Lifecycle Cost Analysis RealCost User Manual

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Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

U.S. Department of Transportation
Federal Highway Administration

REAL COST

FOREWORD

This user manual presents guidance and recommendations for using RealCost version 3.0 to conduct lifecycle cost analysis (LCCA) (Federal Highway Administration (FHWA) 2021). FHWA's RealCost 3.0 is a Microsoft® Excel®-based LCCA tool. This user manual reflects RealCost 3.0's updated and enhanced input data requirements, functions, analysis features, and user interface.

The RealCost 3.0 tool has been updated to work on both Excel 32- and 64-bit systems. This update avoids the need for installation or availability of any third-party or other commercial components other than Excel 2010 or newer on end users' computers.

The user manual contains a brief introduction to LCCA methodology, explained in detail within FHWA's *Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin* (Walls and Smith 1998). The user manual explains the steps to install and operate RealCost 3.0. Appendix A details the procedure to compute LCCA using examples of three pavement and one bridge project. Appendix B helps users understand the customization of RealCost 3.0 for their specific needs. Specifically, the manual provides customization recommendations for linking RealCost 3.0 with an example agency cost Excel spreadsheet, simplifying the interpretation by developing output distributions based on the difference in the lifecycle cost alternatives.

State highway agency personnel and consultants responsible for conducting and reviewing LCCA will find the user manual of interest. The user manual adheres to the technical knowledge provided in the *Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin* that FHWA published in 1998 (Walls and Smith 1998).

Mark Swanlund
Acting Director, Office of Infrastructure
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7. Author(s)
Kelly L. Smith (ORCID: 0000-0003-0460-0460), Linda M. Pierce (ORCID: 0000-0003-4874-6293), George K. Chang (ORCID: 0000-0002-4945-8827), and Atish A. Nadkarni (ORCID: 0000-0002-7931-1965)

8. Performing Organization Report No.

9. Performing Organization Name and Address
Engineering & Software Consultants, Inc.
14123 Robert Paris Court, Chantilly, VA 20151

The Transtec Group
6111 Balcones Drive, Austin, TX 78731

SAIC
1710 SAIC Drive, McLean, VA 22102

Applied Pavement Technology, Inc.
115 W. Main Street, Suite 400, Urbana, IL 61801

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16. Abstract

Lifecycle cost analysis (LCCA) is an engineering economic analysis tool that compares the relative merit of competing project implementation alternatives. LCCA considers both the agency and user costs incurred during the service life of an asset and helps transportation officials select the most preferred alternative. Additionally, LCCA introduces a structured methodology that accounts for the effects of agency activities on transportation users and provides a means to balance those effects with the system's construction, rehabilitation, and preservation needs. This manual aims to help users of the Federal Highway Administration's (FHWA's) RealCost 3.0, a Microsoft® Excel®-based LCCA tool to conduct LCCA. This user manual reflects the updated and enhanced RealCost 3.0's input data requirements, functions, analysis features, and user interface. The RealCost 3.0 tool has been updated to work on both Excel 32- and 64-bit versions and avoids the need for installation or availability of any third-party or other commercial components other than Excel 2010 or newer on end users' computers. The user manual contains a brief introduction to LCCA and adheres to the LCCA methodology explained in detail within FHWA's *Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin* (Walls and Smith 1998). It also explains the steps to install and operate RealCost 3.0. Appendix A details the procedure to compute LCCA using examples of three pavement and one bridge projects. Appendix B helps users understand the customization of RealCost 3.0 for their specific needs. The user manual will interest State highway agency personnel and consultants responsible for conducting and reviewing LCCA.

17. Key Words
RealCost, lifecycle cost analysis, LCCA

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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LIST OF ABBREVIATIONS

AADT	annual average daily traffic
CAB	crushed aggregate base
Caltrans	California Department of Transportation
CDOT	Colorado Department of Transportation
CPI	Consumer Price Index
CPR	concrete pavement restoration
DLL	dynamic-link library
DP	demonstration project
EUAC	equivalent uniform annual cost
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GUI	graphical user interface
HMA	hot-mix asphalt
LCCA	lifecycle cost analysis
M&R	maintenance and rehabilitation
NCHRP	National Cooperative Highway Research Program
NPV	net present value
PCC	portland cement concrete
SHA	State highway agencies
TRB	Transportation Research Board
VPD	vehicles per day
VPHPL	vehicles per hour per lane
VBA	Visual Basic for Applications
WSDOT	Washington State Department of Transportation

CHAPTER 1. INTRODUCTION

Lifecycle cost analysis (LCCA) is an engineering economic analysis method for assessing the total cost of constructing, maintaining, and operating an asset or facility—or a system of assets or facilities—over an extended period (typically, 30 yr or more). LCCA is a valuable investment analysis method for assisting transportation managers in evaluating various design strategy alternatives based on the costs incurred by both the agency and users of the facility (i.e., direct and indirect costs, respectively).

