TECHNIQUES FOR MANUALLY ESTIMATING ROAD USER COSTS ASSOCIATED WITH CONSTRUCTION PROJECTS

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INTRODUCTION

ROAD USER COST APPLICATIONS IN TEXAS

"Road user cost" (RUC) is defined as the estimated daily cost to the traveling public resulting from the construction work being performed. That cost primarily refers to lost time caused by any number of conditions including:

- detours and rerouting that add to travel time
- reduced roadway capacity that slows travel speed and increases travel time; and
- delay in the opening of a new or improved facility that prevents users from gaining travel time benefits.

Road user costs have been included in the calculation of liquidated damages on a limited number of projects for at least 10 years in Texas, and more recently have been used in the determination of daily motorist costs for A+B contracts (contracts that consider both construction cost and project duration in contractor selection). The majority of these RUC studies have been performed in the Houston and Dallas Districts. The experience in Houston has led to the development of a short course to provide instruction in the techniques for determining construction-related RUC *(1)*. The course focuses primarily on the use of computer simulation models for construction on major freeways and signalized arterial roadways.

The concept behind RUC and A+B bidding is best represented in Figure A *(2)*. This graphic shows the relationship between cost and time for a theoretical construction project. The curve titled "Construction Cost" shows that the project has an optimum duration of "C" working days. For a contractor to complete the project in less time than this may require additional resources (labor, equipment, and subcontracts), more expensive materials (fast-setting concrete, pre-cast bridge components, etc.), or both. If the duration of the project extends past the optimum point, time-related costs such as project overhead (portable office trailers, project supervisory personnel, etc.) can increase the cost of the project. This curve may differ from contractor to contractor.

The straight lines at the bottom of the graph represent "Road User" and "Contract Administration" costs. These costs are time-related. The longer the project continues, the higher these costs. Therefore, the total cost of the project is the total of the construction, road user and contract administration costs. In this example, the lowest total project cost occurs at "B" working days.

As illustrated in Figure A, road user cost is an integral part of the total cost equation. For this reason, a methodology for determining RUC that uses sound traffic engineering and economic principles is needed so that RUC can be appropriately considered in the bidding process.

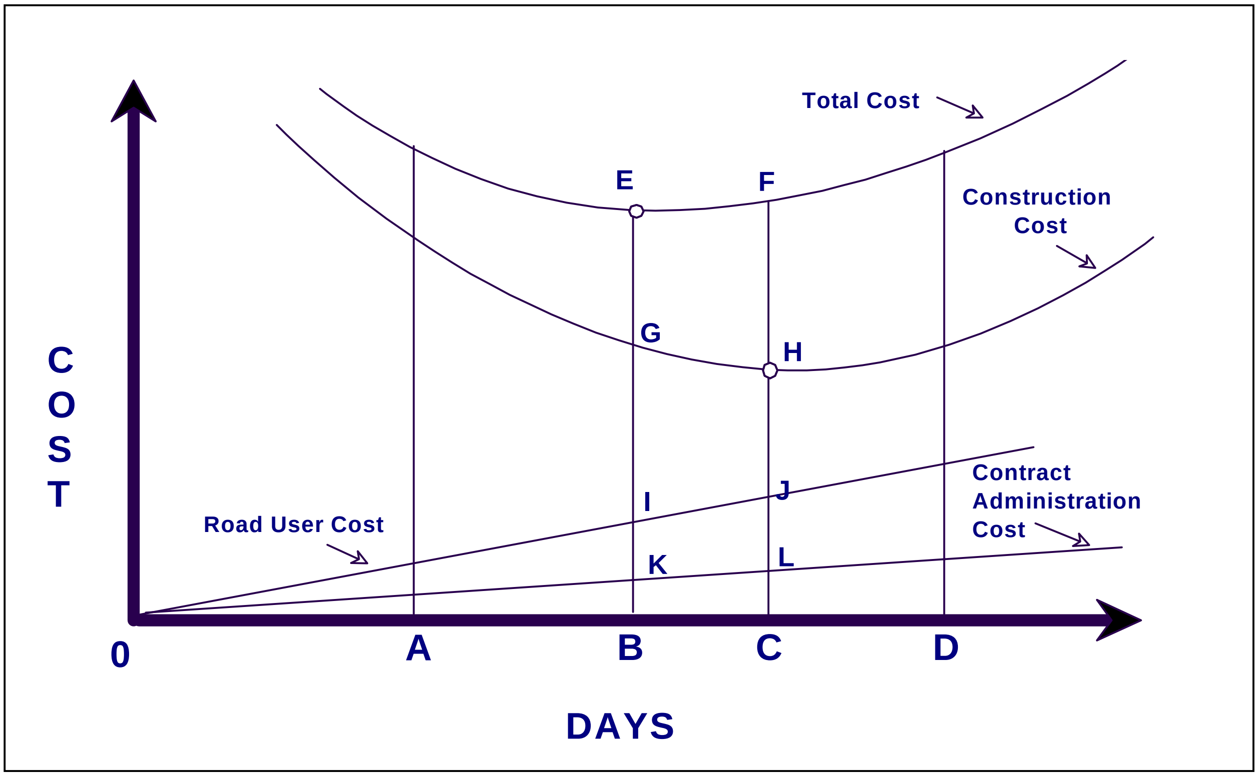


Figure A. Project Costs by Type, Related to Duration

Current TxDOT Guidelines for the Application of Road User Costs

During the 75th Legislative session, Senate Bill 370 was passed and signed into law. Among the many provisions of this law is the requirement that TxDOT "develop a schedule for liquidated damages that accurately reflects the costs associated with project completion delays, including administrative and travel delays" *(3)*. Guidelines developed by the Construction Division were provided to the districts in July 1998 to assist in the process of determining whether RUC should be incorporated into a construction contract *(3a)*. The guidelines are described below:

> *The guidelines outlined herein are to be used as an aid when making decisions on whether to require road user cost on:*
>
> - *projects that add capacity (may include grade separations),*
> - *projects where construction activities are expected to have an economic impact to local communities and businesses, or*
> - *rehabilitation projects in very high traffic volume areas.*
>
> *In addition to at least one of the above, a secondary evaluation should be made considering the following:*
>
> - *Conflicting utilities will be relocated prior to construction and the right-of-way is clear.*
> - *Ensure there is an adequate inspection force.*
> - *Twenty-five percent of the estimated road user cost is greater than the contract administrative liquidated damages.*

- *If any of the secondary criteria is not met, the district should reevaluate the proposed use of road user cost liquidated damages before making the decision.*

Additional guidelines are provided regarding the application of RUC, such as the use of incentives with disincentives, the definition of substantial completion, and recommended special contract provisions to be used for implementing RUC.

PURPOSE OF RESEARCH STUDY

Road user costs in Texas have been applied predominantly on high-profile urban freeway reconstruction projects, which are ideal candidates for RUC application because of the potential for very high motorist delay costs. The July 1998 guidelines provided by TxDOT suggest that all projects that add capacity should be considered for RUC. This applies to a much wider range of projects. Not all potential projects, however, are as complicated as urban freeway reconstruction efforts that require detailed simulation modeling to determine the value of RUC.

There are also questions related to the economic side of the equation: What is the value of time that should be used to determine motorist delay costs? Should other costs, such as vehicle operating costs and accident costs, be included in total road user costs? And should the final calculated value of road user cost be discounted to 25 percent?

The objectives of this research study are:

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 percent.

To address these objectives, this research report is presented in two stand-alone parts. Part I, "Developing a Simplified Manual Technique for Estimating Road User Costs," addresses objectives 1 and 2. Part II, "An Assessment of Value of Time Calculations Used in Texas," addresses objectives 3 and 4.

PART I. DEVELOPING A SIMPLIFIED MANUAL TECHNIQUE FOR ESTIMATING ROAD USER COSTS

CHAPTER 1. RESEARCH APPROACH

PROJECT TYPES

Before a technique for estimating RUC can be devised, an assessment must be made of the types of projects that lend themselves to a simplified method. It is desirable to cover as many different project types as possible with a simplified technique, understanding that (1) certain projects will be too complicated or unique for a generalized approach to be applied, and (2) there are an infinite number of combinations of capacity-upgrade projects.

The first step in this process is to define general categories of projects and the suggested analysis technique for estimating RUC. The project categories are provided in Table 1-1. Each of the pertinent column headings is described below:

Category — Project types and attributes are divided into four broad categories based on the differences in analysis approach and technique.

Description of Projects — Projects and project attributes are described.

Setting — Categories of projects are either classified as urban, rural, or a combination of both.

General Analysis Approach — There are several different approaches to determining RUC depending on the project attributes:

- Phase-by-Phase Approach - The calculated user costs can be used as the basis for liquidated damages for milestone completions of each phase or selected phases of the project. This approach is most applicable to those projects with severe capacity restrictions during construction where phase completion time is critical.

- "Before versus After" Approach - As opposed to a phase-by-phase approach, a "before and after" comparison of user costs focuses on the delay in final completion of a new or improved facility. Each day the final improved facility is delayed is another day that users are unable to realize travel time savings and other benefits from the additional roadway capacity.

- "During Construction versus After" Approach – This approach is a combination of the two described above, and is applicable to projects where the final improvements do not result in an increase in capacity, i.e., rehabilitation projects. The "during construction versus after" approach compares the user costs associated with lane restrictions during construction against the user costs after the construction is completed.

Analysis Technique — Road user costs can be estimated using a number of different techniques. 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).

Reference Guide — Guidelines and procedures have previously been developed for projects that fall in Categories I and II *(1)*. Also included in that manual are procedures for calculating by hand projects such as bypasses and detours. The projects that are described in Categories III and IV lend themselves to the use of the simplified manual techniques developed in this study.

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*

Tables 1-2 and 1-3 show the different project types selected for development of RUC tables as well as general assumptions for calculating RUC values. Table 1-2 includes the projects that correspond to Category II, which are "added capacity projects." Table 1-3 shows the project types that correspond to Category IV, which are "rehabilitation" projects. A full listing of input variables is included in Appendix B. Additional items of note regarding selection of project types are provided below:

- To the extent possible, the roadway classifications, the ADT ranges, and the design features selected are consistent with TxDOT terminology and design standards.

- Roadways in highly urbanized areas are typically characterized by operational features such as closely spaced signals on arterials and closely spaced ramps and interchanges on freeways. Roadways with these attributes are not candidates for simplified manual techniques for estimating RUC due to wide variations in operational conditions. For this reason, the basic urban cross sections for which RUC values have been estimated are characterized as follows:

  - *Urban arterials* — The urban arterials selected for this project are consistent with the description in the Highway Capacity Manual for typical suburban arterials *(4)*. They are characterized by low driveway density, separate left-turn lanes, one to five signals per mile, little pedestrian activity, and low to medium density roadside development. For arterial roadways, the unit of length used for applying RUC values is one-half mile, meaning the table values represent RUC per day per 0.5 mile.

  - *Urban freeways* — The four-lane and six-lane urban 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.

Table 1-2. Project Types And Variables – Added Capacity

DESIGN PARAMETER	RURAL			DESIGN PARAMETER		
	2-lane minor arterial	**4-lane undivided principal arterial**	**4-lane divided principal arterial**		**4-lane Interstate**	**6-lane Interstate**
AADT base year [range]	2,500-100,000	5,000-115,000	5,000-115,000	AADT base year [range]	40,000 - 125,000	50,000 - 135,000
Percent trucks [range]	5% - 20%	5% - 20%	5% - 20%	Percent trucks [range]	5%-25%	5%-25%
Access control	none	none	none	Access control	full	full
Segment length (miles)	1	1	1	Segment length (miles)	1	1
Type of intersection	none	none	none	Median width (feet)	48	48
Number of intersections	none	none	none	Lane width (feet)	12	12
Median width (feet)	0	0	16	Shoulder width (feet)	10	10
Functional classification	minor arterial	principal arterial	principal arterial	Percent grade	0	0
Lane width (feet)	12	12	12	Degree curvature	0	0
Shoulder width (feet)	4	4	10	Free flow speed (mph)	70	70
Percent grade	0	0	0	Speed limit (mph)	65	65
Degree curvature	0	0	0			
% no passing zones	0% to 25%	-	-			
Free flow speed (mph)	70	70	70			
Speed limit (mph)	55	65	65			

DESIGN PARAMETER	URBAN			DESIGN PARAMETER		
	2-lane minor arterial	**4-lane divided principal arterial**	**6-lane divided principal arterial**		**4-lane freeway**	**6-lane freeway**
AADT base year [range]	2,500-40,000	25,00-100,000	2,500-100,000	AADT base year [range]	20,000-300,000	20,000-300,000
Percent trucks [range]	0% - 10%	0% - 10%	0% - 10%	Percent trucks [range]	5% - 10%	5% - 10%
Access control	none	none	none	Access control	full	full
Segment length (miles)	0.5	0.5	0.5	Segment length (miles)	1	1
Type of intersection	none	none	none	Median width (feet)	24	24
Number of intersections	none	none	none	Lane width (feet)	12	12
Median width (feet)	0	14	14	Shoulder width (feet)	10	10
Arterial class – design	suburban	suburban	suburban	Percent grade	0	0
Arterial class – function	minor arterial	principal arterial	principal arterial	Degree curvature	0	0
Lane width (feet)	12	12	12	Free flow speed (mph)	70	70
Shoulder width/lateral clr. (feet)	3	3	3	Speed limit (mph)	55	55
Percent grade	0	0	0			
Degree curvature	0	0	0			
Free flow speed (mph)	35	40	40			
Speed limit (mph)	35	35	35			

Table 1-3. Project Types And Variables — Rehabilitation

RURAL

DESIGN PARAMETER	4-lane divided principal arterial
AADT base year [range]	5,000-115,000
Percent trucks	10%
Access control	none
Segment length (miles)	1
Type of intersection	none
Number of intersections	none
Median width (feet)	16
Functional classification	principal arterial
Lane width (feet)	12
Shoulder width (feet)	10
Percent grade	0
Degree curvature	0
Free flow speed (mph)	70
Speed limit (mph)	65

DESIGN PARAMETER	4-lane Interstate	6-lane Interstate
AADT base year [range]	10,000 - 100,000	50000 - 120000
Percent trucks	15%	15%
Access control	full	full
Segment length (miles)	1	1
Median width (feet)	48	48
Lane width (feet)	12	12
Shoulder width (feet)	10	10
Percent grade	0	0
Degree curvature	0	0
Free flow speed (mph)	70	70
Speed limit (mph)	65	65

URBAN

DESIGN PARAMETER	4-lane divided principal arterial	6-lane divided principal arterial
AADT base year [range]	2,500-100,000	2,000-150,000
Percent trucks	5%	5%
Access control	none	none
Segment length (miles)	0.5	0.5
Type of intersection	none	none
Number of intersections	none	none
Median width (feet)	14	14
Arterial class – design	suburban	suburban
Arterial class – function	principal arterial	principal arterial
Lane width (feet)	12	12
Shoulder width/lateral clr. (feet)	3	3
Percent grade	0	0
Degree curvature	0	0
Free flow speed (mph)	40	40
Speed limit (mph)	35	35

DESIGN PARAMETER	4-lane freeway	6-lane freeway
AADT base year [range]	25,000-125,000	25,000-200,000
Percent trucks [range]	5%	5%
Access control	full	full
Segment length (miles)	1	1
Median width (feet)	24	24
Lane width (feet)	12	12
Shoulder width (feet)	10	10
Percent grade	0	0
Degree curvature	0	0
Free flow speed (mph)	70	70
Speed limit (mph)	55	55

SELECTION OF MANUAL TECHNIQUE

Following review of several possible manual techniques, the researchers decided to construct look-up tables that provide RUC values based on project type and a minimal number of project attributes. Two different approaches were employed: a "before versus after" approach for added capacity projects, and a "during construction versus after" approach for rehabilitation projects. The tables for these two approaches are constructed in a somewhat different way and require different procedures for using the values.

Format for RUC Tables

Added-Capacity Projects Using a "Before versus After" Comparison

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. The absolute difference between the total motorist costs in the "before" condition and total motorist costs in the "after" condition is the total daily excess cost, which is the value to be used in liquidated damages. The delay costs are the most significant of the three component costs. Delays are experienced as the travel speed goes down due to capacity and geometric and operational constraints. The delay from the "before" condition is compared to that of the "after" or improved condition, and the difference represents delay savings. The savings are then multiplied by the value of time to arrive at a dollar value of motorist time costs. For the purpose of estimating RUC for contracting, the value of the excess delay costs will be the only component of RUC considered.

In order to cover the greatest possible range of added-capacity project types, separate tables were developed for 10 different project 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) 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 between the two values represents the daily benefits that the users do not realize until the project is substantially complete and open to traffic. An example of the procedure is presented in Figure 1-1.

Figure 1-1. Examples of RUC Tables for Added-Capacity Projects

Two-Lane Rural Highway (0%-25% No Passing Zones)
(in $/day per mile)

ADT	5% trucks	10% trucks	15% trucks	20% trucks
5000	1,400	1,400	1,500	1,500
7500	2,100	2,200	2,200	2,300
10000	2,800	2,900	3,000	3,100
12500	3,600	3,700	3,800	3,900
15000	4,400	4,500	4,600	4,700
17500	5,200	5,300	5,500	5,600
20000	6,000	6,200	6,400	6,500
22500	7,000	7,200	7,400	7,500
25000	8,000	8,300	8,500	8,700
27500	9,300	9,600	9,800	10,100
30000	10,700	11,000	11,200	11,500
32500	12,300	12,600	12,900	13,200
35000	14,000	14,400	14,800	15,200
37500	16,100	16,500	16,900	17,400
40000	18,300	18,800	19,300	19,800
42500	20,700	21,200	21,800	22,400
45000	23,300	24,000	24,600	25,200
47500	26,000	26,700	27,400	28,100
50000	28,800	29,600	30,300	31,100

Four-Lane Rural Divided Highway
(in $/day per mile)

ADT	5% trucks	10% trucks	15% trucks	20% trucks
5000	1,400	1,400	1,500	1,500
7500	2,100	2,100	2,200	2,300
10000	2,800	2,900	3,000	3,000
12500	3,500	3,600	3,700	3,800
15000	4,200	4,300	4,500	4,600
17500	4,900	5,100	5,200	5,300
20000	5,700	5,800	6,000	6,100
22500	6,400	6,600	6,700	6,900
25000	7,100	7,300	7,500	7,700
27500	7,900	8,100	8,300	8,500
30000	8,700	8,900	9,100	9,400
32500	9,400	9,700	9,900	10,200
35000	10,200	10,500	10,800	11,000
37500	11,000	11,300	11,600	11,900
40000	11,800	12,200	12,500	12,800
42500	12,700	13,000	13,400	13,700
45000	13,500	13,900	14,300	14,600
47500	14,500	14,900	15,300	15,600
50000	15,400	15,800	16,300	16,700

Example problem: A proposed project involves the upgrade of one mile of a two-lane rural highway to a four-lane divided highway. The proposed project will have an average daily traffic (ADT) volume of 40,000 vehicles per day and 15% trucks.

Existing condition: Road user costs are $19,300/day
Proposed condition: Road user costs are $12,500/day
Difference $6,800/day

Costs of motorist delay for each day the project is delayed: $6,800 per day

A detailed example of the method for using the graphs to arrive at an RUC estimate for added-capacity projects is provided in Chapter 2 "Recommended Practices."

Rehabilitation Projects Using a "During Construction Versus After" Comparison

For rehabilitation projects that do not result in the addition of capacity, separate tables were developed for seven different project types under two different lane restriction scenarios. The values provided in the tables are the estimated daily user benefits that are being lost while rehabilitation work is underway. Figure 1-2 provides an example of the procedure for estimating RUC for a rehabilitation project.

Figure 1-2. Example of RUC Table for Rehabilitation Project

Work Zone on a Four-Lane Rural Divided Arterial - 10% Trucks
(in $/day per mile)

One Lane Closed in One Direction		Four Lanes with Reduced Capacity	
ADT	Road User Costs	ADT	Road User Costs
5000	0	5000	0
10000	0	10000	0
15000	100	15000	0
20000	200	20000	0
25000	600	25000	100
30000	1,400	30000	100

Example problem: On a four-lane rural highway with an ADT of 30,000 and 10% truck volume, a one-mile rehabilitation project is proposed that will involve the closing of one lane in one direction.

Road user cost from the table: $1,400/day

A detailed example of this method for arriving at an RUC estimate for a rehabilitation project is provided in Chapter 2 "Recommended Practices."

DERIVATION OF ROAD USER COST VALUES

A model was needed to calculate RUC values for the various tables. The two characteristics that were important in selecting the analysis technique were (1) the model should be consistent with the scale of analysis and the level of assumptions that would have to be made to cover a broad range of project types, and (2) the model should be easy to use but based on sound traffic flow and economic theory.

