the RUC for a given project for contracting purpose. Moreover, the findings of this research study will enable more widespread and consistent use of motorist costs in liquidated damages. However, further support of implementation across the state will be aided by additional research that would validate the present findings. An evaluation of the validity and usefulness of the tabular format and the RUC values themselves should be conducted using actual field cases. The tables were developed using typical cross-sections and traffic operations data, and it would be important to ascertain the compatibility of these assumptions with actual field situations. Several case studies could be identified, and a comparison could be made of table values versus actual field conditions. This process would provide an assessment of the soundness of the table values. Further research into the state-of-the-practice in the estimation of vehicle operating costs and accident costs would provide a basis for determining whether these elements can reasonably and appropriately be incorporated into RUC used for liquidated damages.

8. FUTURE WORK

The work that needs to be completed to develop the final version of the user cost manual is described as follows:

1. Meet UDOT project managers and develop a plan for the Urban Road network in Utah.

2. Collect traffic counts for October 2008 and April 2009 for the study area.

3. Build and calibrate the VISSIM model for the Urban Road networks.

4. Construct RUC look up tables.

5. Validate the developed RUC look-up table with field situations.

6. Meet with UDOT's Technical Advisory Committee (TAC) and present findings.

7. Draft and submit a final report.

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