In the roadway/transportation sector, LCCA can be used to quantify the differential costs of investment strategy alternatives for new construction, reconstruction, rehabilitation, and even preservation projects. LCCA assists in selecting the alternative with the lowest total cost, not just the lowest initial cost. In general, the LCCA process includes the following steps:

1. Establish design strategy alternatives.
2. Determine the timing of activities for each alternative (e.g., year of application for rehabilitation and preservation treatments).
3. Estimate agency and user costs for each alternative.
4. Compute lifecycle costs for each alternative.
5. Analyze the results to assess the sensitivity of each alternative to different input uncertainties.

However, an LCCA should only be used to compare project alternatives that provide equal benefits for the highway user (e.g., it cannot be used to compare a roadway widening project to an overlay project for the same roadway section). In addition, LCCA is not intended to be the only process used for deciding which design strategy alternative is the most applicable; several other factors, such as risk, budget, and political and environmental issues, must also be considered.

Most State highway agencies (SHAs) have developed and implemented LCCA techniques for use in selecting design strategy alternatives for new pavement construction or reconstruction projects, and several agencies use LCCA for rehabilitation projects. A survey conducted in 2009 indicates that approximately 80 percent of the responding States (27 of 33 total responses) reported using LCCA for new construction projects, and 33 percent (11 of 33 total responses) reported using LCCA for rehabilitation projects (National Cooperative Highway Research Program (NCHRP) 2009). A similar survey conducted in 1984 indicated that about 45 percent of States (22 of 49 total responses) use lifecycle costing for pavements (Peterson 1984). Significant progress in the implementation of LCCA has been made in the nearly 3 decades that separate these two surveys, thus indicating the significant benefits SHAs are finding in the LCCA process.

LCCA AND REALCOST

In 1996, the Federal Highway Administration (FHWA) initiated a technology transfer effort under Demonstration Project (DP) 115, "Life-Cycle Cost Analysis in Pavement Design." This project resulted in the development of FHWA's *Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin* (Walls and Smith 1998). This document serves as the primary reference manual for an LCCA instructional workshop. Since March 1997, the publication has been delivered to more than 40 State transportation agencies, along with a proof-of-concept LCCA software tool used for demonstration in the LCCA workshops.

The *Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin* presents the broad fundamental principles involved in LCCA and provides guidance and the recommended process for conducting LCCA of pavements at the project level. A brief overview of the LCCA process described in the publication is provided in the following paragraphs.

The project-level LCCA process begins with the development of pavement design alternatives to accomplish the structural and performance objectives of a project. The analyst then defines the schedule of initial and future activities involved in implementing each of the alternatives. Next, the costs of these activities are estimated. Best practice LCCA calls for including direct agency costs (e.g., expenditures due to construction or maintenance activities) and costs to the facility's users that result from agency work zone operations.

The predicted schedule of activities and associated agency and user costs form each pavement design alternative's projected lifecycle cost stream. These costs are converted into present-year dollars and then summed for each alternative using an economic technique known as discounting. The analyst can then determine which alternative is the most cost effective.