The model selected by researchers for the development of RUC values is MicroBENCOST, a planning-level economic analysis tool developed by TTI under NCHRP Project 7-12 (5). The MicroBENCOST (MBC) program is designed for economic analysis of a variety of highway improvements. It uses standard methodologies for traffic allocation and speed/delay calculations. From an economic standpoint, the advantage of the program is that the calculation of user costs is included in the computations. For example, the program takes into account the vehicle mix (including trucks) and the impact of vehicle speeds when it assigns delay costs. The program calculates user costs for a 24-hour period, 365 days per year.

Use of MicroBENCOST for Developing RUC Tables

Figures 1-3 and 1-4 are flow charts illustrating the basic functions of the MicroBENCOST program and how it was used to develop RUC values for both added-capacity projects and rehabilitation projects as part of this study.

Added-Capacity Projects Using a "Before versus After" Comparison

As illustrated in Figure 1-3, the base geometric and traffic conditions were input and the total motorist time costs for the roadway were determined. As shown in the figure, the values were retrieved from the output provided for the existing or "before" condition and not from the economic measures listed in the final summary. Iterative runs of the program were made for varying levels of ADT and truck percentages.

Rehabilitation Projects Using a "During Construction Versus After" Comparison

As illustrated in Figure 1-4, the full program features were used because specific lane closure scenarios were defined. For the eight different project types selected, two lane closure scenarios were considered: (1) a situation where one lane is closed in the inbound direction, and (2) where there is reduced capacity (due to lane width, lateral clearance, construction activity, etc.).

Figure 1-3. Modification of MicroBENCOST for Development of RUC on Added-Capacity Projects

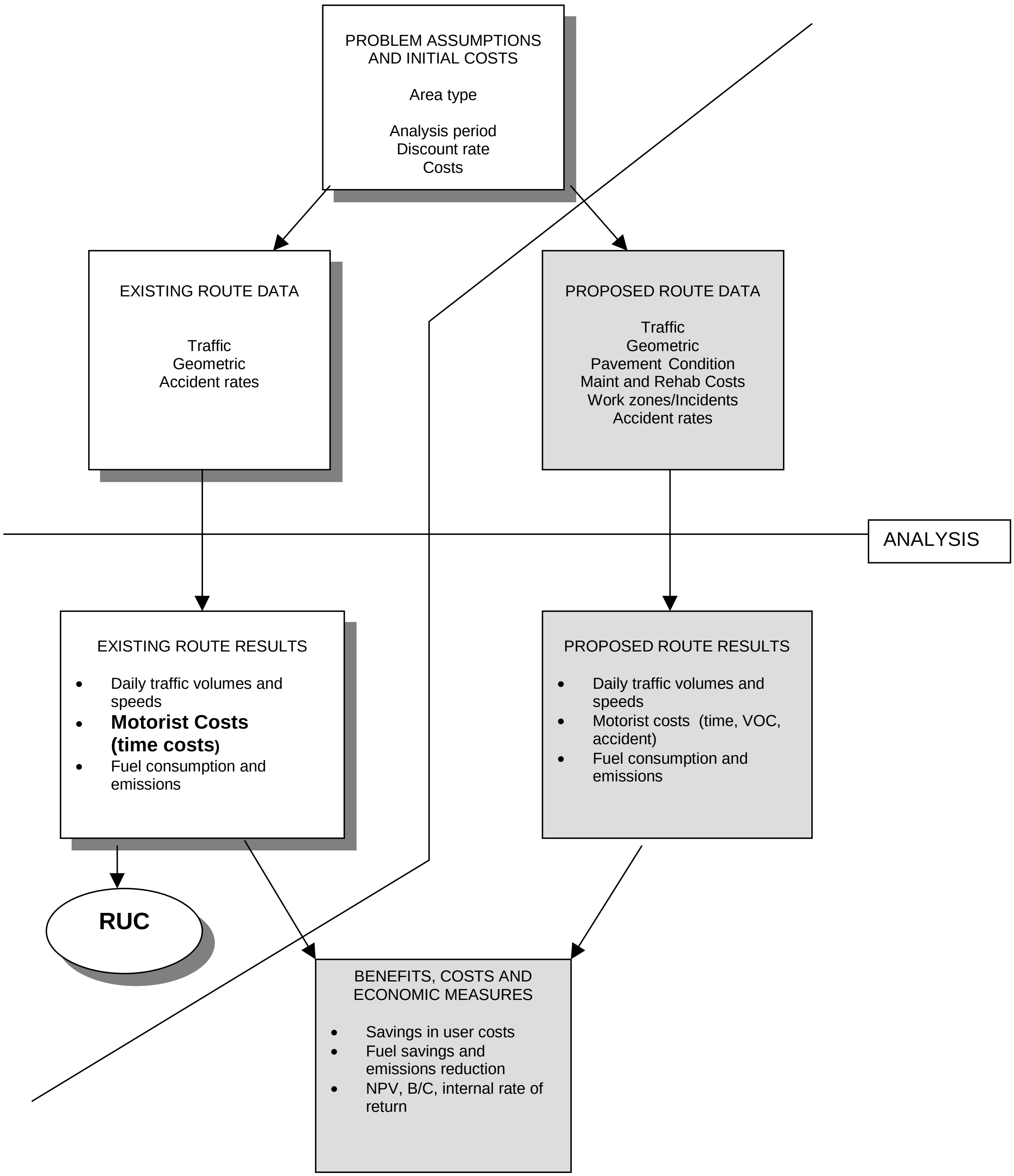
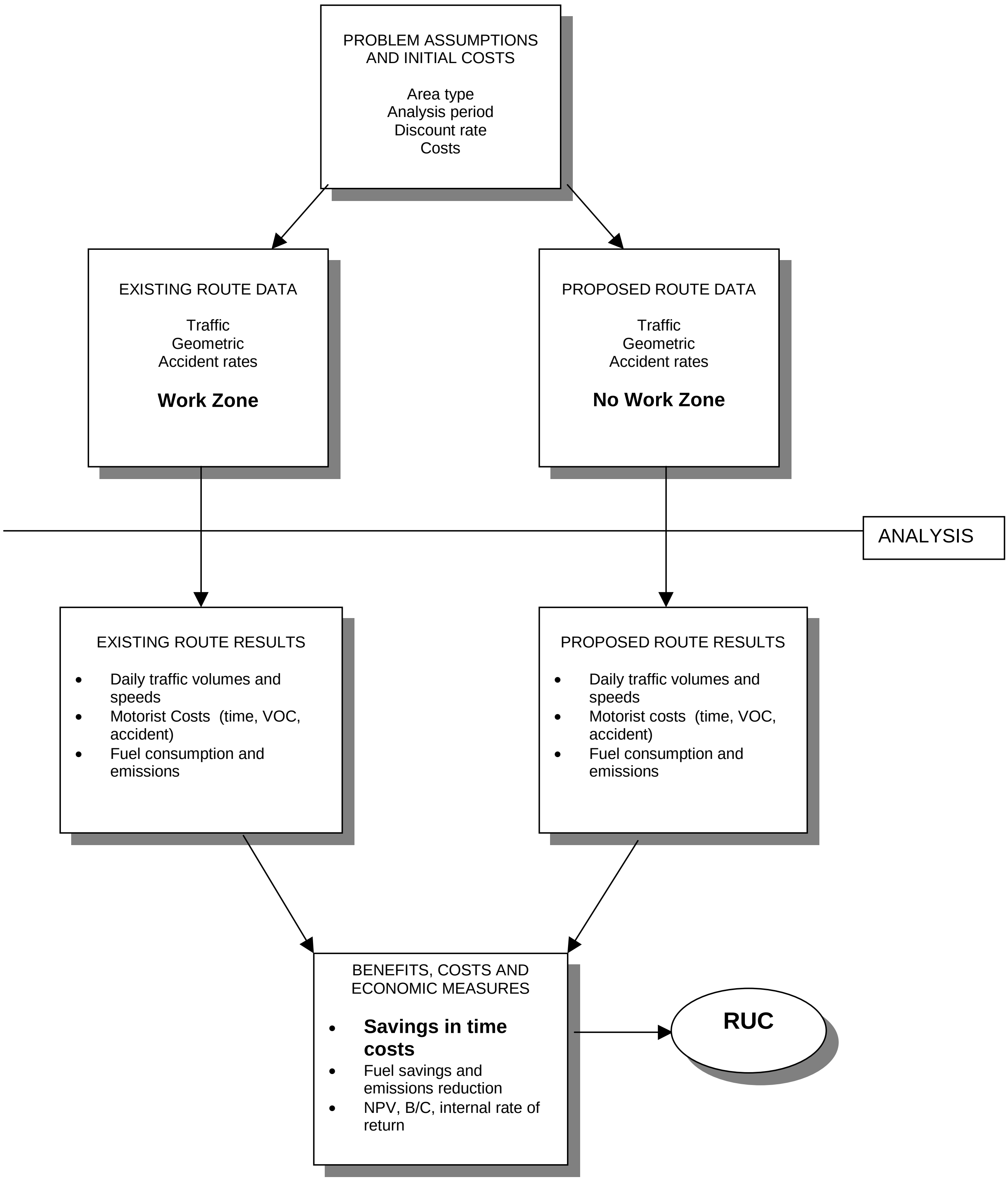


Figure 1-4. Use of MicroBENCOST for Development of RUC on Rehabilitation Projects



Underlying Relationships and Assumptions

MicroBENCOST is a comprehensive program utilizing best practical procedures for highway economic analysis. The program combines both user inputs and defaults for the values used in the analysis. Appendix A provides the detailed input values for each project type and a summary of the notable default parameters used by the program in the derivation of RUC. In all scenarios that were run, the final program was given in user costs per year, which were converted to daily costs.

The following section are modifications made to the default values in the program.

Value of Time

Part II of this report addresses questions regarding the value of time used for RUC estimation. The values used in MicroBENCOST were consistent with the findings of this research effort; i.e., the value of time for passenger car occupants used by TxDOT, as well as that in MicroBENCOST, is reasonable in terms of the value and underlying theory. The value of time used in MicroBENCOST for trucks is also that used by TxDOT. The values used in the program were updated from 1990 to 1998 values using the Consumer Price Index (CPI). The values used are provided in Table 1-4.

Table 1-4. Values of Time used in the Derivation of Road User Costs

Vehicle Type	Value of Time from MBC 1990 dollars	1990 Value of Time Adjusted to 1998 (using CPI)
Small passenger car	$9.75	$12.16
Medium/large passenger car	$9.75	$12.16
Pickup/van	$9.75	$12.16
Bus	$10.64	$13.27
2-axle single unit truck	$13.64	$17.01
3-axle single unit truck	$16.28	$20.30
2-S2 semi truck	$20.30	$25.32
3-S2 semi truck	$22.53	$28.10
2-S1-2 semi truck	$22.53	$28.10
3-S2-2 semi truck	$22.53	$28.10
3-S2-4 semi truck	$22.53	$28.10

Speed-Volume Relationship for Suburban Arterials

For arterial streets in urban areas, traffic signals dominate the flow of traffic and dictate the speed of through traffic. The 1985 *Highway Capacity Manual*, upon which MicroBENCOST is based, outlines procedures that require detailed signal operation, phasing and conflicting cross-street traffic flows to determine delay. The program, therefore, does not use demand-to-capacity ratio for determining vehicular speeds for the arterial analysis in the same way it does for the other analyses. Instead, it computes vehicular delay for arterials using signalized intersection data.

As mentioned previously, it is impractical to develop one set of signal operation, signal spacing, and cross-street volume assumptions that would render meaningful and useful results for a wide range of project types. Therefore, a new speed-volume relationship for urban arterials was devised for the program based on the Bureau of Public Roads (BPR) for speed, flow, and level of service relationship *(6)*:

$$S_r = S_f \frac{1}{(1 + 0.15(d/c)^4)}$$

where

S_r = Average running speed
S_f = Free-flow speed
d/c = Hourly demand-to-capacity ratio

Table 1-5 presents the values used in the program for the speed-volume relationship on suburban arterials with long signal spacings.

Table 1-5. Speed-Volume Relationship for Principal Arterials in Suburban Areas

Hourly Demand-to-Capacity Ratio	Free-Flow Speed (mph)	Average Running Speed (mph)
0	50	50
0.2	50	50
0.4	50	50
0.6	50	49
0.8	50	47
1	50	43
1.2	50	38
1.6	50	25
2	50	15

Development of RUC Values for Rehabilitation Projects

Additional features of MicroBENCOST were used to develop two different scenarios for a "during construction versus after" analysis.

- *Closure of One Lane* — MicroBENCOST contains a work zone routine that can simulate lane closures. It can accept data on the number of days of lane closure, the number of lanes closed by direction, the hours of the lane closure, and the capacity of the remaining lanes during the closure period. The default value provided by MicroBENCOST is 80% of the non-restricted lane capacity. For the scenario involving a one-–lane closure, the routine was run for a 365-day, 24-hour lane closure. The final annual costs were converted to daily costs.

- *All Lanes Opened with Reduced Capacity* — For the reduced capacity scenario, which represents the condition in which the same number of lanes remain open during construction but are affected by reduced lane widths, lateral clearance, and other factors that influence traffic flow, a different analysis approach was taken. The existing and proposed conditions were set up with identical input data, with the exception of the 80% lane capacity value used in the existing condition. In other words, the program was run with the existing condition representing the work zone with reduced capacity, and the proposed condition represented non-construction conditions.

Sensitivity of MicroBENCOST and Comparison with Other Methods

In general, 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. However, 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 of an 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.

MicroBENCOST was compared to several different methods for calculating RUC. The program provides reasonable values in comparison to other methods and given the work zone conditions analyzed. A summary of that comparison is provided in Figure 1-5.

Figure 1-5. Model Comparisons

MODEL USED:

MBC - MicroBENCOST, NCHRP economic analysis software (*7*)
Simulation models - PASSER, FREQ, etc. used in training course examples (*1*)
1310 - Tables developed using HEEM-III for added capacity and QUEWZ-92 for lane use (*2*)
TAC - Transportation Association of Canada, Highway User Cost Tables, 1993 (*8*)
Gaj - Table from "Lane Rental: An Innovative Contracting Practice" (*9*)

RESULTS:

Comparison 1: Added Capacity

Rural 2-lane undivided upgraded to a 4-lane divided

1. Assumptions: 10,000 ADT, 5% trucks, 50% passing allowed
   Results:
   - MBC: $100/day in travel time costs
   - TAC: $153/day in travel time costs
   - 1310: $200/day in travel time costs

2. Assumptions: same as above with 15,000 ADT
   Results:
   - MBC: $200/day in travel time costs
   - TAC: $290/day in travel time costs
   - 1310: $300/day in travel time costs

3. Assumptions: same as above with 20,000 ADT
   Results:
   - MBC: $300/day in travel time costs
   - TAC: not available
   - 1310: $600/day in travel time costs

Comparison 2: Rehabilitation (Lane Use During Construction)

1. Assumptions: 8-Lane freeway, 67,220 ADT, 2 lanes closed in outbound direction from 8 am to 4 pm
   Results:
   - MBC: $1,200/day in travel time costs
   - Simulation model: $280/day in travel time costs
   - Gaj: $10,000/day in travel time costs
   - 1310: $800/day in travel time costs

2. Assumptions: 8-lane freeway, 160,000 ADT, 1 lane closed inbound
   a) Lane closed from midnight to 6 am
   Results:
   - MBC: $10/day in travel time costs
   - Gaj: $3,000/day in travel time costs
   - 1310: $6,000/day in travel time costs (off-peak)

   b) Lane closed from 9 am to 3 pm
   Results:
   - MBC: $2,500/day in travel time costs
   - Gaj: $3,000/day in travel time costs
   - 1310: $6,000/day in travel time costs (off-peak value)

   c) Lane closed from 6 am to noon
   Results:
   - MBC: $6,500/day in travel time costs
   - Gaj: $7,500/day in travel time costs (combination of peak and off-peak)
   - 1310: $71,900/day in travel time costs

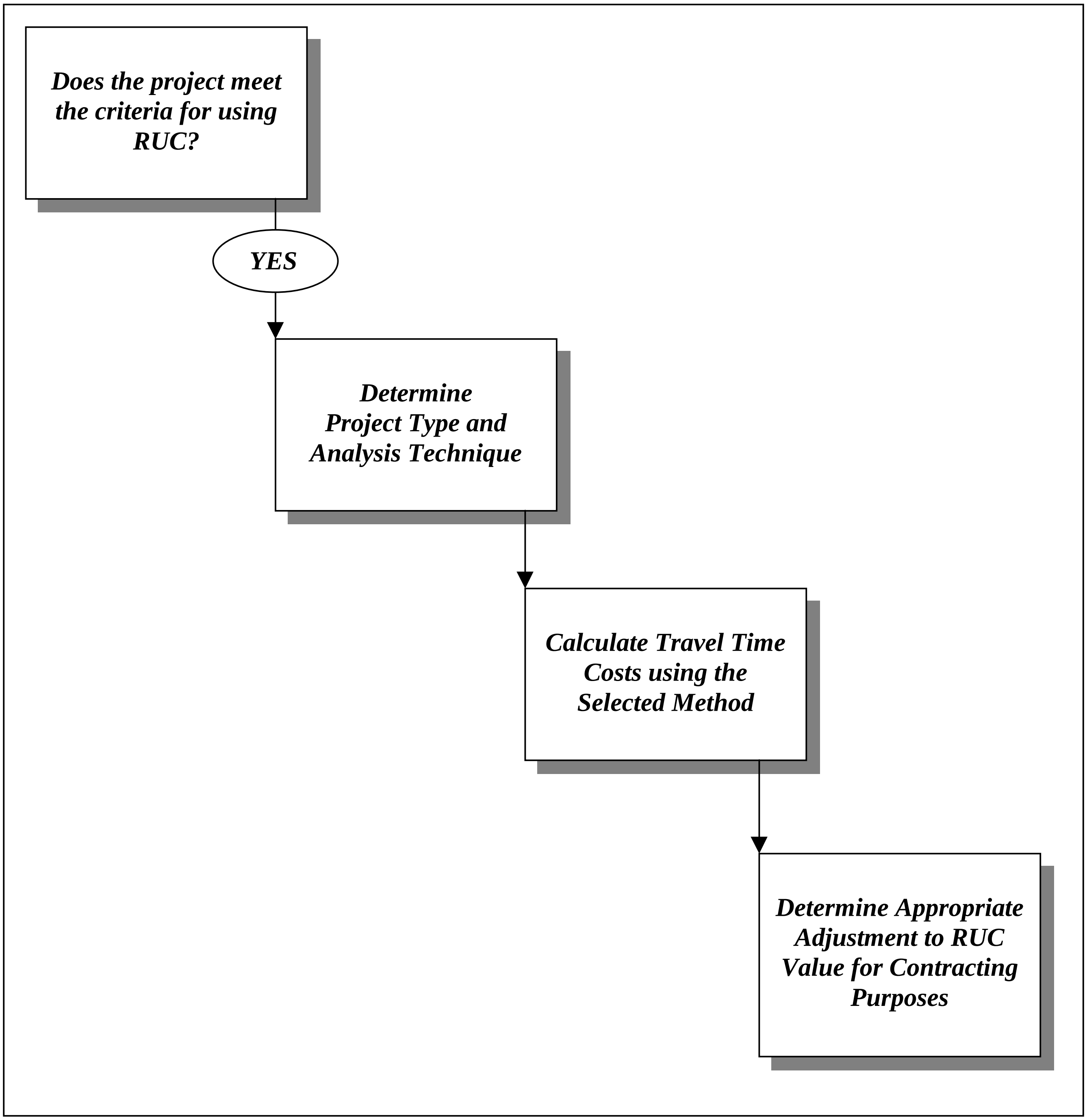
   d) Lane closed from 2 pm to 8 pm
   Results:
   - MBC: $5,000/day in travel time costs
   - 1310: $6,000/day in travel time costs
   - Gaj: $7,500/day in travel time cost

CHAPTER 2. RECOMMENDED PRACTICES

PROCESS FOR DETERMINING ROAD USER COSTS

The purpose of this chapter is to describe the procedure for estimating RUC using the resource documents that are available. Figure 1-6 is a flow chart of the process, and each step of the process is described in the section that follows.

Figure 1-6. Procedure for Estimating Road User Costs



Step One: Does the Project Meet the Criteria for Using RUC?

There are several important factors that must be considered before using RUC in the liquidated damages. The criteria are outlined in a July 1998 TxDOT memorandum *(3a)*. Guidelines developed by the Construction Division were provided to the districts in July 1998 to assist in the process of determining whether the RUC should be incorporated into a construction contract. The guidelines are described below:

> *The guidelines outlined herein are to be used as an aid when making decisions regarding whether to require road user cost on projects:*
>
> *Criteria for the use of RUC:*
>
> - *projects that add capacity (may include grade separations),*
> - *projects where construction activities are expected to have an economic impact on local communities and businesses, and*
> - *rehabilitation projects in very high traffic volume areas.*
>
> *In addition to at least one of the above, a secondary evaluation should be made considering the following:*
>
> - *Conflicting utilities will be relocated prior to construction and the right-of-way is clear,*
> - *Ensure there is an adequate inspection force, and*
> - *Twenty-five percent of the estimated road user cost is greater than the contract administrative liquidated damages.*
>
> *If any of the secondary criteria is not met, the district should reevaluate the proposed use of road user cost liquidated damages before making the decision.*

Additional guidelines are provided in the memorandum regarding the application of RUC, such as the use of incentives with disincentives, the definition of substantial completion, and recommended special contract provisions to be used for implementing RUC *(3a)*.