LCCA Steps

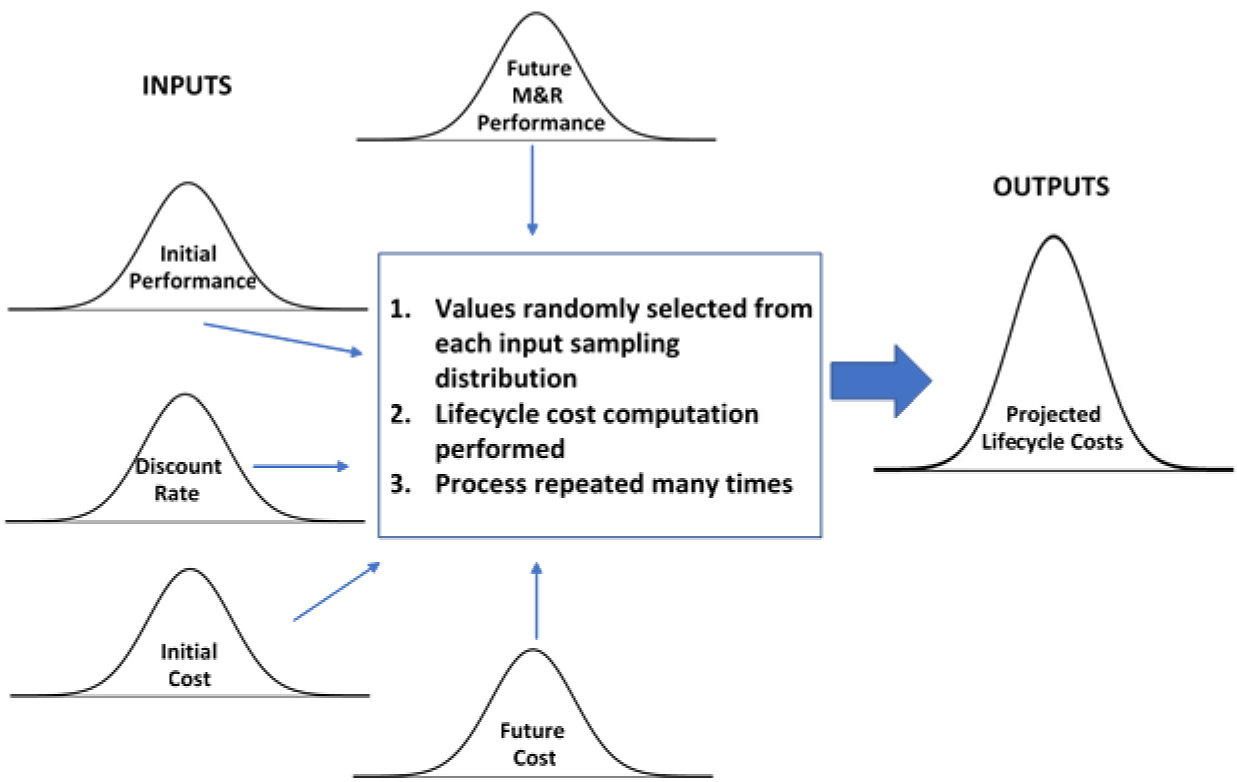
1. Establish design strategy alternatives.
2. Determine activity timing.
3. Estimate costs (agency and user).
4. Compute lifecycle costs.
5. Analyze the results.

LCCA can use two different computational approaches—deterministic and probabilistic. The methods differ in the way they address the variability associated with the LCCA input values. In the deterministic approach, each LCCA input variable is assigned a fixed, discrete value. The analyst then determines the most likely value to occur for each parameter, usually based on historical evidence or professional judgment. Collectively, the input values are used to compute a single lifecycle cost estimate for the alternatives under consideration.

Traditionally, LCCA applications have been deterministic. A deterministic lifecycle cost computation is straightforward and can be conducted manually with a calculator or automatically with a spreadsheet. Additional sensitivity analysis may then be conducted to test the variation in the outputs due to the change in an input value. In a sensitivity analysis, all the other inputs are held constant while assessing the sensitivity of an input parameter. However, a sensitivity analysis in the deterministic approach fails to capture the variation in outputs due to simultaneous variation in multiple inputs. Hence, it fails to fully capture the degree of uncertainty associated with the lifecycle cost estimates.

Probabilistic LCCA utilizes the processing capabilities of computers to simulate and subsequently account for the simultaneous variations in multiple input parameters. The probabilistic approach entails defining individual input parameters by a frequency/probability distribution (that may take many forms) rather than by discrete values. The probabilistic LCCA approach represents the risk analysis of the lifecycle costs for a particular design alternative.

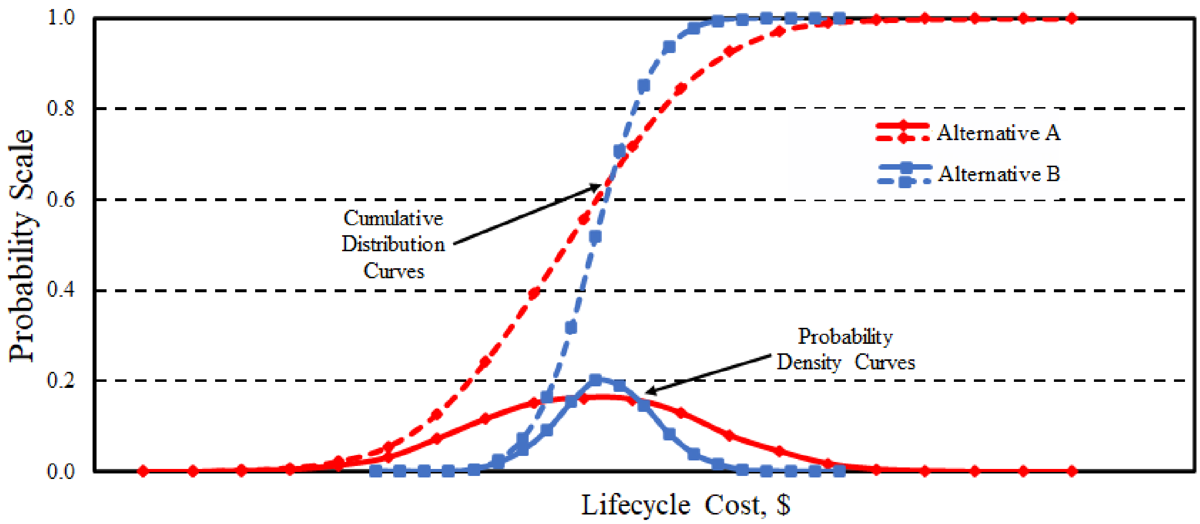
In figure 1, for a given strategy alternative, sample input values are randomly drawn from the defined frequency distributions (in this case, all normal distributions), and the selected values are used to compute one forecasted lifecycle cost value. The sampling process is repeated hundreds or even thousands of times, thereby generating many forecasted lifecycle cost values for the strategy alternative. The resulting forecasted costs can then be analyzed and compared with the forecasted results of competing alternatives to identify which one is most economical.



Source: FHWA.
M&R = maintenance and rehabilitation.

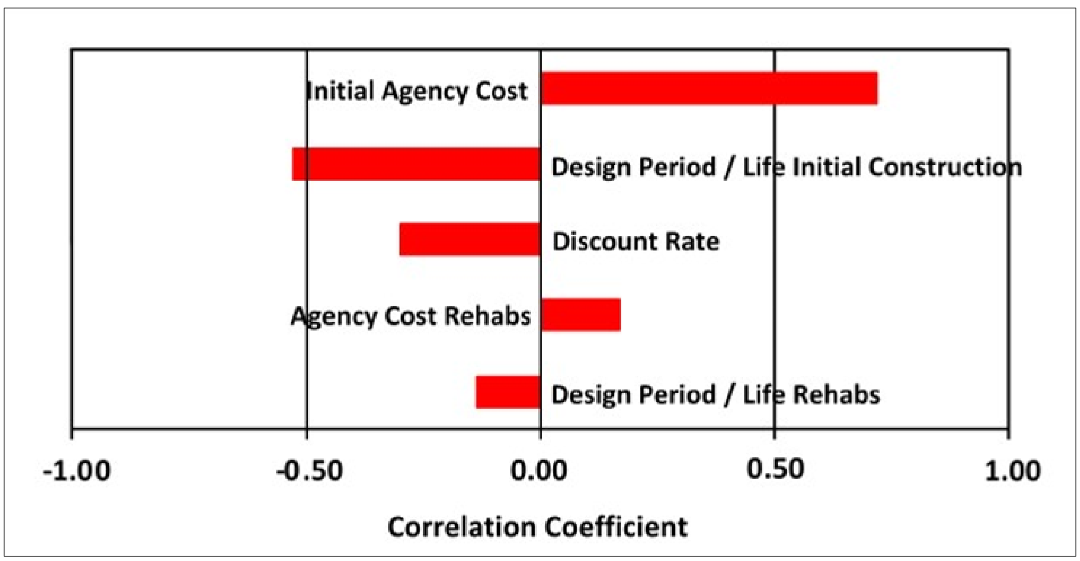
Figure 1. Illustration. Probabilistic LCCA process.

Although more time-consuming than obtaining single lifecycle cost values from deterministic LCCA, a probabilistic analysis provides a much greater understanding of the variability associated with inputs. In addition to determining the effects of variation in inputs on the projected lifecycle costs, a probabilistic LCCA provides ways to increase the reliability of results and enhance user confidence in identifying the most economical alternative. Analyzing probabilistic lifecycle costs of competing alternatives requires a comparison of the probability distribution curves, such as those shown in figure 2, and the associated statistics (e.g., mean, standard deviation, and specified percentile lifecycle costs). Additional analyses, such as sensitivity analysis and extreme tail analysis, can help identify key input variables and determine the need for refinements to the input distributions. For example, the RealCost graph shown in figure 3 indicates that the initial agency cost plays a major role in the lifecycle cost output for the subject alternative. If a better sampling of cost data were available for this input parameter, the effects on projected lifecycle cost could be significant and possibly impact the selection of an alternative.