Step Two: Determine Project Type and Analysis Technique

Once it is determined that RUC will be included in liquidated damages, then an assessment must be made to determine the analysis approach. Table 1-6 provides a simple method for determining the category in which a project is classified and the recommended technique for calculating RUC.

Two reference guides provide assistance in calculating RUC:

- *A Short Course on Techniques for Determining Construction Related Road User Costs.* — This course and guidebook developed by TTI provides instruction primarily on techniques for calculating RUC using the FREQ and PASSER series of models, which are appropriate for projects in Categories I and II. The course and reference document are based on extensive experience in the development of RUC in the Houston District. Also included in the document are some example hand calculations for bypass (new facility) projects and detour routing.

- This research report — Provided herein are look-up tables for estimating RUC values for projects in Categories III and IV under typical project conditions.

Table 1-6. 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** • 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*

Step 3: Calculate Travel Time Costs Using the Selected Method

For projects that fall under Categories III and IV, tables have been constructed that can be used for typical project conditions. These tables are located in Appendix A.

The following considerations should be made when using the tables:

1. The tables are based on general conditions with numerous assumptions. Before using the tables, the input variables listed in Appendix B of this report should be reviewed to ensure the project parameters are not significantly different. In general, MicroBENCOST (the program used to calculate the values) is most sensitive to the volume of traffic; hence the value of ADT is the basis for the RUC values. At lower volumes of traffic, minor variations in the input variables have minimal impact on the final outcome. However, as traffic volumes increase, all significant variations in the input data should be considered important.

   Geometric data such as lane width, median width, and shoulder width have less of an impact on the output other than input variables unless they fall out of normal ranges. Wide variation in the percentage of trucks, 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. As an alternative, project RUC can be calculated using methods described in *A Short Course on Techniques for Determining Construction Related Road User Costs (1).*

2. The tables should not be used for arterial roadway projects in urban areas with signal spacing of less than one-half mile. The urban arterial roadways for which the tables are developed are suburban roadways with low driveway density, separate left-turn lanes, one to two signals per mile, little pedestrian activity, and low to medium density roadside development. Note that the RUC values given in the urban arterial tables are on a 0.5 mile unit basis.

3. The four-lane and six-lane urban 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.

4. The two categories of tables, “Added Capacity” and “Rehabilitation,” require different procedures for determining RUC.

a) Example for an Added Capacity Project – Category III

Two-Lane Rural Highway (0-25% No Passing Zones) (in $/day per mile				
ADT	5% trucks	10% trucks	15% trucks	20% trucks
5000	1400	1400	1500	1500
7500	2100	2200	2200	2300
10000	2800	2900	3000	3100
12500	3600	3700	3800	3900
15000	4400	4500	4600	4700
17500	5200	5300	5500	5600
20000	6000	6200	6400	6500
22500	7000	7200	7400	7500
25000	8000	8300	8500	8700
27500	9300	9600	9800	10100
30000	10700	11000	11200	11500
32500	12300	12600	12900	13200
35000	14000	14400	14800	15200
37500	16100	16500	16900	17400
40000	18300	18800	19300	19800
42500	20700	21200	21800	22400
45000	23300	24000	34600	25200
47500	26000	26700	27400	28100
50000	28800	29600	30300	31100

Four-Lane Rural Divided Highway (in $/day per mile)				
ADT	5% trucks	10% trucks	15% trucks	20% trucks
5000	1400	1400	1500	1500
7500	2100	2100	2200	2300
10000	2800	2900	3000	3000
12500	3500	3600	3700	3800
15000	4200	4300	4500	4600
17500	4900	5100	5200	5300
20000	5700	5800	6000	6100
22500	6400	6600	6700	6900
25000	7100	7300	7500	7700
27500	7900	8100	8300	8500
30000	8700	8900	9100	9400
32500	9400	9700	9900	10200
35000	10200	10500	10800	11000
37500	11000	11300	11600	11900
40000	11800	12200	12500	12800
42500	12700	13000	13400	13700
45000	13500	13900	14300	14600
47500	14500	14900	15300	15600
50000	15400	15800	16300	16700

Problem: A proposed project involves the upgrade of 1.5 miles of a two-lane rural highway to a four-lane divided highway. The proposed project will have an average daily traffic (ADT) volume of 25,000 vehicle per day and 15% trucks.

Solution:

Existing condition:	Road user costs are	$8,500/day/mile
Proposed condition:	Road user costs are	<u>$7,500/day/mile</u>
	Difference	$1,000/day/mile X 1.5 miles

Costs of motorist delay for each day the project is delayed: $1,500 per day.

b) Example for a Rehabilitation Project – Category IV

Work Zone on a Four-Lane Rural Divided Arterial - 10% Trucks (in $/day per mile)			
One Lane Closed in One Direction		Four Lanes with Reduced Capacity	
ADT	Road User Costs	ADT	Road User Costs
5000	0	5000	0
10000	0	10000	0
15000	100	15000	0
20000	200	20000	0
25000	600	25000	100
30000	1,400	30000	100
35000	2,600	35000	200
40000	4,300	40000	400
45000	6,200	45000	700
50000	8,300	50000	1,300
55000	10,300	55000	1,800
60000	12,500	60000	2,500
65000	14,600	65000	3,400
70000	16,600	70000	4,500
75000	18,500	75000	5,600
80000	20,200	80000	6,800

Problem:

On a four-lane rural highway with an ADT of 45,000 and 10% truck volume, a two-mile rehabilitation project is proposed in which four lanes will still be open to traffic but capacity will be restricted.

Solution:

Road user cost from the table: $700/day X 2 miles = $ 1,400/day

Step 4: Determine Appropriate Adjustment to RUC Value for Contracting Purposes

The percentage of RUC to be included in liquidated damages can be approached in two different ways. The first way is to use the default cap of 25% of calculated RUC. This value is based on previous research that showed that the additional construction costs paid to speed up a project had an economic value roughly four times that of the savings in delay costs to road users. Maintaining the current practice of including 25% of RUC is readily defensible.

The second approach is to adjust the level of RUC applied to liquidated damages based on the unique features of the project. Any level of RUC, up to and including 100%, is defensible. In making a decision about the level to use, it is recommended that the following factors be considered:

1. *Importance of on-time completion* — Local factors will determine the importance of on-time completion. This factor could be important because of upcoming events, or other upcoming projects. It could be that the project is very high-profile or the subject of intense local concern. Under any of those and other circumstances, TxDOT may want to consider raising the level of RUC in the liquidated damages.

2. *Current contracting capacity and pool of projects available* — As indicated in the research, the competitiveness of the bidding environment may warrant consideration in selecting an appropriate level of RUC. If contractors' capacity is being stretched because of a high volume of work underway, then they will likely approach a bid that includes high RUC with caution, since they could be at risk of substantial liquidated damages. They may very well bid higher than they would otherwise, recognizing their potential for liquidated damages and simply including those expenses in their bid price. Conversely, if the bidding environment is more competitive (many contractors without enough work), then the likelihood of overrunning the schedule may be easier to control and therefore the contractors would be more likely to bid less of a premium price to cover potential liquidated damages. Further, if there are numerous other jobs bidding, contractors may forego bidding on jobs with high RUC in order to bid on less risky jobs.

3. *Reasonableness of calculated excess RUC* — The level of RUC included in liquidated damages should be reasonable. Looking at the charts showing RUC, one can see that they range from very small ($100/day for suburban arterial upgrade) to very high (>$65,400/day for urban freeway upgrade). In the case of the very small, discounting RUC to $25 per day probably has very little impact, since contractor and TxDOT fixed expenses are likely much higher. If RUC are to be used at all, they probably should not be discounted. On the high end, $65,400+ per day may seem to be extreme, in which case the RUC should be discounted to a more reasonable amount.

4. *Complexity of project and extent of "unknowns"* — TxDOT may want to consider how much RUC to include on projects that have the potential of delays due to unknowns. The Department's guidelines for application of RUC already recognize that right-of-way and utility relocation issues impact on the applicability of RUC. If a project has other potential

unknowns, such as underground facilities, archaeology, cemeteries, etc., it may be wise to discount or eliminate RUC as a component in liquidated damages.

ROAD USER COST TABLES

The following tables are provided in Appendix A:

- Added Capacity Projects
    - Rural two-lane minor arterial (Table A-1)
    - Rural four-lane undivided arterial (Table A-2)
    - Rural four-lane divided arterial (Table A-3)
    - Rural four-lane interstate highway (Table A-4)
    - Rural six-lane interstate highway (Table A-5)
    - Suburban two-lane minor arterial (Table A-6)
    - Suburban four-lane divided arterial (Table A-7)
    - Suburban six-lane divided arterial (Table A-8)
    - Urban four-lane freeway (Table A-9)
    - Urban six-lane freeway (Table A-10)

- Rehabilitation Projects (no capacity increase)
    - Rural four-lane divided arterial (Table A-11)
    - Rural four-lane interstate highway (Table A-12)
    - Rural six-lane interstate highway (Table A-13)
    - Suburban four-lane divided arterial (Table A-14)
    - Suburban six-lane divided arterial (Table A-15)
    - Urban four-lane freeway (Table A-16)
    - Urban six-lane freeway (Table A-17)

IMPLEMENTATION RECOMMENDATIONS

Future Research

This study provides simplified manual techniques for calculating RUC and clarifies the process for determining appropriate values to be used in construction contracts. The findings of this research study will enable more widespread and consistent use of motorist costs in liquidated damages. Further support of implementation across the state will be aided by additional research in the following areas:

- *Field Testing of the RUC Tables* — 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 MicroBENCOST computer runs using actual field conditions. This process would provide an assessment of the soundness of the table values.

- *Use of MicroBENCOST for Category III and IV Projects* — As noted in the vast array of input assumptions included in Appendix B, there are infinite combinations of design parameters and operational conditions. Consideration should be given to the use of MicroBENCOST at the district level to analyze conditions specific to each unique project. Version 2.0 of MicroBENCOST is under final revision and could be reviewed for this application. One particular benefit of version 2.0 is the incorporation of updated *Highway Capacity Manual* methodology for calculating vehicular speed and delay.

- *Inclusion of Other Motorist Costs* — 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.

Communication of Results

Critical to the appropriate application of RUC values is the communication of these research findings and implementation guidelines to those directly involved in project development. The TxDOT Transportation Conference and other gatherings of field engineering and design personnel are obvious avenues for disseminating information. With growing access to the Internet, this report should be made available for downloading from the web, which will greatly enhance access to the tables.

It is recommended that in the communication of RUC procedures, district personnel be made aware of the role consulting traffic engineers can play in estimating RUC for projects that require simulation models. In many cases consulting traffic engineers are involved in the design process and can be utilized for this work effort as well.

PART II. AN ASSESSMENT OF VALUE OF TIME CALCULATIONS USED IN TEXAS

AN ASSESSMENT OF VALUE OF TIME CALCULATIONS USED IN TEXAS

SUMMARY OF FINDINGS

The purpose of this study was to (1) identify the key elements of road user costs as used by TxDOT, (2) examine TTI Research Report 396-2F *(10)*, NCHRP 2-18 (2) *(11)*, and other research behind recent journal articles to identify which elements of TxDOT's RUC have been the subject of recent research, and (3) make recommendations regarding the current practice as appropriate. From an implementation perspective, the above tasks required (1) an assessment of the state of the practice regarding the value of time (VOT) used in calculating RUC, (2) determining whether the VOT used in Texas is consistent with those used by other states around the country, and (3) an assessment of a set of specific factors regarding the employment of VOT calculations in other states.

First, value of time is just one component in the total equation of calculated road user costs. The total equation can be expressed as:

$$RUC = VOC + AC + VOT$$

Where,

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

This report addresses the value of time component in the road user cost equation.

TxDOT's current practice is to include RUC as a part of liquidated damages in some construction contracts. At present, RUC as applied are limited to the VOT component. This research examines the current methodology employed by TxDOT to estimate the VOT and makes recommendations on future use.

As discussed in TTI Research Report 396-2F *(10)*, in NCHRP 2-18 (2) *(11)*, and in this report, the literature on the VOT specifically is extensive and well-developed. Critical to this report though is the notion that values of time, particularly as they relate to automobiles, have most often been determined by using mode or route choice models (i.e., toll versus free roads; auto versus bus travel). Given the relative limited number of toll roads and the relatively low percentage of individuals using mass transit, Texas' current VOT methodology was developed in 1986 for the TxDOT by the TTI using a speed choice model. The realities that prompted the selection of a speed choice model over mode or route choice still exist today. Given Texas' use of a speed choice model, three major components are relevant for consideration: vehicle operating costs, accident costs, and traveling speed. Accident costs in turn embrace two important variables: the value of life and accident rates.

Value of time for trucks in Texas was not calculated using a speed choice model, but rather using values developed from a 1975 study by McFarland and Buffington *(12)* adjusted by the wholesale price index for industrial commodities. While the 1975 model (when adjusted for inflation) yields values consistent with those employed by other states, the values are significantly lower than those suggested in NCHRP 2-18 (2) *(11)*. (Compare $150 to $200 per hour in the NCHRP study versus $22 [adjusted] in the McFarland and Buffington study.) However, as is the case with McFarland and Buffington, in the NCHRP 2-18(2) *(11)* study the number of actual cases analyzed is relatively small. Clearly there is room for further, more comprehensive research regarding the VOTfor trucks.

For the purposes of this study, telephone interviews with appropriate Department of Transportation officials in North Carolina, Pennsylvania, California, Washington, Florida, Virginia, New York, Georgia, and Ohio were conducted. Findings show that the values employed in Texas are reasonably consistent with those used in other states. As indicated in Table 2-1, the survey revealed VOT for automobiles ranged from $8.70 to $12.60 per hour. [Note: In discussing VOT rates per hour, the rates refer to the hourly value per person. Some states, as discussed elsewhere in this report, then multiply the per person rate times an average vehicle occupancy rate to arrive at a figure that represents the VOT for the vehicle.] VOT for trucks (where calculated) ranged from $21.14 to $26.40 per hour. In two states, North Carolina and Georgia, no separate VOT calculation is made for trucks.

It is important to note that the values in Table 2-1 represent only "inputs" into VOT calculations employed by the various states. Several states then employ formulas containing such variables as average ridership, employment rate, and employment-toworking age ratios. These formulas are discussed in detail later in this report.

Table 2-1. Summary of Comparable Values for Selected States

State	Value of Time Autos	Value of Time Trucks
North Carolina	$8.70	—
New York	9.00	21.14
Florida	11.12	22.36
Georgia	11.65	—
TEXAS	**11.97**	**21.87**
Virginia	11.97	21.87
California	12.10	30.00
Pennsylvania	12.21	24.18
Washington	12.51	50.00
Ohio	12.60	26.40
Median	**$11.97**	**$23.61**
Mean	**$11.38**	**$27.23**

RECOMMENDATIONS

This research into the value of time as used by TxDOT has resulted in the following recommendations:

- The value of time for passenger vehicles as developed in TTI Research Report 396-2F *(10)* by Chui and McFarland and as adjusted by the CPI should remain as the operative value in Texas at this time. It remains theoretically defensible in light of both current literature and Texas travel patterns and produces results empirically consistent with values employed by other states.

- Further research should be conducted to determine a more accurate value of time for trucks and commercial vehicles. While the VOT for trucks used in Texas is, admittedly, consistent with that employed by other states studied, the methodologies employed in the NCHRP 2-18(2) *(11)* study are worthy of serious consideration. [Note: NCHRP 2-18(2) *(11)* is also cited in the literature as *Hickling Lewis Brod Inc.*]

- TxDOT should consider a relaxed policy regarding the application of discounts to RUC included in construction contracts. Previous research and subsequent analyses have shown that the current practice is sufficiently conservative to assure accuracy, and that circumstances exist where conditions warrant giving higher weight to RUC.

- Consideration should be given to a study to determine whether (and if so, at what point) risks perceived by contractors associated with liquidated damage charges get transformed into additional costs to the State with the view of imposing a variable rate of recovery of RUC.

AN ASSESSMENT OF VALUE OF TIME CALCULATIONS USED IN TEXAS

Components of Road User Cost Calculations

A review of the literature (and a survey of selected states discussed later in this report) shows that beyond the basic methodological approaches, there are three fundamental components of RUC: vehicle operating costs, accident costs, and value of time costs. In general terms, this relationship can be expressed as:

$$RUC = VOC + AC + VOT$$

Where,

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

Vehicle Operating Cost

The vehicle operating cost (VOC) component includes costs for fuel, tires, engine oil, maintenance, and depreciation. Further, some VOC costs vary with speed.

Accident Cost

The accident cost (AC) component generally reflects three different subcomponents: fatal accidents, non-fatal injury accidents, and accidents involving property damage only. Some states also include a multiplier factor to account for accident costs for unreported property damage in damage-only accidents. Therefore, accident costs can be expressed as:

$$AC = FA + NFA + (PDO)x$$

Where,

FA = fatal accidents
NFA = non-fatal injury accidents
PDO = property damage only accidents
x = adjustment factor for unreported PDO accidents

Value of Time

The value of time (VOT) component is the focus of this report and is discussed in detail elsewhere. While there are many variations in how the component is calculated, in its simplest conceptual form, VOT is basically a function of an hourly wage rate, most often multiplied by an average ridership component such that:

$$VOT = f\,(AWR)\,(occupancy)$$

Where

AWR = average wage rate
AR = average ridership

For purposes of including road user costs as a part of liquidated damages, or, for that matter, for comparing alternatives, the VOT is the most relevant of the three RUC components. Unless a project is directed at remedying a safety problem, it is assumed for simplicity that the accident patterns in the "after" scenario are not significantly different from the "before" conditions, thereby warranting the exclusion of accident costs as a significant before/after variable. Vehicle operating costs are dismissed because they apply under both conditions as well, with only relatively modest variations resulting from travel speed. The value of time, however, varies inversely with the operating speed, and is significantly impacted by before/after conditions. For the current purpose, TxDOT may reasonably include only the value of time (VOT) component of road user costs as a means of comparing before and after conditions.

Models for Estimating the Value of Time

Several models are available for estimating the value of time. Most commonly those models are referred to as route choice, mode choice, and speed choice models. Route choice models were used to develop some of the first willingness-to-pay values of time. These values were calculated by determining how much motorists would be willing to pay to use a toll road to save time. The VOT was calculated as being equal to the toll charge (less savings in vehicle operating costs and accident costs) divided by the savings in time. Although later studies used more sophisticated statistical techniques, this remained the type of tradeoff in route choice models.

The mode choice model is similar to the route choice model except the choice is between taking a car that costs more versus a bus, which takes more time.

The final type of model is the speed choice model. The tradeoff in this model is that a person can travel at a higher rate of speed and save time but has vehicle operating costs, accident cost, and speeding ticket cost increases with faster speeds above a certain level (Florida Department of Transportation).

REVIEW OF THE LITERATURE

As noted elsewhere in this study, the literature on value of time is well developed. Values are most often determined by estimating mode choice models, while some studies have used route choice models *(11)*. Texas, on the other hand, has adopted a value of time based on a speed choice model for reasons addressed later in this study *(10)*.

Literature on the Value of Time

What follows is an examination of five major studies – four conducted in the United States, as well as one in the United Kingdom. The studies span a range of twelve years, from 1986 to 1998, and are entitled:

- *The Value of Travel Time: New Estimates Developed Using a Speed Choice Model (10)*;
- *Urban Transportation Economics (13)*;
- *The Value of Automobile Travel Time: Implications for Congestion Policy (14)*;
- *Valuation of Travel-Time Savings and Predictability in Congested Conditions for Highway User-Cost Estimation* (Hickling Lewis Brod Inc. [NCHRP 2-18(2) *(11)]*; and,
- *The Value of Travel Time: A Review of British Evidence (15).*

All provide excellent and detailed reviews of the literature, as well as a state of the practice. The value of time currently employed in Texas is based on the findings of the research of Chui and McFarland (adjusted by the consumer price index). Each of the studies are quoted at length here to provide the reader with an overview of their various findings regarding VOT and the methodologies employed to determine them. The review is presented in the order in which the studies were published.

The following are excerpts from the cited works pertinent to this study:

<u>The Value of Travel Time: New Estimates Developed Using a Speed Choice Model</u>. Chui and McFarland. 1986.