Source: FHWA.

Figure 2. Graph. Probability density and cumulative distribution curves.



Source: FHWA.
Rehabs = rehabilitations.

Figure 3. Chart. Correlation sensitivity plot for a given alternative (Walls and Smith 1998).

A Microsoft® Excel®-based tool that utilized @RISK risk analysis software as a probabilistic add-in function was developed as a proof of concept for LCCA methodology under FHWA DP 115 (Palisade n.d.). This tool illustrated the usefulness of the LCCA methodology during three case study workshops involving the participation of stakeholders from 10 different States and both the asphalt and concrete pavement industries.

The positive feedback from the LCCA and case study workshops motivated FHWA to advance the initial version of the original DP 115 LCCA by initiating a contract in 2001. This advanced program retained the original Excel platform but replaced the @RISK add-in software with built-in probabilistic functions. Designated as "RealCost," the program was released in 2002 as version 2.0. The primary features of the program included:

- Deterministic and probabilistic computational approaches.
- Optional user cost-analysis capability.
- Graphical user interface (GUI) tools.
- Customized input screens and graphical display charts.
- Risk-analysis functionality for examining the effects of input variables on resulting lifecycle costs.

RealCost was created with two distinct purposes. The first was to provide an instructional tool for design decisionmakers who want to learn about LCCA (i.e., the software allows the users to investigate the effects of cost, service life, and economic inputs on the overall lifecycle cost). For this purpose, the GUI was designed to make the software easier to use and clearly convey the steps needed to carry out an LCCA. The second purpose was to provide a computational tool for designers to incorporate lifecycle costs into their roadway infrastructure investment decisions. The software was designed so that a basic understanding of the LCCA process is sufficient to operate the software.

The contribution of RealCost is the automation of the LCCA methodology presented in the *Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin* (Walls and Smith 1998). As described in the preceding paragraph, the software calculates both the agency and user lifecycle costs associated with a new construction/reconstruction and a rehabilitation activity in the given alternative strategy. RealCost can generate both deterministic and probabilistic computations of lifecycle costs expressed in tabular and graphical formats.

In addition, RealCost also automates FHWA's work zone user cost calculation method discussed in the *Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin* (Walls and Smith 1998). The method compares traffic demand to roadway capacity on an hourly basis, thereby defining the traffic flow conditions from which user costs are determined. The method is computation intensive and ideally suited to a spreadsheet application.

The software does not calculate agency costs or service lives for individual construction or rehabilitation activities. These values that reflect a highway agency's construction and rehabilitation practices need to be calculated separately by an analyst and can then be entered into the RealCost program. Alternatively, a user can create a worksheet(s) within the program to make such calculations, which can then be linked to the appropriate input fields. (Note: While customizations such as this are encouraged for effective use of the program, users are advised not to substantially alter any of the program's basic functionality or standard features and worksheets, as that complicates FHWA's free support efforts. Users should communicate additional needs of the application to FHWA so that the desired features can be incorporated and made available in future upgrades to the software.)

While RealCost computes and compares the lifecycle costs of competing strategy alternatives, its analysis outputs alone do not identify the best choice for implementing a project. The lowest lifecycle cost option may not always be implemented when other factors are considered. As with any economic tool, LCCA provides critical information to the overall decisionmaking process, but not the answer itself.

Several updated versions of RealCost have been released since the original version. Among some of the changes made to the program were added checks for the probabilistic functions (v 2.0.2 and v 2.1.3) in 2003, the establishment of equal bin sizes/ranges for lifecycle cost probability distributions of competing alternatives (v 2.1.1) in 2003, and the addition of a dual unit's option (i.e., English or metric) (v 2.2.0) in 2004. The next significant changes to the program were instituted in 2009 (v 2.5.0). Key changes included:

- Number of alternatives simultaneously analyzed increased from two to six.
- Number of possible activities for each alternative increased from 7 (including the initial event) to 24.
- User cost-related data items are no longer required when the user cost calculation is turned off or if external user cost calculations are performed.
- Modifications to remaining life-value calculations were made to consider both structural and service life remaining at the end of the analysis period. For each activity, service life and optionally structural life can be specified.
- Ability to define up to four different traffic distributions (e.g., weekday, weekend) as selected at the activity was added. Different distributions can be selected for various activities within the same alternative.
- Program optimized to reduce file size and improve execution time.
- Usability and user-friendliness improved.

The latest changes to the program were instituted in 2020 as part of v 3.0.NN, which is available for download on the FHWA web page for LCCA software (FHWA 2020). Key changes included:

- Making the RealCost application compatible with Excel 32-bit and 64-bit versions.
- Ensuring the RealCost application is 508 compliant.
- Adding a new traffic calculator in the RealCost application.

- Updating the RealCost user manual to reflect the changes in v 3.0 and ensuring 508 compliance (this document).

The RealCost software program consists of an Excel workbook with additional Visual Basic for Applications (VBA) programming code. The workbook consists of a collection of worksheets designed to perform different functions. The VBA code can perform Monte Carlo simulation in the analysis, and is also used to construct the GUI.

RealCost has two mechanisms for entering and working with data: the GUI (Switchboard) and worksheets. The Switchboard is the primary interface mechanism. Each input button on the Switchboard provides access to an input screen consisting of multiple components, as described in the following and illustrated in figure 4:

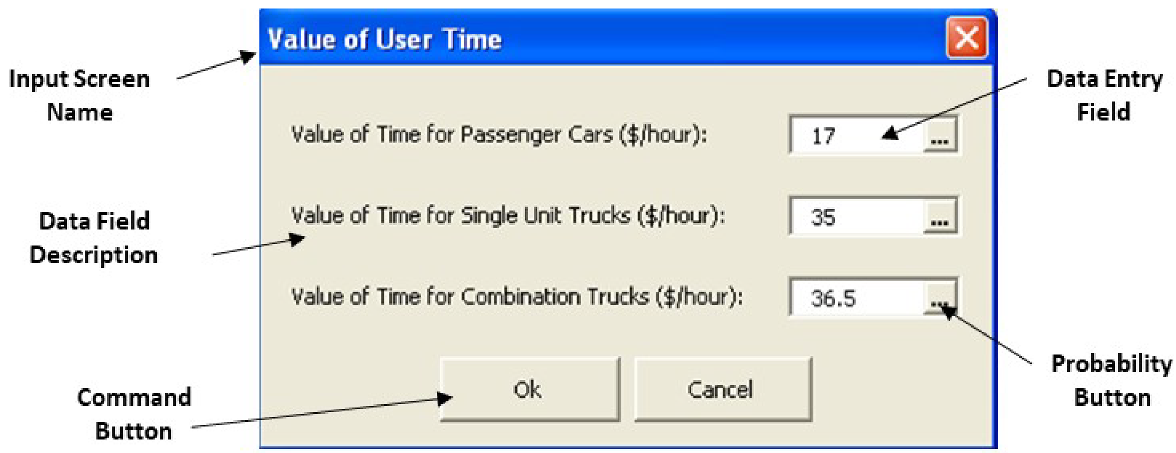
- Input screen name—the name used in RealCost to refer to the input screen.

- Data entry field—the area on the input screen for data input.

- Data field description—the phrase used to identify the data entry field.

- Command button—the GUI device that triggers a command or series of commands to the software.

- Probability button—a specific type of command button that opens an additional input screen where probabilistic inputs can be assigned.



Source: FHWA.

Figure 4. Screenshot. An example input screen for data entry, Value of User Time.

The Worksheets interface is available when the Switchboard interface is closed. Users may enter data in the appropriate worksheet cells, which carry the same labels as the corresponding fields on the Switchboard interface. While the Switchboard is the primary means of interacting with the software, all the entered data are stored in Excel worksheet cells. Data entered into an input screen's data entry field are automatically transferred to corresponding cells in the appropriate underlying worksheet. For example, the worksheet extract in table 1 contains the data entered in the Value of User Time input screen shown in figure 4. Data can be entered directly in the worksheets, but the Switchboard interface is required for some functions, as discussed in the section Moving Between the Switchboard and Worksheets.

Table 1. An example worksheet extract, Value of User Time.

Description	Value ($/h)
Value of Time for Passenger Cars	17.00
Value of Time for Single Unit Trucks	35.00
Value of Time for Combination Trucks	36.50

RealCost also stores all outputs (e.g., calculation results, analysis results) in the worksheets. Users can access these outputs similarly to data inputs.