The speed-choice model was chosen for estimating the values of time because it can be applied across a representative, state sample of Texas motorists. Two other techniques that are judged to be good theoretical approaches, the choice of mode (especially bus vs. auto) and the choice of route (especially toll road vs. alternative free route) methods, cannot be used as effectively, and few situations are available in Texas where choices involving toll roads are made. The speed-choice model has been criticized by some researchers as having the weakness of assuming that motorists know their expected costs of different types as related to travel speed. This criticism, however, can also be applied to the other techniques. For example, in the bus/auto modal choice situation, it is assumed that the driver knows his out-of-pocket vehicle operating costs, even though the trip usually involves several different highway types, intersections, etc., not to mention widely varying traffic volumes and other operating conditions. In addition, expected accident costs, as perceived by the motorists, must be estimated to use this approach in a valid way. Similar calculations must be made of operating costs and accident costs on toll roads versus alternate free routes to use the route-choice models. Therefore, in this study, it is concluded that the speed-choice model is at least as valid theoretically as the other techniques and has the definite advantage of being applicable to a statewide cross-section of Texas motorists.

The principal data problem is using the speed-choice model involved the estimation procedure for the cost of fatalities. To estimate this cost, two different approaches were used in this study to estimate the value of life, the earnings approach, and the willingness-to-pay approach. For many of the individuals in the survey both approaches gave roughly the same value of time. However, for some individuals who indicated a willingness to pay a very high amount to travel on a 4-lane divided highway as compared to a 2-lane highway, the willingness-to-pay approach to calculating the value of life gave a very high value of life. It is the authors' opinion that some of these answers may be misleading when used as a guide to the value of life. More research is needed on the willingness-to-pay approach to the value of life, including further study of the data developed in this study. At this time, it is the authors' opinion that the values of time based on the EARN data set are the best values to use in benefit-cost analyses in Texas even though further refinement of the data set and techniques may change this opinion to favor the willingness-to-pay set.

It is recommended, therefore that the values of time developed in this study using the speed-choice model with the EARN data set be used in benefit-cost analyses in Texas. The recommended value of time of a passenger vehicle driver calculated using the EARN data set for 4-lane divided highways is $7.70 per house in 1984 dollars (or $8.00 per hour when updated to 1985 using the consumer price index.) These values represent the average values weighted by estimated annual hours of travel for each individual in the data set. Using an *occupancy rate of 1.3 persons per car, the recommended 1985 value of time for passenger vehicles is $10.40 per vehicle-hour...The recommended 1985 value of time for trucks is $19.00 per vehicle-hour.*

[Note: Value of time for commercial trucks in Texas was first developed in 1975 by Buffington and McFarland. The value ($19.00 per vehicle-hour) reported in the 1986 study was simply an update of the value derived in the 1975 study. As reported by Chui and McFarland,]

Because of lack of adequate responses from truck drivers in the survey, the value of time of truck drivers is not obtained by using the speed choice model; instead, it is derived by updating the 1975 values of Buffington and McFarland in the following manner.

The value of time in each of the three truck types listed in the Buffington and McFarland study is first weighted by the 1980 percentage distribution of the respective truck type in all trucks on Texas highways to arrive at the weighted value of time of each truck type. Secondly, the three weighted values of time of truck types…are summed together to yield a 1975 value of time for all trucks. Lastly, the 1975 value of time for all trucks is updated to 1985 by multiplying by the ratio of wholesale price index for industrial commodities (WPI) of 1985 to that of 1975 to arrive at the 1985 value of time for trucks. Table 9 [Note: Table 2-2 appears below.] *shows the three types of truck and lists the 1975 values of time for each type, the 1980 percentage distributions of the three truck types, the 1975 weighted value of time for each truck type, the 1975 value of time for all trucks, and the 1985 value of time for all trucks.*

Table 2-2. Derivation of Value of Time for Truck Drivers (Chui and McFarland)

Truck Type	Description	1975 Value of Time (Dollars)	Percent Distribution (Percent)	1975 Weighted Value of Time (Dollars)
3	Single-unit trucks, other than 2-axle, 4-tires	8.02	31.2	2.50
4	Truck semi-trailer combinations, 4 or less axles	10.00	8.4	0.84
5	All other trucks and semitrailers or trailer combinations, 5 or more axles	11.10	60.4	6.70

1975 Value of Time for all trucks: = $2.50 + $0.84 + $6.70
= $10.04

1985 Value of Time for all trucks: = $\$10.04 \times (WPI_{85}/WPI_{75})$

= $10.04 X (323.5/171.5)
= $19.00

<u>Urban Transportation Economics</u>. Small. 1992.

Research has generated an enormous amount of literature regarding empirical estimates of value of time. It has been thoroughly reviewed by Hensher (1978) and Bruzelius (1979), and more selectively by MVA Consultancy et al. (1987, pp. 125–136). The latter work also describes the results of a coordinated set of British studies, most of which use the stated-preference approach described earlier.

Although the amount of explained variability is far higher than one might wish, there are a few consensus conclusions. First, the value of in-vehicle time for non-business travel is usually found to be less than the gross wage rate; furthermore, it rises with that wage rate (or with income), though not necessarily proportionally. For work trips, Bruzelius (p. 154) gives the ratio of value of time to gross wage as 20 percent to 30 percent; but several U.S. studies, including some not reviewed by him, provide considerably higher values: 42 percent of gross wage in Chicago (Lisco, 1967; Lave, 1969); 61 percent in six U.S. cities (Thomas, 1968); 72 percent in Los Angeles (Cambridge Systematics, 1977); 66 percent of net after-tax wage for a sample prior to the opening of BART in the San Francisco Bay Area (Small, 1983a); and 180 percent and 73 percent of net wage for auto and transit users, respectively, from a post-Bart sample in the same areas (Train, 1980). Furthermore, several studies in England yield ratios of value of time to gross wage ranging from approximately 22–50 percent (for the highest income group) to 108 percent (for the lowest income group) (MVA Consultancy et al., pp. 134–135). For Australia, on the other hand, a more recent study concludes that in-vehicle time is valued at only 28 percent of the gross wage on average (Hensher, 1989, p. 225, Table 1).

From this rather wide range, I conclude that a reasonable average value of time for home to work is 50 percent of the gross wage rate, while recognizing that it varies among different industrialized cities from perhaps 20 to 100 percent of the gross wage rate, and among population subgroups by even more.

The evidence of MVA Consultancy et al,. is fairly convincing in rejecting a simple proportionality between value of time and income. Although members of their highest-income group have incomes more than three times those of the lowest group, their values of time were only 30 to 40 percent higher (pp. 133–135, 150, 152.) Of course, income may not be a good proxy for post-tax marginal wage rate, so the issue is still in some doubt. In any case, the evidence presented is equally convincing in rejecting a constant value of time (p. 133). One may therefore wish that they and other authors would adopt the convention of reporting all results as fractions of the wage, whether or not that fraction is constant, to facilitate comparisons across regions and nations.

A second consensus is that walking and waiting are sufficiently onerous, relative to being in a vehicle, that its value is two or three time that of in-vehicle time (Bruzelius, 1979, p. 1952). There is considerable speculation, stated earlier, that the onerousness of transfers (which entail waiting) is poorly understood.

Business travel seems, as expected, to have a higher time value than commuting travel, although not necessarily equal to the wage rate as is some *assumed (MVA Consultancy et al., p. 129). Travel for leisure activities (i.e., non-work and non-commuting) may have time value higher or lower than commuting (Bruzelius, 1979, p. 156). The study by MVA Consultancy et al. provides some evidence that social and recreation trips involve higher values than trips for shopping or personal business, and that the value on weekends is higher than on weekdays (p. 152).*

Two other tentative findings may be noted. Guttman (1975) finds that travel during peak periods is valued more highly than off-peak, although MVA Consultancy et al. find no such effect (p. 158). MVA Consultancy et al. (p. 150) confirm the expectation that value of time increases with total trip length, being an estimated 20 percent higher for commuter trips over 30 minutes than for trips less than 20 minutes (p. 150).

"The Value of Automobile Travel Time: Implications for Congestion Policy." Calfee and Winston. 1997.

Specifically, we estimate how much automobile commuters are willing to pay to reduce travel time under a variety of travel conditions and assumptions about how the toll revenues will be spent.

Our study, however, does not simply amount to another estimate of the value of travel time that should be added to a long list of previous estimates. Value of time estimates differ greatly depending on the travel mode (e.g., bus versus car) and the purpose of the trip (e.g., work versus pleasure). In addition, the value of time estimate should be appropriate for the problem at hand. We are specifically interested in estimating the amount that automobile commuters are willing to reduce travel time on a congested road. This value is likely to be difficult to obtain from a transportation mode choice model (the most popular approach to estimating the value of travel time)...

We therefore focus directly on automobile commuters who face congestion. Because market data reflecting the imposition of congestion tolls are not available, we conducted a preference study of these commuters. Based on their stated preference we obtained an estimate of the value of automobile travel time that, to the best of our knowledge, is the first to bear directly on congestion policy. Our findings should change the terms of the current debate: estimated commuters' value of travel time is low – much lower than estimates typically derived from transportation mode choice models – and is surprisingly insensitive to travel conditions and how toll revenues are used. It appears that even high-income commuters, having adjusted to congestion through their modal, residential, workplace, and departure time choices, simply do not value travel time savings enough to benefit substantially from tolls.

Because we needed to estimate consumer preferences for alternatives that do not exist, we relied upon stated preference methods that the market research community has developed to assess consumer preference for new products and new product attributes. A conceptually satisfying method for measuring consumer trade-offs among attributes is to have consumers rank-order several *“packages” that involve different combinations of prices and other characteristics.*

The stated preference models were estimated from a random sample of 1170 respondents. Survey respondents were automobile commuters in major U.S. metropolitan areas who regularly drove to work and faced some congestion. Response rates were roughly 67 percent approximately three weeks after the mailing, slightly better than the usual response rates for the National Family Opinion panel.

The calculations reveal the commuters’ WTP [willingness-to-pay] *as a fraction of their wage is surprisingly insensitive to the payment mechanism, how the toll revenue is used, who owns the road, and expected traffic growth...Average WTP per hour ranges from 14 to 26 percent of the gross hourly wage, with an average over the entire sample of 19 percent – conspicuously lower than most of those based on transportation mode choice and route choice models. Small (1992) concludes from a survey of mode choice models that a reasonable average value is 50 percent of the gross wage, while Miller’s (1989) survey of route choice models yields an average value closer to 60 percent of the gross wage. Small points out that estimates of the value of time do vary among industrialized cities from 20 to 100 percent of the gross wage, thus our estimate can be interpreted as being at the very low end of previous estimates derived from mode choice models.*

Valuation of Travel-Time Savings and Predictability in Congested Conditions for Highway User-Cost Estimation. Hickling Lewis Brod, Inc. 1997.

The literature on the value of passenger travel time is extensive and well developed. Values of travel time have most often been determined by estimating mode choice models (logit, probit) and evaluating the marginal rates of substitution between the costs and travel times of the alternative models. Some studies have used route choice models. Another approach is to examine residential housing costs, the hypothesis being that people will pay more for housing locations that reduce their travel costs (especially for work trips).

In mid 1995, 2500 surveys were sent to residents along the SR91 corridor in Orange and Riverside Counties in Southern California. Addresses were obtained from a commercial firm and limited to zip codes adjacent to the corridor. The first 200 were a pilot test mailed on July 7, while the other 2300 were the main survey mailed on November 15. In the case of the main survey, extensive follow-up was undertaken. Reminder post cards were sent out after one week and again after two weeks; if no response was received by the end of the third week, a duplicate survey instrument was sent, again followed by weekly reminder post cards.

When the first completed survey instrument (the transportation survey) was received at the project office, the customized state preference survey questionnaire was mailed within one day. This was followed by the same follow-up procedure of reminder cards and, if necessary, a duplicate questionnaire.

Ultimately, 1348 completed and usable transportation surveys, and 959 completed and usable SP surveys were received. (About six percent of the non-responses were bad addresses and other miscellaneous factors.) These figures represent response rates of 53.9 percent and 71.1 percent on the two survey parts.

The stated preference passenger travel questionnaire asks people to choose among situations in which they have to trade off total travel time, the fraction of travel time in congested conditions, and trip costs. Using the survey data, separate models for calculating the impact of congestion on the values of travel time and travel-time predictability were developed. The models are estimated using logit choice estimation techniques.

For a household annual income of $15,000, the value of travel time is $2.64 an hour; for an income level of $55,000 the travel time value is $5.34 an hour; and an income level of $95,000 has a corresponding travel time value of $8.05 an hour. These values are within the range found in the literature, albeit somewhat at the lower end.

A similar analytical approach was used for freight carriers, although on a much smaller scale. Information was collected through stated preference survey. The stated preference experiments are designed from the carrier's point of view. In particular, they are designed to evaluate how the carrier would trade off freight costs and improvements in transit time reliability in selecting how early to depart from the origin point for a typical shipment that has a desired arrival time at the destination. Again, models are constructed to assess the importance of transit-time reliability in shipping decisions.

Compared with passenger travel (where the results are quite robust), the empirical results are somewhat inconclusive on the freight side. A number of factors contribute to the weakness of the freight side results but a small sample size probably accounts for most of the unfavorable findings. Of the 168 freight carriers selected, a total of 20 telephone interviews were completed. While the results did confirm the importance of transit time and freight costs in shipping decisions, they failed to measure a significant value for changes in transit-time predictability. Carriers on average value savings in transit time at $144.22 – $192.83 per hour and savings in schedule delays at $371 per hour.

<u>The Value of Travel Time: A Review of British Evidence</u>. Mark Wardman, vol 32, part 3, September 1998, pp. 285–316.

The initial British empirical research into the valuation of travel time savings was conducted in the 1960s...The 1970s witnessed advances in methodology with the development of disaggregate choice modeling based on random utility theory, and increases in computing power to facilitate such analysis...A significant event in value-of-time research was the commissioning in 1980 by the UK Department of Transport of the first of what can be termed national value-of-time studies. Fifteen years has elapsed since the initial *research upon which appraisal practice was based, and a review of the state of the art and fresh empirical work were clearly warranted, given the significant methodological advances that had been made. An important feature of the study was the consideration of evidence from experimental data collection methods, such as Stated Preference (SP), alongside results based on conventional Revealed Preference (RP) methods...This paper is based on a review of available British evidence that has been amassed since 1980...*

The significance of this review is that it is the most comprehensive assessment of studies yielding value-of-time estimates that has yet been undertaken. It is solely concerned with the value of in-vehicle time, although the reviewed studies provide a wealth of evidence on the estimated valuations of other forms of time such as walking time, waiting time, idle time, search time, delay time, and travel-time variability.

We reviewed 105 studies where the data were collected between 1980 and early 1996, and these yielded 444 value-of-time estimates across a wide range of circumstances...Of the 105 studies reviewed, 8 percent were specifically concerned with the value of time estimation, and these provide 9 percent of the 444 value-of-time estimates. Fifty-nine percent of the studies, containing 51 percent of the values, were primarily concerned with forecasting travel behavior, while the purpose of the remaining 33 percent of studies, from which 40 percent of the value-of-time estimates were obtained, was the valuation of a range of travel attributes, but not specifically travel time.

The vast majority of the studies are of comparatively recent origin, with 70 percent undertaken in the 1990s and only 12 percent conducted prior to 1987.

Only a few (6 percent) of the 444 value-of-time estimates were obtained from RP models...Of the SP models, the choice exercise dominates, with 71 percent of the SP values of time.

The recommended Department of Transport (HEN2) value of non-working time, after converting to a behavioral value, is 6.35 pence per minute [$5.98 per hour USD]*...London commuters are estimated to have value of time 35 percent higher than leisure travelers* [$8.07 per hour USD]*, while commuters elsewhere and peak travelers had values 14 percent higher.*

There are some large variations in the value of time according to mode. As would be expected, all the specified categories have higher values than the base-bus-user category. We would expect car users to have relatively high value of time because of their relatively large incomes...Rail users' valuations of rail are higher than car users' values, and there is presumably an income effect at work here, while rail may also be regarded as providing a less attractive travelling environment.

These studies represent some of the most comprehensive work to date relative to value of time. However, they by no means represent all of the work done. The following represent a sampling of value of time estimates derived in other studies.

- Bruzelius (1979) also reviewed the empirical literature on the value of time. He states that walking and waiting time are valued from two to three times more than in-vehicle time and that in-vehicle time for work trips is between 20 and 30 percent of the wage rate *(16)*.

- Small *(13)*, as noted earlier, and Waters *(17)* suggest a value of time for work trips at about 50 percent of the wage rate on average and that it varies with income or wage rate, but not necessarily linearly.
- Hendrickson and Plank use a disaggregate model of mode and departure time choice to determine separate value for in-vehicle, congested, and transit wait times. The findings indicate values of $1.71, $4.50, and $17.14 per hour, respectively *(18)*.
- Guttman (1979) estimates that the value of time during peak hours is $1.17 per hour as opposed to off-peak value of $1.91 per hour. He also finds that the average value of time for commuters traveling every day is $1.91 per hour versus $2.95 per hour for those who travel less frequently but at least once a month *(19)*.
- The California Energy Commission used the "Personal Vehicle Model," a demand forecasting model that projects vehicle stock, vehicle miles of travel, and fuel consumption for personal cars and trucks, to estimate the congestion costs, including the disutility of aggravation, are $10.60 per hour in 1992 dollars *(20)*.
- Litman (1997) indicates that the value of user time alone accounts for over 20 percent of the total cost of average automobile use during peak times in urban areas. As a basis for deriving the costs, he uses a 1992 value of time schedule for British Columbia because it is "current and comprehensive." That study assumes that the value of the personal vehicle driver's time is 50 percent of the current average wage, which he assumes to be $12 per hour *(21)*.
- Levinson, et al. (1996) produced a report comparing the costs of intercity passenger travel by air, automobile, and high-speed rail in the California Corridor between San Francisco and Los Angeles. As a part of that study, they estimate that travel time costs $10 per hour for vehicles traveling at 100 km per hour *(21)*.

Literature on Value of Travel Time Calculations in Texas and the Relationship to Contracting Strategies

Value of time calculations are just one element of a broader category of road user cost that, in turn, can be applied in a number of different analytical techniques including cost/benefit analysis and A+B or time-cost bidding. This concept was first employed, according to McFarland, et al (1994) in the late 1970s and early 1980s *(2)*.

> *The approach apparently was first used in Mississippi in the late 1970s, where it was used on only one contract. It next was used, in the early 1980s, by about five states, including Texas, on a few contracts, and in England on numerous contracts…*
>
> *An A+B contracting procedure requires the contractor bidding on a job to bid how many days he will take to do the work as well as the construction cost. The contract is then awarded to the bidder whose combined construction cost bid plus estimated time cost bid, or A+B bid, is the lowest…*
>
> *An interesting strategy…is to have the contractor bid contract completion days as in the preceding strategy and to not pay a bonus for early completion, but to charge liquidated damages for any overrun past the number of days he bids.*

As McFarland, et al. indicate, however, questions "have arisen about the level of liquidated damages that should be used on different projects in different situations."

Previous research by the Texas Department of Transportation indicates that project completion times and total projects costs can often be reduced by charging the contractors higher liquidated damages. Accurately estimating liquidated damages for project overruns is becoming increasingly important as motorist costs begin to be included in the liquidated damages schedules…

Policy in Texas has called for using a standard liquidated damages schedule on most highway projects, with the level of liquidated damages depending on the estimated cost of the project.

According to McFarland, et al. research conducted by the Texas Transportation Institute indicates that,

Under certain assumptions, including motorist costs in liquidated damages can lead to a better solution with less total transportation cost (construction cost plus other TxDOT costs plus motorist excess costs associated with construction delays). The savings in motorists costs from such a policy was shown to be at least twice as much as the net cost to the Department, the precise multiple depending upon the shape of the contractor's cost curves. If the Department had sufficient funding to build all construction projects with a benefit-cost ratio of greater than 1.0, and there were a high degree of accuracy in the estimates of motorist costs, then it could be strongly recommended that full excess motorist costs be included in liquidated damages and bonuses.

However…since there is a shortage of highway construction funds, only part of motorist costs [should] be included in liquidated damages. Therefore, if sufficient highway funds are available for funding all projects that give a benefit-cost ratio greater than 1.0, then a policy should be followed of including full excess motorist costs in liquidated damages. If funds are available only for projects that give a benefit-cost ratio, for example, of 2.0 or greater, then only half of excess motorist costs should be included in liquidated damages, since the marginal benefit-cost ratio for spending to reduce excess motorist cost is 2 to 1.

In Texas, recent calculations indicate that the marginal return to highway expenditures is about 4 to 1. Applying this ratio would lead to the recommendation that about one-eighth or 12.5 percent of the motorist costs…should be included in liquidated damages.

As a result of their research, McFarland, et al. developed a series of 13 tables that provide estimates of additional daily costs of delayed completion and additional hourly costs of lane closures in various locations (rural vs. urban), lane configurations, and car/truck mixes, and various traffic counts. However, as noted by McFarland, et al. since accident costs are not included in the table values, the 12.5 percent figure quoted above should probably be increased.

Also, considering that the discomfort and inconvenience from traveling through construction zones is probably above average and considering that *severe congestion in work zones is estimated to have a time cost that is twice as high as normal, it is recommended that 25 percent of the motorist costs in these tables be included in liquidated damages,"*

Discussion of Road User Costs as Part of a Contracting Strategy

There is perhaps another concept that should be addressed in terms of the percentage of road user costs included in liquidated damages. This concept might best be viewed in the context of risk.

There are two dimensions of risk to the contractor associated with A+B contracting. Always, there is the risk associated with the price of construction (the "A" portion). Can the contractor do the work at the bid price? In addition, however, there is the risk associated with the contractor's commitment to finish the project within the time-frame included in his/her bid or face the consequences associated with liquidated damages (the "B" portion).

So, two questions arise: 1) under what conditions does the State begin to pay a price premium for the level of risk being assumed by the contractor in order for the contractor to be competitive on the "B" portion of A+B contracting? and 2) is the benefit of the time saved justified by the cost of the price premium? The figure below illustrates these questions.

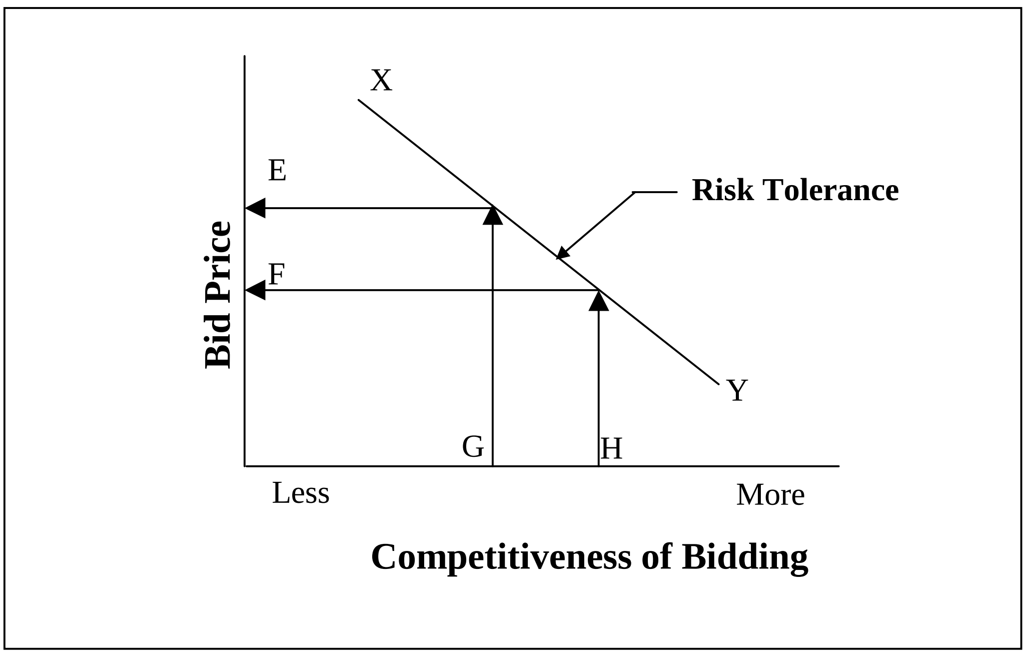


Figure 2-1. Conceptual Representation of the Relationship Among Bid Price, Competitiveness, and Risk Tolerance

For example, assume line XY represents risk that a contractor perceives associated with the time portion of the bid (B portion, or liquidated damages associated with excess RUC). The more competitive the environment in which the contractor bids, the more willing the contractor is to internalize the risk and therefore not reflect it in a price premium. The competitiveness of the bidding environment is calculated internally by each contractor based on the amount of work available for bidding, level of current business, number of contractors bidding, and other factors. In this example, the competitive bidding environment is represented as point “G.” Under this environment, the contractor’s acceptable risk would lead to a bid of price “E.”

The less competitive the economic environment (lots of work, few bidders, etc.) the more likely the contractor is to charge a premium associated with his/her perceived risk. Further, the less competitive the economic environment, the greater percentage of the risk premium calculated by the contractor will likely be borne by the State. This condition is represented in the figure as bidding environment “H” and bid price “F.”

The graphic and the accompanying scenario are intended to be a general description of a relationship, not a tool for making decisions. They simply support McFarland’s contention that it may be prudent to use less than 100% of the calculated RUC when incorporated into liquidated damages.

Consequently, it may well be in the best interests of the State to adopt a flexible/variable liquidated damages percentage in order to accommodate market realities and maximize the incentives of A+B contracting while minimizing the cost paid by the State.

Figure 2-2 shows the project cost curves described in the introduction to this research report. As indicated previously, lowest construction cost occurs at “C” days of project duration, while lowest total project cost occurs at “B” days. Inset within the drawing are dashed lines showing the difference in road user and construction costs associated with shortening the project from “C” to “B” days. The construction costs will increase, as illustrated by the differential between “G” and “H,” while road user costs will decline (from “J” to “I”). Prior research ( ) has recommended that the construction differential be valued at roughly four times that of the RUC because of the marginal benefits of construction dollars. There may be circumstances under which TxDOT would defensibly choose to use a different discount on the RUC.

The percentage of RUC to be included in liquidated damages can be approached two different ways. The first way is to use the default cap of 25% of calculated RUC. This value is based on previous research that showed that the additional construction costs paid to speed up a project had an economic value roughly four times that of the savings in delay costs to road users. Maintaining the current practice of including 25% of RUC is readily defensible.

The second approach is to adjust the level of RUC applied to liquidated damages based on the unique features of the project. Any level of RUC up to 100% is defensible. In making a decision about the level to use, it is recommended that the following factors be considered:

1. *Importance of on-time completion* — Local factors will determine the importance of on-time completion. It could be important because of upcoming events, or other upcoming projects. It could be that the project is very high-profile or the subject of intense local concern. Under any of those and other circumstances, TxDOT may want to consider raising the level of RUC in the liquidated damages.

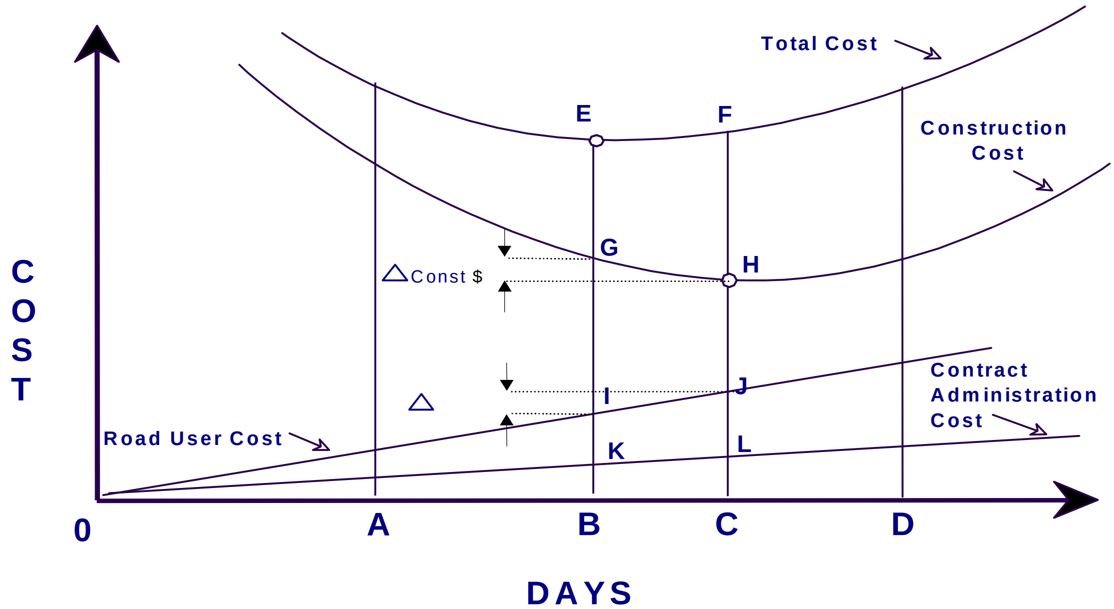


Figure 2-2. Project Cost Curves, Highlighting Differential Between Lowest Total Cost Days and Lowest Construction Cost Days

2. *Current contracting capacity and pool of projects available* — As indicated in the research, the competitiveness of the bidding environment may warrant consideration in selecting an appropriate level of RUC. If contractors' capacity is being stretched because of a lot of work underway, then they will likely approach a bid that includes high RUC with caution, since they could be at risk of substantial liquidated damages. They may very well bid higher than they would otherwise, recognizing their potential for liquidated damages and simply including those expenses in their bid price. Conversely, if the bidding environment is more competitive (many contractors without enough work), then the likelihood of overrunning the schedule may be easier to control and therefore the contractors would be more likely to bid less of a premium price to cover potential liquidated damages. Further, if there are numerous other jobs bidding, contractors may forego bidding on jobs with high RUC in order to bid on less risky jobs.

3. *Reasonableness of calculated excess RUC* — The level of RUC included in liquidated damages should be reasonable. Looking at the charts showing RUC, one can see that they range from very small ($400/day for suburban arterial) to very high (>$300,000/day for urban freeway). In the case of the very small, discounting RUC to $100 per day probably has very little impact, since contractor and TxDOT fixed expenses are likely much higher. If RUC are to the used at all, they probably should not be discounted. On the high end, $300,000+ per day would seem to be an extreme damage, suggesting that, in most cases, these RUCs should be discounted to a more reasonable amount.

4. *Complexity of project and extent of "unknowns*" — TxDOT may want to consider how much of RUC to include on projects that have the potential of delays due to unknowns. The Department's guidelines for application of RUC already recognize that right-of-way and utility relocation issues impact on the applicability of RUC. If a project has other potential unknowns, such as underground facilities, archaeology, cemeteries, etc., it may be wise to discount or eliminate RUC as a component in liquidated damages.

SURVEY OF SELECTED STATES REGARDING THE VALUE OF TIME

Telephone interviews were conducted with appropriate transportation department officials in nine states: Ohio, Georgia, North Carolina, Pennsylvania, Washington, Florida, Virginia, New York, and California. Each was asked a set of questions regarding the VOT that was used in their particular state as well as specific questions regarding the calculation of the value and how the value was ultimately used. The results of the survey are presented below.

What is the value of time used in your state?

A summary of the responses is shown in Table 2-3. Each of the states responded to this question based on their current practices. It should be noted that there is substantially more variance in the responses to truck VOT than for autos. As will be evident in the individual responses to other questions below, the states surveyed had a reasonably consistent understanding of the "value of time," but varying responses to the inclusion of other road user costs. Thus the costs depicted in this table (VOT only) should be consistent.

Table 2-3. Summary of Comparable Values for Selected States

State	Value of Time Autos	Value of Time Trucks
North Carolina (23)	$8.70	—
New York (24)	9.00	21.14
Florida (25)	11.12	22.36
Georgia (26)	11.65	—
TEXAS	**11.97**	**21.87**
Virginia (27)	11.97	21.87
California (28)	12.10	30.00
Pennsylvania (29)	12.21	24.18
Washington (30)	12.51	50.00
Ohio (31)	12.60	26.40
Median	**$11.97**	**$23.61**
Mean	**$11.38**	**$27.23**

The values from Table 2-3 are depicted graphically in Figures 2-3 and Figure 2-4.

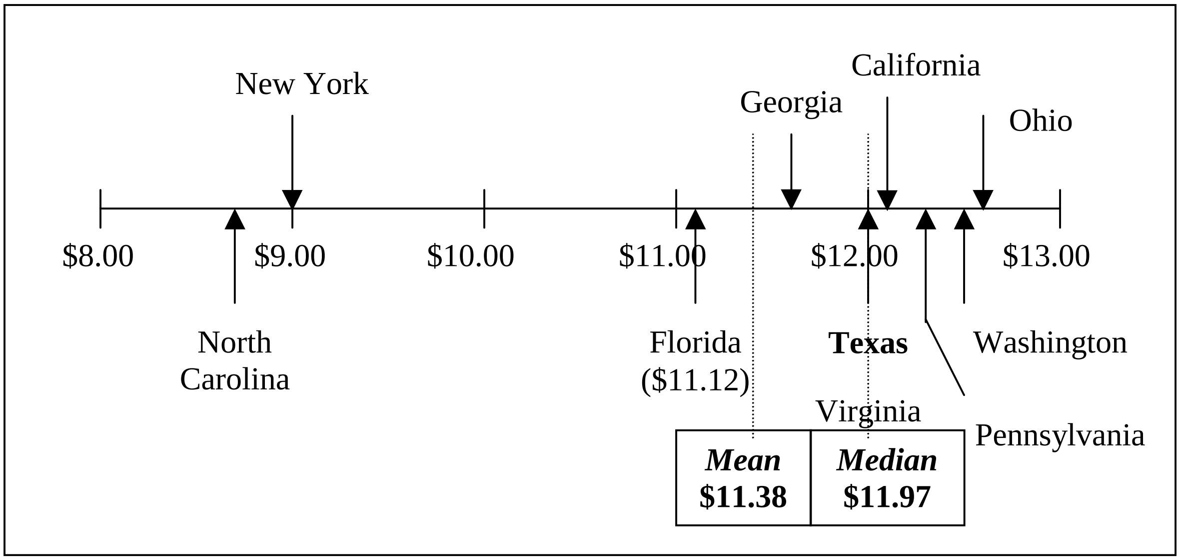


Figure 2-3. 1998 Auto Road User Time Values for Selected States

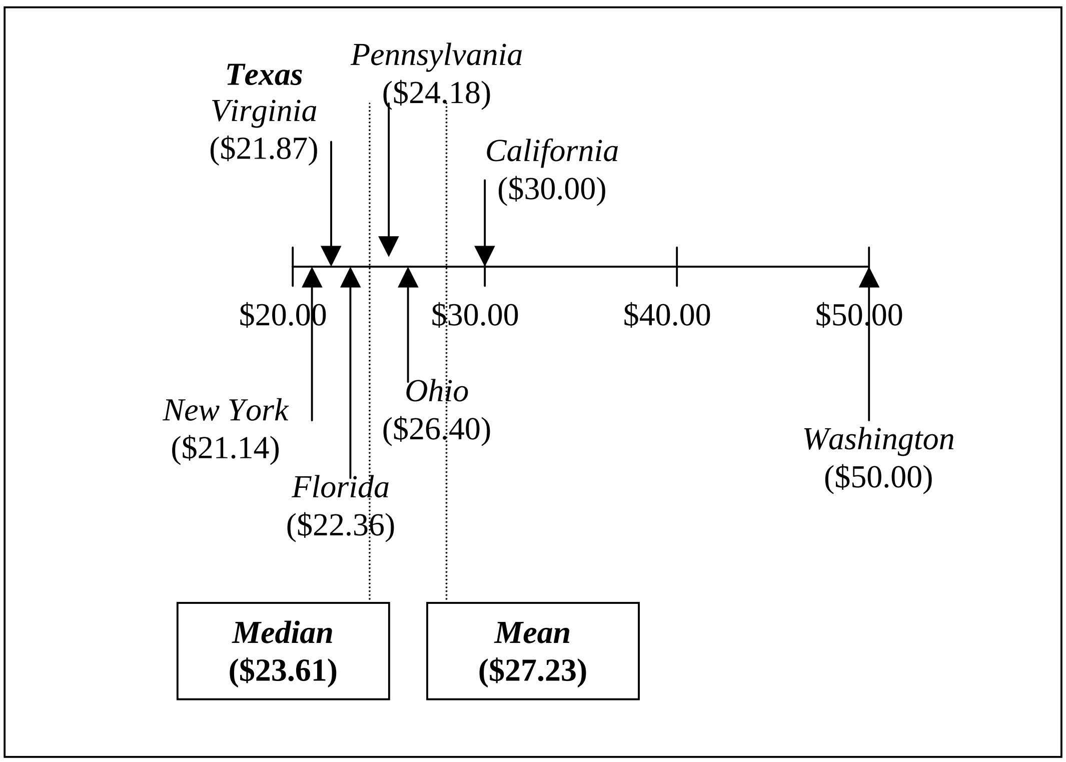


Figure 2-4. 1998 Truck Road User Time Values for Selected States

Was the value of time developed internally or externally?

In all states, except Virginia, "models" of widely varying degrees of sophistication were developed internally. Virginia uses the values developed by Chui and McFarland *(10)*. It should also be noted that Florida uses values developed by the Center for Urban Transportation Research, which, in turn, bases its models on research done by Florida State University and Florida A&M University.

Is there any particular research report(s) that you have relied on in making/using the calculation?

As noted, Virginia relies totally on the Chui and McFarland report *(10)*. North Carolina relies heavily on internal research, specifically its own *Technical Report 8: Transportation Project Evaluation Using the Benefits Matrix Model* *(23)*. Other states have used a wide range of studies, many of them quoted here, as well as internal research.

When was the current VOT figure you're using developed? How frequently is it updated? How is the update done?

Most states use a value of time at least five years old. Georgia only uses "current" values in that the VOT is represented by the current average hourly wage. Almost all states "update" their VOT annually based on some factor to represent inflation (most often the Consumer Price Index). As far as major research on the derivation of the value itself, the survey revealed that no state has a set schedule for revisions, but rather update only on a perceived need basis.

What are the components of road user cost? Wage? Vehicle operating costs? Accident costs? Can you disaggregate the rate to these or other components?

In Georgia, value of time figures are based exclusively (and directly) on the average wage rate in the county were the analysis is being performed. New York uses a value derived from the minimum wage multiplied by average auto occupancy multiplied by the ratio of employment to adult population. All other states utilized a statewide wage rate. As to the greater question of the road user cost calculation, the calculations performed by the states surveyed take the following general form:

$$RUC = VOC + AC + VOT$$

Where

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

Vehicle operating costs are calculated on a cent per mile basis including fuel, tires, oil, maintenance, and depreciation at various speeds. Some states use a "composite vehicle" based on the observed mix of vehicles using the roadway. Others apply different operating cost values to different vehicle classes based on a representative sample. Either method should yield approximately the same result. Vehicle accident costs typically assign a value for a fatal accident, a non-fatal injury accident, and a value for an accident that results in property damage only. As noted elsewhere in this report, states use a variety of sources for wage data including average county wage data and average state wage data.

Do you take into consideration the value of time of any passengers in the vehicle (e.g., Texas multiplies per person values by 1.25 to account for the average number of occupants)?

All states except North Carolina and Georgia report calculating average ridership in developing values on a per-automobile basis. In every case (except North Carolina and Georgia), average occupancy rates were calculated based on direct observation/monitoring or in surveys of motorists.

Are all vehicles calculated (i.e., passenger cars, trucks, commercial vehicles) at the same rate? If not, what are the different rates?

As noted above, all states except Georgia and North Carolina report having VOT rates that distinguish between automobiles and commercial trucks. Georgia and North Carolina count all vehicles in total.

Do you use different value of time rates for different applications? (e.g., commute vs. non-commute, peak vs. off-peak, etc.)

While several states (New York, Pennsylvania, Florida, California, Washington, and Ohio) mentioned that they were very aware of different VOT rates for commute versus non-commute, for example, as a practical matter, no distinction was made in the analyses that are currently preformed.

For what are the value of time calculations used?

All states reported using value of time measures in conducting benefit/cost analyses in the pre-engineering/planning stages of work. Only California, Florida, Washington, and New York report currently using VOT calculations in liquidated damage settlements. Six of the states surveyed reported using A+B bidding on some projects and including VOT calculations in incentive/disincentive provisions.

Is any consideration given to the value of time relating to commerce (i.e., relative to either the impact of delays on the transportation of goods or to the impact on commerce in terms of the access to businesses adjacent to construction)?

California is the only state that reported giving consideration in a quantitative sense to the impact of lane closures, exit closures, or access restrictions to adjacent or surrounding businesses. Other states reported providing subjective consideration to these factors.

Has the value of time you've calculated actually been used in a legal proceeding or as a means of negotiating a settlement? Has it ever been challenged?

Only one state, Florida, reported any specific court challenges to the VOT used in a particular cost-benefit study. No state reported any specific court challenges as a result of A+B contracting litigation.

There are other findings from the survey that are pertinent to a discussion of the development and implementation of value of time calculations. For example, CalTrans (California) has long-used VOT for cost/benefit analysis in the pre-engineering and planning stages based on their own internally developed models. Values are developed for each particular project on an individual basis. They were very hesitant to provide any general values-of-time for quotation in this report or any values that might be considered representative of "typical" or "average" projects. The $12.10 and $30.00 per hour values quoted in this study were provided as "approximations" only. Currently, values of time are used only in cost-benefit analysis and alternative analysis. Studies are underway at the present time to determine the feasibility of using values in A+B contracting strategies.

Ohio uses a value of $ 0.21 per minute for automobiles and $ 0.44 per minute for trucks (converted to $12.60 and $26.80 per hour respectively for this study). The values are developed internally using publicly available research. The current values have been in use for approximately five years and adjusted on an as-needed basis.