PURPOSE OF THE USER MANUAL

This user manual provides basic instructions for using RealCost, a software program that FHWA originally developed to support the application of LCCA in the pavement project-level decisionmaking process. The manual provides directions for entering the data required to perform an LCCA and incorporating the software's outputs into project-level decisionmaking. The manual is primarily targeted at pavement designers and design decisionmakers who use LCCA and RealCost to compare the cost-effectiveness of design strategy alternatives for a given project.

While RealCost was developed with pavement LCCA applications in mind, it has the potential to be used for other roadway infrastructure assets, such as bridges, tunnels, drainage systems, and safety features (other applications, such as equipment fleet and snow/ice removal processes, are also possible). Such applications require competing strategies with different initial or future cost streams that are determined by the costs of individual construction and rehabilitation activities and the expected timings of those activities. As part of appendix A illustrating pavement LCCA using RealCost, an example exercise demonstrates how RealCost can be applied to bridges.

ORGANIZATION OF THE USER MANUAL

This user manual is organized into three chapters and three appendixes. Following this introductory chapter, the manual provides instructions on installing RealCost, starting the program and navigating through its various input screens and worksheets, saving and retrieving input files, and saving and exiting the workbook (chapter 2). The third and final chapter contains detailed directions on using RealCost to perform decision-support analyses regarding design strategy alternatives. It describes and illustrates entering data into input screens and worksheets and provides guidance and recommendations for the inputs, where appropriate. It also describes and illustrates the simulation process and the lifecycle cost outputs. Correspondingly, it gives guidance in evaluating and interpreting the results of the LCCA.

Appendix A contains a glossary of terms and definitions associated with the RealCost program. Appendix B presents four example applications of RealCost using data and information from actual highway projects. Three of the examples are for pavement projects, while the fourth represents a bridge project. Appendix C provides a short discussion of the current use of RealCost among highway agencies. It describes how it can be integrated into an agency's project development process and presents summaries of how some agencies have customized it to fit their unique pavement design alternative selection procedures.

SUGGESTED READING

RealCost follows FHWA's best practice LCCA methodology, which is fully documented in the 1998 *Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin* (Walls and Smith). The interim technical bulletin presents a formal treatment of LCCA methodology, the economic basis of discounting future expenditures, and probability; it also recommends input values. The interim technical bulletin is also the source of RealCost's default values. LCCA best practices are outlined in FHWA's *Life-Cycle Cost Analysis Primer* (2002), and FHWA's *Economic Analysis Primer* (2003).

Although this user manual provides a working knowledge of RealCost, the related documents described in the preceding paragraph—notably the *Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin*—provide a more indepth understanding of the process, which is helpful for including LCCA in the pavement decisionmaking process. Both the *Life-Cycle Cost Analysis Primer* (2002) and the interim technical bulletin are available in electronic format on the FHWA web page for LCCA (FHWA 2020).

CHAPTER 2. THE BASICS

SETUP

System Requirements

RealCost is designed to run in 32-bit or 64-bit Excel 2010 and newer versions and is not supported by versions earlier than Excel 2010. In addition, Microsoft Windows™ 7 Service Pack 1 (or newer) and Excel 2010 (or newer) are essential to run the software. However, the preferred Excel version is either an Office™ 365 subscription, Excel 2019, or newer.

Following are the minimum recommended system requirements for using RealCost:

- Excel 2010 or newer, with current service pack loaded.
- Windows 7 or newer, with current service pack loaded.
- Printer (RealCost requires a printer driver to use the Report function in the software).
- 2 GHz processor.
- 2 GB RAM.
- 1 GB hard drive space.

Download RealCost

As mentioned in chapter 1, RealCost is available for download on FHWA's web page for LCCA. The download file is a zip file that needs to be saved to a folder on the hard drive. Once downloaded, users should unzip the files to a folder where they would like to have RealCost available, keeping the same subfolder structure as in the zip file.

There is no installation needed to run RealCost. Therefore, users do not need administrative rights to upgrade RealCost versions. However, users will need to follow the setup instructions in the following section before running RealCost.

STARTING, NAVIGATING, AND EXITING

Working Folder Setup

Because Excel treats the VBA code in RealCost much like a macro, Excel must be set to allow macros to run before RealCost can be used.