There is no set schedule related to updating the value of time calculations employed in New York. On average, the calculations are said to be updated approximately every five years. The determination of whether an update is needed is made on an annual basis.

North Carolina uses perhaps the most simple method for calculating value of time by simply using the average annual hourly wage rate in the county where the analysis is being done. That value serves as one component of a benefits matrix model with five dimensions: user benefits, cost, impact of the improvement on economic development, environmental impacts, and relationship of the project to the state arterial system. Of most importance to this study is the "user benefits" component that includes vehicle cost savings, accident cost savings, and travel time cost savings.

Georgia uses a process almost identical to that employed in North Carolina to determine a VOT. No estimate is made regarding average ridership per vehicle. The VOT is simply the average hourly wage in the county where the analysis is being conducted.

Florida employs the value of time at several stages of the analytical process, particularly early in the "investment analysis" (cost/benefit) stage. Like other states, Florida does not distinguish between peak versus off-peak or commute versus non-commute values. However, Florida does employ rural versus non-rural values of time. The urban rate was quoted as approximately $12.00 per hour while the rural value was approximately $10.00 per hour.

Washington's experience is similar to California's in several respects. The state has long used VOT for cost/benefit analysis in the pre-engineering and planning stages based on its own internally developed models. As in California, values are developed for each particular project on an individual basis. Again, the values quoted in this study were provided as "approximations" only. However, unlike California, Washington users values of time are used both in cost-benefit analysis studies and in developing A+B contracting strategies.

Virginia, as noted earlier, uses the calculations produced by the Chui and McFarland report exclusively as its value of time. No adjustments are made to take into account conditions that may exist that are particular to the Virginia area.

Comparison of Texas' Practice with Those of Other States

As a general rule, Texas' methodological practices regarding value of time estimates for automobiles are consistent with those employed by other states and that consistency is reflected in the actual values that are employed. The value of time used in the instance of automobiles is, in fact, the median value of the states surveyed and within five percent of the mean value.

The value of time used in the instance of trucks is more problematic. While the methodology itself is not inconsistent with that used in other states, and while the VOT used in Texas is within eight percent of the median value reported by other states, it is only within 25 percent of the mean value. Because (1) of the disparity of the mean value reported by other states and the Texas value with respect to trucks, and (2) the truck values calculated in Chui and McFarland in 1984 were in fact adapted from a study by Buffington and McFarland done in 1975, the VOT used for trucks as well as the state's methodological practice with regard to VOT as applied to trucks can be concluded open to question.

RECOMMENDATIONS FOR TEXAS AND IMPLICATIONS FOR FUTURE RESEARCH

1. Values for autos are consistent with those in other states. Modeling techniques are in line with other states' and are more advanced than many. There is no compelling need for immediate research. Values must be monitored annually to insure accuracy.

2. Values for trucks deserve further research. The sample size used in the McFarland study was small. The variation in findings of recent research regarding trucks is significant. A major research effort regarding the value of time concerning commercial vehicles should be undertaken.

3. TxDOT should consider a relaxed policy regarding the application of discounts to road user costs included in construction contracts. Previous research and subsequent analyses have shown that the current practice is sufficiently conservative to assure accuracy, and that circumstances exist where conditions warrant giving higher weight to RUC.

4. Consideration should be given to a study to determine whether (and if so, at what point) risks perceived by contractors associated with liquidated damage charges get transformed into additional costs to the state, with the view of imposing a variable rate of recovery of RUC.

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APPENDIX A – ROAD USER COST TABLES

NOTE: On some of the Rehabilitation Project tables, the calculated road user costs differentials do not appear consistent at very high traffic volumes (e.g., see “Work Zone on Six-Lane Divided Arterial”). The differential in road user costs between the normal condition and the reduced capacity work zone condition actually declines. This decline begins when the traffic volumes are so high that, even under “normal” full capacity conditions, there is substantial delay. Therefore, the difference in the delay between “normal” conditions and “reduced capacity” conditions is not as large as it is for lower “normal” volumes that operate free flow.

Table A-1. Two-Lane Rural Highway (0%-25% No Passing Zones)
ADDED CAPACITY
(in $/day per mile)

ADT	5% trucks	10% trucks	15% trucks	20% trucks
5000	1,400	1,400	1,500	1,500
7500	2,100	2,200	2,200	2,300
10000	2,800	2,900	3,000	3,100
12500	3,600	3,700	3,800	3,900
15000	4,400	4,500	4,600	4,700
17500	5,200	5,300	5,500	5,600
20000	6,000	6,200	6,400	6,500
22500	7,000	7,200	7,400	7,500
25000	8,000	8,300	8,500	8,700
27500	9,300	9,600	9,800	10,100
30000	10,700	11,000	11,200	11,500
32500	12,300	12,600	12,900	13,200
35000	14,000	14,400	14,800	15,200
37500	16,100	16,500	16,900	17,400
40000	18,300	18,800	19,300	19,800
42500	20,700	21,200	21,800	22,400
45000	23,300	24,000	24,600	25,200
47500	26,000	26,700	27,400	28,100
50000	28,800	29,600	30,300	31,100
52500	31,700	32,500	33,400	34,200
55000	34,700	35,700	36,600	37,600
57500	37,700	38,700	39,800	40,800
60000	40,700	41,800	42,900	44,000
62500	43,900	45,000	46,200	47,400
65000	47,100	48,400	49,700	50,900
67500	50,400	51,800	53,100	54,500
70000	53,700	55,100	56,600	58,000
72500	57,100	58,600	60,100	61,700
75000	60,500	62,100	63,700	65,400
77500	63,900	65,600	67,300	69,100
80000	67,200	69,000	70,800	72,600
82500	70,600	72,600	74,500	76,400
85000	74,100	76,100	78,100	80,100
87500	77,500	79,600	81,700	83,800
90000	81,000	83,200	85,400	87,500
92500	84,200	86,500	88,800	91,000
95000	87,400	89,800	92,100	94,500
97500	90,500	93,000	95,400	97,800
100000	93,600	96,100	98,600	101,100

Table A-2. Four-Lane Rural Undivided Highway
ADDED CAPACITY
Four-Lane Rural Undivided Highway
(in $/day per mile)

ADT	5% trucks	10% trucks	15% trucks	20% trucks
5000	1,400	1,400	1,500	1,500
7500	2,100	2,200	2,200	2,300
10000	2,800	2,900	2,900	3,000
12500	3,500	3,600	3,700	3,800
15000	4,200	4,300	4,400	4,500
17500	5,000	5,100	5,200	5,300
20000	5,700	5,800	6,000	6,100
22500	6,400	6,600	6,700	6,900
25000	7,200	7,900	8,100	8,300
27500	7,900	8,100	8,300	8,500
30000	8,700	8,900	6,600	9,300
32500	9,400	10,200	10,500	10,700
35000	10,200	10,500	10,700	10,900
37500	11,000	11,300	11,500	11,800
40000	11,800	12,100	12,400	12,600
42500	12,600	12,900	13,200	13,500
45000	13,500	13,800	14,100	14,400
47500	14,300	14,700	15,000	15,300
50000	15,200	15,600	16,000	16,300
52500	16,200	16,600	16,900	17,300
55000	17,200	18,200	18,600	19,000
57500	18,200	18,600	19,000	19,500
60000	19,300	19,700	20,200	20,600
62500	20,500	21,700	22,200	22,800
65000	21,700	22,200	22,800	23,300
67500	23,100	23,600	24,100	24,700
70000	24,400	25,800	26,400	27,000
72500	25,800	26,400	27,000	27,600
75000	27,300	27,900	28,500	29,200
77500	28,900	30,500	31,200	32,000
80000	30,500	31,200	32,000	32,700
82500	32,300	33,000	33,800	34,500
85000	34,100	34,900	35,700	36,500
87500	36,000	36,900	37,700	38,500
90000	38,100	39,000	39,900	40,800
92500	40,200	41,200	42,100	43,000
95000	42,500	43,500	44,400	45,400
97500	44,700	45,800	46,800	47,800
100000	47,100	48,200	49,300	50,300
102500	49,500	50,700	51,800	53,000
105000	52,100	53,300	54,500	55,700
107500	54,700	56,000	57,200	58,500
110000	57,400	58,700	60,100	61,400
112500	60,100	61,400	62,800	64,200
115000	62,800	64,300	65,700	67,200

Table A-3. Four-Lane Rural Divided Highway
ADDED CAPACITY
(in $/day per mile)

ADT	5% trucks	10% trucks	15% trucks	20% trucks
5000	1,400	1,400	1,500	1,500
7500	2,100	2,100	2,200	2,300
10000	2,800	2,900	3,000	3,000
12500	3,500	3,600	3,700	3,800
15000	4,200	4,300	4,500	4,600
17500	4,900	5,100	5,200	5,300
20000	5,700	5,800	6,000	6,100
22500	6,400	6,600	6,700	6,900
25000	7,100	7,300	7,500	7,700
27500	7,900	8,100	8,300	8,500
30000	8,700	8,900	9,100	9,400
32500	9,400	9,700	9,900	10,200
35000	10,200	10,500	10,800	11,000
37500	11,000	11,300	11,600	11,900
40000	11,800	12,200	12,500	12,800
42500	12,700	13,000	13,400	13,700
45000	13,500	13,900	14,300	14,600
47500	14,500	14,900	15,300	15,600
50000	15,400	15,800	16,300	16,700
52500	16,400	16,900	17,300	17,700
55000	17,500	18,000	18,400	18,900
57500	18,600	19,200	19,700	20,200
60000	19,900	20,400	21,000	21,500
62500	21,200	21,800	22,300	22,900
65000	22,500	23,200	23,800	24,400
67500	23,900	24,600	25,200	25,900
70000	25,400	26,100	26,800	27,500
72500	27,000	27,700	28,500	29,200
75000	28,700	29,500	30,300	31,000
77500	30,500	31,300	32,100	32,900
80000	32,300	33,200	34,100	34,900
82500	34,300	35,200	36,200	37,100
85000	36,400	37,400	38,400	39,400
87500	38,600	39,700	40,700	41,700
90000	40,800	41,900	43,000	44,100
92500	43,200	44,300	45,500	46,700
95000	45,600	46,800	48,100	49,300
97500	48,100	49,400	50,700	52,000
100000	50,800	52,100	53,500	54,900
102500	53,400	54,900	56,300	57,800
105000	56,100	57,600	59,100	60,600
107500	58,800	60,400	62,000	63,600
110000	61,600	63,200	64,900	66,500
112500	64,400	66,100	67,800	69,600
115000	67,200	69,000	70,800	72,600

Table A-4.Four-Lane Rural Interstate Highway

ADDED CAPACITY

Four-Lane Rural Interstate Highway

(in $/day per mile)

ADT	10% trucks	15% trucks	20% trucks	25% trucks
10000	2,900	3,000	3,100	3,200
12500	3,600	3,800	3,900	4,000
15000	4,400	4,500	4,700	4,800
17500	5,100	5,300	5,500	5,600
20000	5,900	6,100	6,300	6,400
22500	6,600	6,900	7,100	7,300
25000	7,400	7,700	7,900	8,100
27500	8,200	8,500	8,700	9,000
30000	9,000	9,300	9,600	9,800
32500	9,800	10,100	10,400	10,700
35000	10,600	11,000	11,300	11,600
37500	11,500	11,800	12,200	12,600
40000	12,400	12,700	13,100	13,500
42500	13,200	13,700	14,100	14,500
45000	14,200	14,600	15,100	15,500
47500	15,200	15,600	16,100	16,600
50000	16,200	16,700	17,200	17,700
52500	17,300	17,900	18,400	18,900
55000	18,500	19,100	19,700	20,200
57500	19,800	20,400	21,000	21,700
60000	21,200	21,800	22,500	23,100
62500	22,600	23,300	24,000	24,700
65000	24,000	24,800	25,500	26,200
67500	25,600	26,400	27,200	28,000
70000	27,300	28,200	29,000	29,800
72500	29,100	30,000	30,900	31,800
75000	30,900	31,900	32,800	33,800
77500	32,900	33,900	35,000	36,000
80000	35,100	36,200	37,300	38,300
82500	37,300	38,500	39,600	40,800
85000	39,600	40,800	42,000	43,300
87500	42,000	43,300	44,600	45,900
90000	44,500	45,800	47,200	48,600
92500	47,100	48,500	50,000	51,400
95000	49,800	51,300	52,800	54,400
97500	52,600	54,200	55,800	57,400
100000	55,300	57,000	58,700	60,400
102500	58,100	59,900	61,700	63,500
105000	61,000	62,900	64,700	66,600
107500	63,900	65,800	67,800	69,800
110000	66,800	68,900	70,900	73,000
112500	69,800	72,000	74,100	76,300
115000	73,000	75,200	77,500	79,700
117500	76,200	78,500	80,900	83,200
120000	79,300	81,800	84,200	86,700
122500	82,400	85,000	87,500	90,000
125000	85,500	88,100	90,700	93,400
127500	88,500	91,300	94,000	96,700
130000	91,700	94,500	97,300	100,200
132500	94,900	97,800	100,800	103,700
135000	98,200	101,300	104,300	107,300

Table A-5. Six-Lane Rural Interstate Highway

ADDED CAPACITY

(in $/day per mile)

ADT	10% trucks	15% trucks	20% trucks	25% trucks
10000	2,900	3,000	3,100	3,200
12500	3,600	3,700	3,800	3,900
15000	4,300	4,500	4,600	4,700
17500	5,100	5,200	5,400	5,500
20000	5,800	6,000	6,200	6,400
22500	6,600	6,800	7,000	7,200
25000	7,300	7,500	7,700	8,000
27500	8,000	8,300	8,500	8,800
30000	8,800	9,100	9,300	9,600
32500	9,500	9,800	10,100	10,400
35000	10,300	10,600	10,900	11,200
37500	11,000	11,400	11,700	12,100
40000	11,800	12,200	12,500	12,900
42500	12,600	13,000	13,300	13,700
45000	13,300	13,800	14,200	14,600
47500	15,400	14,600	15,000	15,400
50000	14,100	15,400	15,800	16,300
52500	15,700	16,200	16,700	17,100
55000	16,500	17,000	17,500	18,000
57500	17,300	17,800	18,400	18,900
60000	18,100	18,700	19,200	19,800
62500	18,900	19,500	20,100	20,700
65000	19,800	20,400	21,000	21,600
67500	20,600	21,200	21,900	22,500
70000	21,500	22,100	22,800	23,400
72500	22,300	23,000	23,700	24,400
75000	23,200	23,900	24,600	25,300
77500	24,100	24,800	25,600	26,300
80000	25,000	25,800	26,500	27,300
82500	26,000	26,800	27,600	28,400
85000	26,900	27,800	28,600	29,400
87500	27,900	28,800	29,600	30,500
90000	28,900	29,800	30,700	31,600
92500	30,000	30,900	31,800	32,800
95000	31,100	32,000	33,000	33,900
97500	32,200	33,200	34,200	35,200
100000	33,400	34,400	35,500	36,500
102500	34,600	35,700	36,800	37,800
105000	35,900	37,000	38,100	39,200
107500	37,300	38,400	39,600	40,700
110000	38,600	39,800	41,000	42,200
112500	40,000	41,300	42,500	43,800
115000	41,400	42,700	44,000	45,200
117500	42,800	44,100	45,400	46,800
120000	44,300	45,600	47,000	48,400
122500	45,800	47,200	48,600	50,100
125000	47,400	48,900	50,300	51,800
127500	49,100	50,600	52,100	53,600
130000	50,800	52,400	54,000	55,500
132500	52,600	54,200	55,800	57,500
135000	54,400	56,100	57,800	59,400

Table A-6. Two-Lane Suburban Arterial

ADDED CAPACITY

(in $/day per 0.5 mile)

ADT	0% trucks	5% trucks	10% trucks
2500	400	400	400
5000	800	800	800
7500	1,200	1,200	1,300
10000	1,600	1,700	1,700
12500	2,100	2,100	2,100
15000	2,500	2,600	2,600
17500	3,000	3,100	3,100
20000	3,500	3,600	3,700
22500	4,200	4,300	4,300
25000	4,900	5,000	5,100
27500	5,800	5,900	6,000
30000	6,900	7,000	7,200
32500	8,200	8,300	8,500
35000	9,500	9,700	9,800
37500	10,800	11,100	11,300
40000	12,400	12,600	12,800

Table A-7. Four-Lane Suburban Arterial
ADDED CAPACITY
(in $/day per 0.5 mile)

ADT	0% trucks	5% trucks	10% trucks
2500	400	400	400
5000	800	800	900
7500	1,200	1,200	700
10000	1,600	1,700	1,300
12500	2,000	2,100	2,100
15000	2,400	2,500	2,600
17500	2,900	2,900	3,000
20000	3,300	3,300	3,400
22500	3,700	3,800	3,900
25000	4,100	4,200	4,300
27500	4,600	4,700	4,800
30000	5,000	5,100	5,300
32500	5,500	5,600	5,800
35000	6,000	6,100	6,300
37500	6,500	6,700	6,800
40000	7,100	7,300	7,400
42500	7,700	7,900	8,000
45000	8,400	8,500	8,700
47500	9,100	9,300	9,500
50000	9,900	10,100	10,300
52500	10,700	11,000	11,200
55000	11,600	11,900	12,200
57500	12,700	13,000	13,300
60000	13,900	14,200	14,500
62500	15,100	15,400	15,800
65000	16,300	16,700	17,100
67500	17,700	18,100	18,500
70000	19,000	19,400	19,800
72500	20,400	20,800	21,300
75000	21,700	22,200	22,700
77500	23,200	23,700	24,200
80000	24,800	25,400	25,900
82500	26,500	27,100	27,700
85000	28,400	29,100	29,700
87500	30,400	31,000	31,700
90000	32,300	33,000	33,800
92500	34,200	35,000	35,800
95000	36,100	36,900	37,800
97500	38,200	39,100	39,900
100000	40,200	41,200	42,100

Table A-8. Six-Lane Suburban Divided Arterial

ADDED CAPACITY

(in $/day per 0.5 mile)

ADT	0% trucks	5% trucks	10% trucks
2500	400	400	400
5000	800	800	900
7500	1,200	1,200	1,300
10000	1,600	1,700	1,700
12500	2,000	2,100	2,100
15000	2,400	2,500	2,600
17500	2,900	2,900	3,000
20000	3,300	3,300	3,400
22500	3,700	3,800	3,800
25000	4,100	4,200	4,300
27500	4,500	4,600	4,700
30000	4,900	5,000	5,100
32500	5,300	5,400	5,600
35000	5,800	5,900	6,000
37500	6,200	6,300	6,500
40000	6,600	6,800	6,900
42500	7,100	7,200	7,400
45000	7,500	7,700	7,900
47500	8,000	8,200	8,400
50000	8,500	8,700	8,900
52500	9,000	9,200	9,400
55000	9,500	9,700	10,000
57500	10,100	10,300	10,500
60000	10,600	10,900	11,100
62500	11,200	11,500	11,700
65000	11,900	12,100	12,400
67500	12,500	12,800	13,100
70000	13,200	13,500	13,800
72500	14,000	14,300	14,600
75000	14,800	15,100	15,500
77500	15,600	16,000	16,300
80000	16,500	16,900	17,300
82500	17,500	17,900	18,300
85000	18,500	18,900	19,300
87500	19,600	20,000	20,500
90000	20,800	21,300	21,700
92500	22,100	22,600	23,100
95000	23,200	23,800	24,300
97500	24,500	25,000	25,600
100000	25,900	26,400	27,000

Table A-9. Four-Lane Urban Freeway
ADDED CAPACITY
(in $/day per mile)

ADT	5% trucks	10% trucks
20000	5,700	5,900
30000	8,600	8,900
40000	11,600	11,900
50000	14,600	15,100
60000	17,800	18,300
70000	21,100	21,700
80000	25,700	26,500
90000	31,300	32,200
100000	36,600	37,700
110000	44,300	45,600
120000	53,100	54,600
130000	63,900	65,700
140000	77,600	79,800
150000	90,300	92,800
160000	102,900	105,800
170000	115,500	118,800
180000	128,200	131,900
190000	141,100	145,100
200000	154,800	159,200
210000	169,500	174,400
220000	184,100	189,300
230000	198,400	204,100
240000	212,600	218,600
250000	227,500	234,000
260000	242,100	249,100
270000	256,700	264,000
280000	270,500	278,200
290000	283,300	291,300
300000	295,700	304,200

Table A-10. Six-Lane Urban Freeway
ADDED CAPACITY
(in $/day per mile)

ADT	5% trucks	10% trucks
20000	5,700	5,800
30000	8,500	8,800
40000	11,500	11,800
50000	14,400	14,800
60000	17,400	17,900
70000	20,400	21,000
80000	23,500	24,200
90000	26,700	27,400
100000	29,900	30,800
110000	33,700	34,700
120000	38,600	39,700
130000	44,000	45,300
140000	49,500	50,900
150000	55,000	56,500
160000	62,200	64,000
170000	70,700	72,700
180000	79,700	81,900
190000	90,100	92,700
200000	102,500	105,400
210000	116,400	119,700
220000	128,900	132,600
230000	142,000	146,100
240000	154,300	158,700
250000	167,200	171,900
260000	179,400	184,500
270000	192,400	197,800
280000	205,100	210,900
290000	218,300	224,600
300000	232,100	238,800

Table A-11. Work Zone on a Four-Lane Rural Divided Arterial - 10% Trucks
REHABILITATION
(in $/day per mile)

One Lane Closed in One Direction		All Lanes Open with Reduced Capacity	
ADT	Road User Costs	ADT	Road User Costs
5000	0	5000	0
10000	0	10000	0
15000	100	15000	0
20000	200	20000	0
25000	600	25000	100
30000	1,400	30000	100
35000	2,600	35000	200
40000	4,300	40000	400
45000	6,200	45000	700
50000	8,300	50000	1,300
55000	10,300	55000	1,800
60000	12,500	60000	2,500
65000	14,600	65000	3,400
70000	16,600	70000	4,500
75000	18,500	75000	5,600
80000	20,200	80000	6,800
85000	21,600	85000	7,900
90000	22,600	90000	8,800
95000	23,200	95000	9,600
100000	23,700	100000	10,400
105000	24,000	105000	10,900
110000	24,200	110000	11,400
115000	24,400	115000	12,000

Table A-12.Work Zone on a Four-Lane Rural Interstate Highway - 15% trucks
REHABILITATION
(in $/day per mile)

One Lane Closed in One Direction		All Lane Open with Reduced Capacity	
ADT	Road User Costs	ADT	Road User Costs
10000	0	10000	0
15000	0	15000	0
20000	100	20000	0
25000	100	25000	0
30000	300	30000	100
35000	900	35000	100
40000	1,900	40000	100
45000	1,700	45000	200
50000	5,200	50000	300
55000	7,500	55000	400
60000	9,800	60000	1,200
65000	12,300	65000	2,200
70000	14,600	70000	3,000
75000	17,200	75000	4,000
80000	19,100	80000	4,400
85000	21,600	85000	6,400
90000	23,700	90000	7,600
95000	25,600	95000	9,400
100000	27,800	100000	12,000
105000	29,100	105000	13,900
110000	30,200	110000	15,500
115000	31,400	115000	17,100
120000	31,800	120000	18,200
125000	31,900	125000	18,800
130000	31,800	130000	18,700
135000	31,800	135000	18,800

Table A-13. Work Zone on a Six-Lane Rural Interstate Highway - 15% trucks
REHABILITATION
(in $/day per mile)

One Lane Closed in One Direction		All Lanes Open with Reduced Capacity	
ADT	Road User Costs	ADT	Road User Costs
10000	0	10000	0
15000	0	15000	0
20000	0	20000	0
25000	0	25000	0
30000	100	30000	0
35000	100	35000	100
40000	100	40000	100
45000	200	45000	100
50000	200	50000	100
55000	300	55000	100
60000	500	60000	200
65000	1,200	65000	200
70000	1,600	70000	300
75000	2,400	75000	400
80000	3,300	80000	500
85000	4,600	85000	700
90000	5,900	90000	1,300
95000	7,300	95000	2,600
100000	9,300	100000	3,400
105000	11,700	105000	4,100
110000	13,900	110000	5,500
115000	15,800	115000	6,000
120000	14,300	120000	6,300
125000	19,300	125000	7,900
130000	21,500	130000	9,900
135000	23,400	135000	11,100

Table A-14. Work Zone on a Four-Lane Urban Divided Arterial - 5% trucks
REHABILITATION
(in $/day per 0.5 mile)

One Lane Closed in One Direc		All Lanes Open with Reduced Capacity	
ADT	oad User Cos	ADT	Road User Cost
2500	0	2500	0
5000	0	5000	0
10000	0	10000	0
15000	100	15000	0
20000	300	20000	0
25000	900	25000	100
30000	1,900	30000	200
35000	3,500	35000	400
40000	5,200	40000	900
45000	7,100	45000	1,500
50000	8,300	50000	2,400
55000	9,200	55000	3,200
60000	9,700	60000	3,700
65000	10,100	65000	4,500
70000	10,600	70000	5,700
75000	11,100	75000	6,800
80000	11,500	80000	7,900
85000	11,200	85000	8,400
90000	10,800	90000	8,500
95000	10,100	95000	7,900
100000	9,000	100000	6,800

Table A-15. Work Zone on a Six-Lane Suburban Divided Arterial - 5% trucks
REHABILITATION
(in $/day per 0.5 mile)

One Lane in One Direction		All Lanes Open with Reduced Capacity	
ADT	Road User Costs	ADT	Road User Costs
2000	0	2000	0
7000	0	7000	0
12000	0	12000	0
17000	0	17000	0
22000	0	22000	0
27000	100	27000	0
32000	200	32000	100
37000	400	37000	100
42000	700	42000	200
47000	1,200	47000	300
52000	2,000	52000	400
57000	2,900	57000	700
62000	3,800	62000	1,200
67000	5,200	67000	1,800
72000	6,600	72000	2,600
77000	7,800	77000	3,500
82000	9,000	82000	4,300
87000	10,300	87000	4,900
92000	10,900	92000	5,300
97000	11,100	97000	6,000
100000	11,200	100000	6,600
		105000	8,100
		110000	9,300
		115000	10,400
		120000	11,400
		125000	12,000
		130000	12,500
		135000	12,500
		140000	12,000
		145000	11,300
		150000	10,100

Table A-16. Work Zone on a Four-Lane Urban Freeway - 5% trucks
REHABILITATION
(in $/day per mile)

One Lane in One Direction		All Lanes Open with Reduced Capacity	
ADT	Road User Costs	ADT	Road User Costs
25000	100	25000	0
30000	200	30000	100
35000	800	35000	100
40000	1,300	40000	100
45000	2,700	45000	200
50000	4,300	50000	200
55000	7,000	55000	400
60000	9,300	60000	1,000
65000	11,600	65000	1,800
70000	14,000	70000	2,900
75000	16,300	75000	3,200
80000	18,700	80000	3,600
85000	21,100	85000	4,600
90000	23,600	90000	6,100
95000	25,900	95000	8,000
100000	28,100	100000	10,300
105000	29,800	105000	12,700
110000	31,100	110000	15,300
115000	32,000	115000	17,500
120000	32,800	120000	19,300
125000	33,200	125000	20,300

Table A-17. Work Zone on a Six-Lane Urban Freeway - 5% trucks
REHABILITATION
(in $/day per mile)

One Lane in One Direction		All Lanes Open with Reduced Capacity	
ADT	Road User Costs	ADT	Road User Costs
25000	0	25000	0
30000	100	30000	0
35000	100	35000	100
40000	100	40000	100
45000	200	45000	100
50000	200	50000	100
55000	300	55000	100
60000	400	60000	200
65000	900	65000	200
70000	1,400	70000	300
75000	1,800	75000	400
80000	2,500	80000	500
85000	3,700	85000	600
90000	5,200	90000	1,400
95000	6,700	95000	2,200
100000	8,300	100000	3,300
105000	10,600	105000	4,300
110000	13,400	110000	4,900
115000	15,700	115000	4,900
120000	17,500	120000	5,400
125000	19,000	125000	6,300
130000	21,100	130000	7,700
135000	23,100	135000	9,100
140000	25,100	140000	10,900
145000	27,100	145000	13,300
150000	28,800	150000	15,500
155000	30,300	155000	17,800
160000	31,900	160000	20,400
		165000	23,000
		170000	22,500
		175000	27,200
		180000	29,000
		185000	30,100
		190000	30,900
		195000	31,100
		200000	30,700

APPENDIX B – MICROBENCOST VARIABLES

MicroBENCOST Selected Default Data Tables

Key to Codes in Default Tables:

Area Type

Code	Type
1	Rural
2	Urban

Functional Class

Code	Area Type	Functional Class
1	1	Interstate
2	1	Other Principal Arterial
3	1	Minor Collector
4	1	Major Collector
5	1	Minor Collector
1	2	Interstate
2	2	Other Freeway/Expressway
3	2	Other Principal Arterial
4	2	Minor Collector
5	2	Collector

Vehicle Type

Code	Type
1	Small passenger vehicle
2	Medium/large passenger vehicle
3	Pickup/van
4	Bus
5	2-axle single unit truck
6	3-axle single unit truck
7	2-S2 semi truck
8	3-S2 semi truck
0	Other

Reference: William F. McFarland, et al. *MicroBENCOST User's Manual – Version 1.0*. Prepared for the National Cooperative Highway Research Program, Project 7-12. Texas Transportation Institute. October 1993.

Table B-1. *MICROBENCOST INPUT VALUES*

PROJECT TYPE	INPUT VARIABLE	2-lane urban arterial	4-lane urban divided arterial	6-lane urban divided arterial	4-lane urban fwy	6-lane urban fwy
	Current year	1998	1998	1998	1998	1998
	Area type	urban	urban	urban	urban	urban
ADDED CAPACITY	Project type	added capacity	added capacity	added capacity	added capacity	added capacity
	Alternate rt. switch	no	no	no	no	no
	Total constr. cost	$1	$1	$1	$1	$1
	Discount rate	0%	0%	0%	0%	0%
	Analysis period	1	1	1	1	1
	Year impr. completed	1998	1998	1998	1998	1998
	Auto/truck costs	Table 1-4	Table 1-4	Table 1-4	Table 1-4	Table 1-4
	Functional class	minor arterial	principal arterial	principal arterial	other freeway/expressw	other freeway/expressw
	Percent trucks [range]	0% - 10%	0% - 10%	0% - 10%	5% to 10%	5% to 10%
	No. of route segments	1	1	1	1	1
	Type of distribution	Hours of day	Hours of day	Hours of day	Hours of day	Hours of day
	HOV lane present	no	no	no	no	no
	Base year	1998	1998	1998	1998	1998
	AADT base year [range]	2500 - 40000	2500 - 100000	2500 - 100000	20000 - 300000	20000 - 300000
	Growth rate	0%	0%	0%	0%	0%
	Compos. of auto fleet	default	default	default	default	default
	Compos. of truck fleet	default	default	default	default	default
	Traffic distribution	default	default	default	default	default
	Access control	none	none	none	full	full
	Segment length	0.5 mile	0.5 mile	0.5 mile	1	1
	Type of intersection	none	none	none	none	none
	Number of intersections	none	none	none	none	none
	Number of lanes inbound	1	2	3	2	3
	Number of lanes outbound	1	2	3	2	3
	Enter by road bed/direct.	no	no	no	no	no
	Median width	0	14	14	24	24
	Arterial class - design	suburban	suburban	suburban		
	Arterial class - function	minor arterial	principal arterial	principal arterial		
	Avg seg length btwn inters	0	0	0	0	0
	Lane width	12	12	12	12	12
	Shoulder width/lateral clearance	3	3	3	10	10
	Percent grade	0	0	0	0	0
	Degree curvature	0	0	0	0	0
	Addl local AADT	0	0	0	0	0
	Free flow speed	35	40	40	70	70
	Speed limit	35	35	35	55	55
	Capacity/lane/hour	default	default	default	default	default
	speed-volume relationship	Table 1-5	Table 1-5	Table 1-5		
	No. of work zones	0	0	0	0	0
	No. of incidents	0	0	0	0	0

Table B-2. *MICROBENCOST INPUT VALUES*

PROJECT TYPE	INPUT VARIABLE	2-lane rural	4-lane rural divided highway	4-lane rural divided highway	4-lane rural IH	6-lane rural IH
	Current year	1998	1998	1998	1998	1998
	Area type	rural	rural	rural	rural	rural
ADDED CAPACITY	Project type	added capacity	added capacity	added capacity	added capacity	added capacity
	Alternate rt. switch	no	no	no	no	no
	Total constr. cost	$1	$1	$1	$1	$1
	Discount rate	0%	0%	0%	0%	0%
	Analysis period	1	1	1	1	1
	Year impr. completed	1998	1998	1998	1998	1998
	Auto/truck costs	Table 1-4	Table 1-4	Table 1-4	Table 1-4	Table 1-4
	Functional class	minor arterial	principal arterial	principal arterial	interstate	interstate
	Percent trucks [range]	5% to 20%	5% to 20%	5% to 20%	5% to 25%	5% to 25%
	No. of route segments	1	1	1	1	1
	Type of distribution	Hours of day	Hours of day	Hours of day	Hours of day	Hours of day
	HOV lane present	no	no	no	no	no
	Base year	1998	1998	1998	1998	1998
	AADT base year [range]	2500 - 100000	5000 - 115000	5000 - 115000	40000 - 125000	50000 - 135000
	Growth rate	0%	0%	0%	0%	0%
	Compos. of auto fleet	default	default	default	default	default
	Compos. of truck fleet	default	default	default	default	default
	Traffic distribution	default	default	default	default	default
	Access control	none	none	none	full	full
	Segment length	1	1	1	1	1
	Type of intersection	none	none	none	none	none
	Number of intersections	none	none	none	none	none
	Number of lanes inbound	1	2	2	2	3
	Number of lanes outbound	1	2	2	2	3
	Enter by road bed/direct.	no	no	no	no	no
	Median width	0	0	16	48	48
	Avg seg length btwn inters	0	0	0	0	0
	Lane width	12	12	12	12	12
	Shoulder width/lateral clearance	4	4	10	10	10
	Percent grade	0	0	0	0	0
	Degree curvature	0	0	0	0	0
	Percent no passing zones	0% to 25%				
	Addl local AADT	0	0	0	0	0
	Free flow speed	70	70	70	70	70
	Speed limit	55	65	65	65	65
	Capacity/lane/hour	default	default	default	default	default
	No. of work zones	0	0	0	0	0
	No. of incidents	0	0	0	0	0

Table B-3. *MICROBENCOST INPUT VALUES*

4-lane urban divided arterial with work zone / **6-lane urban divided arterial with work zone**

PROJECT TYPE	INPUT VARIABLE	One lane closed inbound	All lanes open with reduced capacity	INPUT VARIABLE	One lane closed inbound	All lanes open with reduced capacity
	Current year	1998	1998	Current year	1998	1997
	Area type	urban	urban	Area type	urban	urban
REHABILITATION	Project type	added capacity	added capacity	Project type	added capacity	added capacity
	Alternate rt. switch	no	no	Alternate rt. switch	no	no
	Total constr. cost	$1	$1	Total constr. cost	$1	$1
	Discount rate	0%	0%	Discount rate	0%	0%
	Analysis period	2	2	Analysis period	2	2
	Year impr. completed	1998	1998	Year impr. completed	1998	1998
	Auto/truck costs	Table 1-4	Table 1-4	Auto/truck costs	Table 1-4	Table 1-4
	Functional class	principal arterial	principal arterial	Functional class	principal arterial	principal arterial
	Percent trucks	5%	5%	Percent trucks	5%	5%
	No. of route segments	1	1	No. of route segments	1	1
	Type of distribution	Hours of day	Hours of day	Type of distribution	Hours of day	Hours of day
	HOV lane present	no	no	HOV lane present	no	no
	Base year	1998	1998	Base year	1998	1997
	AADT base year [range]	2500-100000	2500-100000	AADT base year [range]	2500-150000	2500-150000
	Growth rate	0%	0%	Growth rate	0%	0%
	Compos. of auto fleet	default	default	Compos. of auto fleet	default	default
	Compos. of truck fleet	default	default	Compos. of truck fleet	default	default
	Traffic distribution	default	default	Traffic distribution	default	default
	Access control	none	none	Access control	none	none
	Segment length	0.5	0.5	Segment length	0.5	0.5
	Type of intersection	none	none	Type of intersection	none	none
	Number of intersections	0	0	Number of intersections	none	none
	Number of lanes inbound	2	2	Number of lanes inbnd	3	3
	Number of lanes outbound	2	2	Number of lanes outbnd	3	3
	Enter by road bed/direct.	yes	yes	Enter by road bed/direct.	yes	yes
	Median width	14	14	Median width	14	14
	Arterial class - design	suburban	suburban	Arterial class - design	suburban	suburban
	Arterial class - function	principal arterial	principal arterial	Arterial class - function	principal arterial	principal arterial
	Avg seg length btwn inters	0	0	Avg seg lgth btwn inters	0	0
	Lane width	12	12	Lane width	12	12
	Shoulder width or lateral clr	3	3	Shoulder width or lat clr	3	3
	Percent grade	0	0	Percent grade	0	0
	Degree curvature	0	0	Degree curvature	0	0
	Addl local AADT	0	0	Addl local AADT	0	0
	Free flow speed	40	40	Free flow speed	40	40
	Speed limit	35	35	Speed limit	35	35
	Capacity/lane/hour	784	80% of default	Capacity/lane/hour	784	80% of default
	Speed-volume relationship	Table 1-5	Table 1-5	Speed-volume relation.	Table 1-5	Table 1-5
	No. of work zones	1	0	No. of work zones	1	0
	No. of incidents	0	0	No. of incidents	0	0
	Year of workzone closure	1998		Year of workzone closure	1998	
	No. of days workzone in place	365		No. of days workzone in place	365	
	Number of lanes closed	1 inbound, 0 outbound		Number of lanes closed	1 inbound, 0 outbound	
	Beg hour of closure	0		Beg hour of closure	0	
	End hour of closure	24		End hour of closure	24	
	Capacity/lane/hour	80% of default		Capacity/lane/hour	80% of default	

Table B-4. *MICROBENCOST INPUT VALUES*

4-lane rural divided highway with work zone

INPUT VARIABLE	One lane closed inbound	All lanes open with reduced capacity
Current year	1998	1998
Area type	rural	rural
Project type	added capacity	added capacity
Alternate rt. switch	no	no
Total constr. cost	$1	$1
Discount rate	0%	0%
Analysis period	2	2
Year impr. completed	1998	1998
Auto/truck costs	Table 1-4	Table 1-4
Functional class	principal arterial	principal arterial
Percent trucks	10%	10%
No. of route segments	1	1
Type of distribution	Hours of day	Hours of day
HOV lane present	no	no
Base year	1998	1998
AADT base year [range]	5000 - 115000	5000 - 115000
Growth rate	0%	0%
Compos. of auto fleet	default	default
Compos. of truck fleet	default	default
Traffic distribution	default	default
Access control	none	none
Segment length	1	1
Type of intersection	none	none
Number of intersections	none	none
Number of lanes inbound	2	2
Number of lanes outbound	2	2
Enter by road bed/direct.	yes	yes
Median width	16	16
Avg seg length btwn inters	0	0
Lane width	12	12
Shoulder width	10	10
Percent grade	0	0
Degree curvature	0	0
Addl local AADT	0	0
Free flow speed	70	70
Speed limit	60	60
Capacity/lane/hour	1455	80% of default
No. of work zones	1	0
No. of incidents	0	0
Year of workzone closure	1998	
No. of days workzone	365	
Number of lanes closed	1 inbound, 0 outbound	
Beg hour of closure	0	
End hour of closure	24	
Capacity/lane/hour	80% of default	

4-lane rural IH with work zone

INPUT VARIABLE	One lane closed inbound	All lanes open with reduced capacity
Current year	1998	1998
Area type	rural	rural
Project type	added capacity	added capacity
Alternate rt. switch	no	no
Total constr. cost	$1	$1
Discount rate	0%	0%
Analysis period	2	2
Year impr. completed	1998	1998
Auto/truck costs	Table 1-4	Table 1-4
Functional class	interstate	interstate
Percent trucks	15%	15%
No. of route segments	1	1
Type of distribution	Hours of day	Hours of day
HOV lane present	no	no
Base year	1998	1998
AADT base year [range]	10000 - 100000	10000 - 100000
Growth rate	0%	0%
Compos. of auto fleet	default	default
Compos. of truck fleet	default	default
Traffic distribution	default	default
Access control	full	full
Segment length	1	1
Type of intersection	none	none
Number of intersections	0	0
Number of lanes inbound	2	2
Number of lanes outbound	2	2
Enter by road bed/direct.	yes	yes
Median width	48	48
Lane width	12	12
Shoulder width	10	10
Percent grade	0	0
Degree curvature	0	0
Addl local AADT	0	0
Free flow speed	70	70
Speed limit	65	65
Capacity/lane/hour	1835	80% of default
No. of work zones	1	0
No. of incidents	0	0
Year of workzone closure	1998	
No. of days workzone	365	
Number of lanes closed	1 inbound, 0 outbound	
Beg hour of closure	0	
End hour of closure	24	
Capacity/lane/hour	80% of default	

6-lane rural IH with work zone

INPUT VARIABLE	One lane closed inbound	All lanes open with reduced capacity
Current year	1998	1998
Area type	rural	rural
Project type	added capacity	added capacity
Alternate rt. switch	no	no
Total constr. cost	$1	$1
Discount rate	0%	0%
Analysis period	2	2
Year impr. completed	1998	1998
Auto/truck costs	Table 1-4	Table 1-4
Functional class	interstate	interstate
Percent trucks	15%	15%
No. of route segments	1	1
Type of distribution	Hours of day	Hours of day
HOV lane present	no	no
Base year	1998	1998
AADT base year [range]	50000-120000	50000-120000
Growth rate	0%	0%
Compos. of auto fleet	default	default
Compos. of truck fleet	default	default
Traffic distribution	default	default
Access control	full	full
Segment length	1	1
Type of intersection	none	none
Number of intersections	none	none
Number of lanes inbound	3	3
Number of lanes outbnd	3	3
Enter by road bed/direct.	yes	yes
Median width	48	48
Lane width	12	12
Shoulder width	10	10
Percent grade	0	0
Degree curvature	0	0
Addl local AADT	0	0
Free flow speed	70	70
Speed limit	65	65
Capacity/lane/hour	1835	80% of default
No. of work zones	1	0
No. of incidents	0	0
Year of workzone closure	1998	
No. of days workzone	365	
Number of lanes closed	1 inbound, 0 outbnd	
Beg hour of closure	0	
End hour of closure	24	
Capacity/lane/hour	80% of default	

Table B-5. ***MICROBENCOST INPUT VALUES***

4-lane urban freeway with work zone

INPUT VARIABLE	One lane closed Inbound	All lanes open with reduced capacity
Project type	added capacity	added capacity
Discount rate	0%	0%
Auto/truck costs	Table 1-4	Table 1-4
No. of route segments	1	1
Base year	1998	1998
Compos. of auto fleet	default	default
Access control	full	full
Number of intersections	0	0
Enter by road bed/direct.	yes	yes
Shoulder width	10	10
Addl local AADT	0	0
Capacity/lane/hour	1943	80% of default
Year of workzone closure	1998	
Beg hour of closure	0	

6-lane urban freeway with work zone

INPUT VARIABLE	One lane closed inbound	All lanes open with reduced capacity
Project type	added capacity	added capacity
Discount rate	0%	0%
Auto/truck costs	Table 1-4	Table 1-4
No. of route segments	1	1
Base year	1998	1998
Compos. of auto fleet	default	default
Access control	full	full
Number of intersections	0	0
Enter by road bed/direct.	no	no
Shoulder width	10	10
Addl local AADT	0	0
Capacity/lane/hour	1943	80% of default
Year of workzone closure	1998	
Beg hour of closure	0	

Table B-6 Composition of Automobile Fleet by Functional Class and by Area

				Base Year		End of Analysis Period	
Area Type	**Functional Class**	**Vehicle Type**	**Vehicle Description**	**% of Fleet**	**Occupancy Rate**	**% of Fleet**	**Occupancy Rate**
1	1	1	Small pass	17.4	1.3	17.4	1.3
1	1	2	Med/large pass	50.8	1.3	50.8	1.3
1	1	3	Pickup/van	31.8	1.3	31.8	1.3
1	1	4	Bus	0.0	20.0	0.0	20.0
1	1	0	Other	0.0	0.0	0.0	0.0
1	1	0	Other	0.0	0.0	0.0	0.0
1	1	0	Other	0.0	0.0	0.0	0.0
1	1	0	Other	0.0	0.0	0.0	0.0
1	1	0	Other	0.0	0.0	0.0	0.0
1	2	1	Small pass	17.4	1.3	17.4	1.3
1	2	2	Med/large pass	50.8	1.3	50.8	1.3
1	2	3	Pickup/van	31.8	1.3	31.8	1.3
1	2	4	Bus	0.0	20.0	0.0	20.0
1	2	0	Other	0.0	0.0	0.0	0.0
1	2	0	Other	0.0	0.0	0.0	0.0
	2	0	Other	0.0	0.0	0.0	0.0
1	2	0	Other	0.0	0.0	0.0	0.0
1	2	0	Other	0.0	0.0	0.0	0.0
1	3	1	Small pass	17.4	1.3	17.4	1.3
1	3	2	Med/large pass	50.8	1.3	50.8	1.3
1	3	3	Pickup/van	31.8	1.3	31.8	1.3
1	3	4	Bus	0.0	20.0	0.0	20.0
1	3	0	Other	0.0	0.0	0.0	0.0
1	3	0	Other	0.0	0.0	0.0	0.0
1	3	0	Other	0.0	0.0	0.0	0.0
1	3	0	Other	0.0	0.0	0.0	0.0
1	3	0	Other	0.0	0.0	0.0	0.0
1	4	1	Small pass	17.4	1.3	17.4	1.3
1	4	2	Med/large pass	50.8	1.3	50.8	1.3
1	4	3	Pickup/van	31.8	1.3	31.8	1.3
1	4	4	Bus	0.0	20.0	0.0	20.0
1	4	0	Other	0.0	0.0	0.0	0.0
1	4	0	Other	0.0	0.0	0.0	0.0
1	4	0	Other	0.0	0.0	0.0	0.0
1	4	0	Other	0.0	0.0	0.0	0.0
1	4	0	Other	0.0	0.0	0.0	0.0
1	5	1	Small pass	17.4	1.3	17.4	1.3
1	5	2	Med/large pass	50.8	1.3	50.8	1.3
1	5	3	Pickup/van	31.8	1.3	31.8	1.3
1	5	4	Bus	0.0	20.0	0.0	20.0
1	5	0	Other	0.0	0.0	0.0	0.0
1	5	0	Other	0.0	0.0	0.0	0.0
1	5	0	Other	0.0	0.0	0.0	0.0
1	5	0	Other	0.0	0.0	0.0	0.0
1	5	0	Other	0.0	0.0	0.0	0.0

Table B-6 Composition of Automobile Fleet by Functional Class and by Area (cont.)

				Base Year		End of Analysis Period	
Area Type	Functional Class	Vehicle Type	Vehicle Description	% of Fleet	Occupancy Rate	% of Fleet	Occupancy Rate
2	1	1	Small pass	17.4	1.3	17.4	1.3
2	1	2	Med/large pass	50.8	1.3	50.8	1.3
2	1	3	Pickup/van	31.8	1.3	31.8	1.3
2	1	4	Bus	0.0	20.0	0.0	20.0
2	1	0	Other	0.0	0.0	0.0	0.0
2	1	0	Other	0.0	0.0	0.0	0.0
2	1	0	Other	0.0	0.0	0.0	0.0
2	1	0	Other	0.0	0.0	0.0	0.0
2	1	0	Other	0.0	0.0	0.0	0.0
2	2	1	Small pass	17.4	1.3	17.4	1.3
2	2	2	Med/large pass	50.8	1.3	50.8	1.3
2	2	3	Pickup/van	31.8	1.3	31.8	1.3
2	2	4	Bus	0.0	20.0	0.0	20.0
2	2	0	Other	0.0	0.0	0.0	0.0
2	2	0	Other	0.0	0.0	0.0	0.0
2	2	0	Other	0.0	0.0	0.0	0.0
2	2	0	Other	0.0	0.0	0.0	0.0
2	2	0	Other	0.0	0.0	0.0	0.0
2	3	1	Small pass	17.4	1.3	17.4	1.3
2	3	2	Med/large pass	50.8	1.3	50.8	1.3
2	3	3	Pickup/van	31.8	1.3	31.8	1.3
2	3	4	Bus	0.0	20.0	0.0	20.0
2	3	0	Other	0.0	0.0	0.0	0.0
2	3	0	Other	0.0	0.0	0.0	0.0
2	3	0	Other	0.0	0.0	0.0	0.0
2	3	0	Other	0.0	0.0	0.0	0.0
2	3	0	Other	0.0	0.0	0.0	0.0
2	4	1	Small pass	17.4	1.3	17.4	1.3
2	4	2	Med/large pass	50.8	1.3	50.8	1.3
2	4	3	Pickup/van	31.8	1.3	31.8	1.3
2	4	4	Bus	0.0	20.0	0.0	20.0
2	4	0	Other	0.0	0.0	0.0	0.0
2	4	0	Other	0.0	0.0	0.0	0.0
2	4	0	Other	0.0	0.0	0.0	0.0
2	4	0	Other	0.0	0.0	0.0	0.0
2	4	0	Other	0.0	0.0	0.0	0.0
2	5	1	Small pass	17.4	1.3	17.4	1.3
2	5	2	Med/large pass	50.8	1.3	50.8	1.3
2	5	3	Pickup/van	31.8	1.3	31.8	1.3
2	5	4	Bus	0.0	20.0	0.0	20.0
2	5	0	Other	0.0	0.0	0.0	0.0
2	5	0	Other	0.0	0.0	0.0	0.0
2	5	0	Other	0.0	0.0	0.0	0.0
2	5	0	Other	0.0	0.0	0.0	0.0
2	5	0	Other	0.0	0.0	0.0	0.0

Table B-7. Composition of Truck Fleet By Functional Class and by Area

				Base Year	End of Analysis Period
Area Type	Functional Class	Vehicle Type	Vehicle Description	% of Fleet	% of Fleet
1	1	5	2-axle single unit	12.0	12.0
1	1	6	3-axle single unit	4.3	4.3
1	1	7	2-S2 semi’s	75.1	75.1
1	1	8	3-S2 semi’s	0.0	0.0
1	1	7	2-S1-2 semi’s	0.0	0.0
1	1	8	3-S2-2 semi’s	0.0	0.0
1	1	8	3-S2-4 semi’s	0.0	0.0
1	1	0	Other	0.0	0.0
1	1	0	Other	0.0	0.0
1	2	5	2-axle single unit	22.8	22.8
1	2	6	3-axle single unit	8.4	8.4
1	2	7	2-S2 semi’s	12.6	12.6
1	2	8	3-S2 semi’s	56.2	56.2
1	2	7	2-S1-2 semi’s	0.0	0.0
1	2	8	3-S2-2 semi’s	0.0	0.0
1	2	8	3-S2-4 semi’s	0.0	0.0
1	2	0	Other	0.0	0.0
1	2	0	Other	0.0	0.0
1	3	5	2-axle single unit	29.2	29.2
1	3	6	3-axle single unit	16.4	16.4
1	3	7	2-S2 semi’s	9.1	9.1
1	3	8	3-S2 semi’s	45.3	45.3
1	3	7	2-S1-2 semi’s	0.0	0.0
1	3	8	3-S2-2 semi’s	0.0	0.0
1	3	8	3-S2-4 semi’s	0.0	0.0
1	3	0	Other	0.0	0.0
1	3	0	Other	0.0	0.0
1	4	5	2-axle single unit	28.9	28.9
1	4	6	3-axle single unit	17.9	17.9
1	4	7	2-S2 semi’s	13.4	13.4
1	4	8	3-S2 semi’s	39.8	39.8
1	4	7	2-S1-2 semi’s	0.0	0.0
1	4	8	3-S2-2 semi’s	0.0	0.0
1	4	8	3-S2-4 semi’s	0.0	0.0
1	4	0	Other	0.0	0.0
1	4	0	Other	0.0	0.0
1	5	5	2-axle single unit	17.4	17.4
1	5	6	3-axle single unit	50.8	50.8
1	5	7	2-S2 semi’s	31.8	31.8
1	5	8	3-S2 semi’s	0.0	0.0
1	5	7	2-S1-2 semi’s	0.0	0.0
1	5	8	3-S2-2 semi’s	0.0	0.0
1	5	8	3-S2-4 semi’s	0.0	0.0
1	5	0	Other	0.0	0.0
1	5	0	Other	0.0	0.0

Table B-7. Composition of Truck Fleet By Functional Class and by Area (cont.)

				Base Year	End of Analysis Period
Area Type	**Functional Class**	**Vehicle Type**	**Vehicle Description**	**% of Fleet**	**% of Fleet**
2	1	5	2-axle single unit	19.0	19.0
2	1	6	3-axle single unit	8.2	8.2
2	1	7	2-S2 semi's	9.1	9.1
2	1	8	3-S2 semi's	63.7	63.7
2	1	7	2-S1-2 semi's	0.0	0.0
2	1	8	3-S2-2 semi's	0.0	0.0
2	1	8	3-S2-4 semi's	0.0	0.0
2	1	0	Other	0.0	0.0
2	1	0	Other	0.0	0.0
2	2	5	2-axle single unit	19.0	19.0
2	2	6	3-axle single unit	8.2	8.2
2	2	7	2-S2 semi's	9.1	9.1
2	2	8	3-S2 semi's	63.7	63.7
2	2	7	2-S1-2 semi's	0.0	0.0
2	2	8	3-S2-2 semi's	0.0	0.0
2	2	8	3-S2-4 semi's	0.0	0.0
2	2	0	Other	0.0	0.0
2	2	0	Other	0.0	0.0
2	3	5	2-axle single unit	35.5	35.5
2	3	6	3-axle single unit	11.8	11.8
2	3	7	2-S2 semi's	10.4	10.4
2	3	8	3-S2 semi's	42.3	42.3
2	3	7	2-S1-2 semi's	0.0	0.0
2	3	8	3-S2-2 semi's	0.0	0.0
2	3	8	3-S2-4 semi's	0.0	0.0
2	3	0	Other	0.0	0.0
2	3	0	Other	0.0	0.0
2	4	5	2-axle single unit	40.6	40.6
2	4	6	3-axle single unit	20.8	20.8
2	4	7	2-S2 semi's	6.9	6.9
2	4	8	3-S2 semi's	31.7	31.7
2	4	7	2-S1-2 semi's	0.0	0.0
2	4	8	3-S2-2 semi's	0.0	0.0
2	4	8	3-S2-4 semi's	0.0	0.0
2	4	0	Other	0.0	0.0
2	4	0	Other	0.0	0.0
2	5	5	2-axle single unit	43.5	43.5
2	5	6	3-axle single unit	19.0	19.0
2	5	7	2-S2 semi's	12.8	12.8
2	5	8	3-S2 semi's	24.7	24.7
2	5	7	2-S1-2 semi's	0.0	0.0
2	5	8	3-S2-2 semi's	0.0	0.0
2	5	8	3-S2-4 semi's	0.0	0.0
2	5	0	Other	0.0	0.0
2	5	0	Other	0.0	0.0

Table B8. Daily Traffic Volume Distribution by Hour of Day

Area Type	Functional Class	Hour of Day Volume Group	% of ADT During Hour	% Inbound Direction
1	1	1	1.8	48
1	1	2	1.5	48
1	1	3	1.3	45
1	1	4	1.3	53
1	1	5	1.5	53
1	1	6	1.8	53
1	1	7	2.5	57
1	1	8	3.5	56
1	1	9	4.2	56
1	1	10	5.0	54
1	1	11	5.4	51
1	1	12	5.6	51
1	1	13	5.7	50
1	1	14	6.4	52
1	1	15	6.8	51
1	1	16	7.3	53
1	1	17	9.3	49
1	1	18	7.0	43
1	1	19	5.5	47
1	1	20	4.7	47
1	1	21	3.8	46
1	1	22	3.2	48
1	1	23	2.6	48
1	1	24	2.3	47
1	2	1	1.8	48
1	2	2	1.5	48
1	2	3	1.3	45
1	2	4	1.3	53
1	2	5	1.5	53
1	2	6	1.8	53
1	2	7	2.5	57
1	2	8	3.5	56
1	2	9	4.2	56
1	2	10	5.0	54
1	2	11	5.4	51
1	2	12	5.6	51
1	2	13	5.7	50
1	2	14	6.4	52
1	2	15	6.8	51
1	2	16	7.3	53
1	2	17	9.3	49
1	2	18	7.0	43
1	2	19	5.5	47
1	2	20	4.7	47
1	2	21	3.8	46
1	2	22	3.2	48
1	2	23	2.6	48
1	2	24	2.3	47
1	2	1	1.8	48
1	2	2	1.5	48
1	2	3	1.3	45
1	2	4	1.3	53
1	2	5	1.5	53
1	3	6	1.8	53

Table B8. Daily Traffic Volume Distribution by Hour of Day (Cont.)

Area Type	Functional Class	Hour of Day Volume Group	% of ADT During Hour	% Inbound Direction
1	3	7	2.5	57
1	3	8	3.5	56
1	3	9	4.2	56
1	3	10	5.0	54
1	3	11	5.4	51
1	3	12	5.6	51
1	3	13	5.7	50
1	3	14	6.4	52
1	3	15	6.8	51
1	3	16	7.3	53
1	3	17	9.3	49
1	3	18	7.0	43
1	3	19	5.5	47
1	3	20	4.7	47
1	3	21	3.8	46
1	3	22	3.2	48
1	3	23	2.6	48
1	3	24	2.3	47
1	4	1	1.8	48
1	4	2	1.5	48
1	4	3	1.3	45
1	4	4	1.3	53
1	4	5	1.5	53
1	4	6	1.8	53
1	4	7	2.5	57
1	4	8	3.5	56
1	4	9	4.2	56
1	4	10	5.0	54
1	4	11	5.4	51
1	4	12	5.6	51
1	4	13	5.7	50
1	4	14	6.4	52
1	4	15	6.8	51
1	4	16	7.3	53
1	4	17	9.3	49
1	4	18	7.0	43
1	4	19	5.5	47
1	4	20	4.7	47
1	4	21	3.8	46
1	4	22	3.2	48
1	4	23	2.6	48
1	4	24	2.3	47
1	5	1	1.8	48
1	5	2	1.5	48
1	5	3	1.3	45
1	5	4	1.3	53
1	5	5	1.5	53
1	5	6	1.8	53
1	5	7	2.5	57
1	5	8	3.5	56
1	5	9	4.2	56
1	5	10	5.0	54
1	5	11	5.4	51
1	5	12	5.6	51

Table B8. Daily Traffic Volume Distribution by Hour of Day (Cont.)

Area Type	Functional Class	Hour of Day Volume Group	% of ADT During Hour	% Inbound Direction
1	5	13	5.7	50
1	5	14	604	52
1	5	15	608	51
1	5	16	7.3	53
1	5	17	9.3	49
1	5	18	7.0	43
1	5	19	505	47
1	5	20	4.7	47
1	5	21	308	46
1	5	22	3.2	48
1	5	23	2.6	48
1	5	24	2.3	47
2	1	1	1.2	47
2	1	2	0.8	43
2	1	3	0.7	46
2	1	4	0.5	48
2	1	5	0.7	57
2	1	6	1.7	58
2	1	7	5.1	63
2	1	8	7.8	60
2	1	9	6.3	59
2	1	10	5.2	55
2	1	11	4.7	46
2	1	12	5.3	49
2	1	13	5.6	50
2	1	14	5.7	50
2	1	15	5.9	49
2	1	16	6.5	46
2	1	17	7.9	45
2	1	18	8.5	40
2	1	19	5.9	46
2	1	20	3.9	48
2	1	21	3.3	47
2	1	22	2.8	47
2	1	23	2.3	48
2	1	24	1.7	45
2	2	1	1.2	47
2	2	2	0.8	43
2	2	3	0.7	46
2	2	4	0.5	48
2	2	5	0.7	57
2	2	6	1.7	58
2	2	7	5.1	63
2	2	8	7.8	60
2	2	9	6.3	59
2	2	10	5.2	55
2	2	11	4.7	46
2	2	12	5.3	49
2	2	13	5.6	50
2	2	14	5.7	50
2	2	15	5.9	49
2	2	16	6.5	46
2	2	17	7.9	45
2	2	18	8.5	40

Table B8. Daily Traffic Volume Distribution by Hour of Day (Cont.)

Area Type	Functional Class	Hour of Day Volume Group	% of ADT During Hour	% Inbound Direction
2	2	19	5.9	46
2	2	20	3.9	48
2	2	21	3.3	47
2	2	22	2.8	47
2	2	23	2.3	48
2	2	24	1.7	45
2	3	1	1.2	47
2	3	2	0.8	43
2	3	3	0.7	46
2	3	4	0.5	48
2	3	5	0.7	57
2	3	6	1.7	58
2	3	7	5.1	63
2	3	8	7.8	60
2	3	9	6.3	59
2	3	10	5.2	55
2	3	11	4.7	46
2	3	12	5.3	49
2	3	13	5.6	50
2	3	14	5.7	50
2	3	15	5.9	49
2	3	16	6.5	46
2	3	17	7.9	45
2	3	18	8.5	40
2	3	19	5.9	46
2	3	20	3.9	48
2	3	21	3.3	47
2	3	22	2.8	47
2	3	23	2.3	48
2	3	24	1.7	45
2	4	1	1.2	47
2		2	0.8	43
2	4	3	0.7	46
2	4	4	0.5	48
2	4	5	0.7	57
2	4	6	1.7	58
2	4	7	5.1	63
2	4	8	7.8	60
2	4	9	6.3	59
2	4	10	5.2	55
2	4	11	4.7	46
2	4	12	5.3	49
2	4	13	5.6	50
2	4	14	5.7	50
2	4	15	5.9	49
2	4	16	6.5	46
2	4	17	7.9	45
2	4	18	8.5	40
2	4	19	5.9	46
2	4	20	3.9	48
2	4	21	3.3	47
2	4	22	2.8	47
2	4	23	2.3	48
2	4	24	1.7	45