It is recommended that users create a local working folder on their computers, such as the following:

C:\RealCost Work

Place the RealCost workbook file in the main working folder:

C:\RealCost Work\RealCost-3.N.N.xlsm (where N,N are subversion numbers)

Then, create two specific subfolders within the main working folders:

- C:\RealCost Work\32-bit
- C:\RealCost Work\64-bit

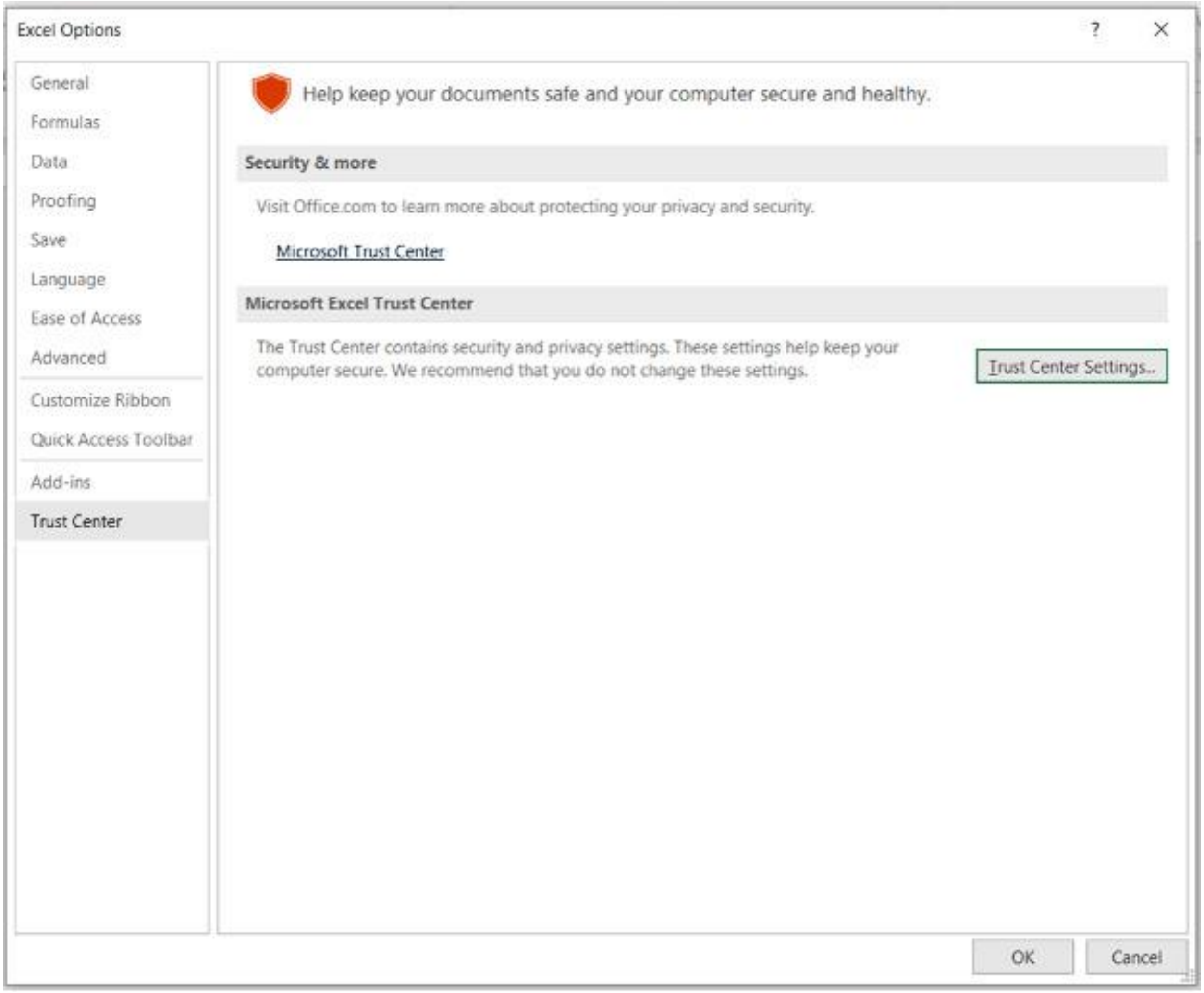
Place the supporting dynamic-link library (DLL) files in the subfolders as follows:

- C:\RealCost Work\32-bit\libiomp5md.dll
- C:\RealCost Work\32-bit\LCCADLL32.dll
- C:\RealCost Work\64-bit\libiomp5md.dll
- C:\RealCost Work\64-bit\LCCADLL64.dll

Do not rename, move, or delete the DLL files. Otherwise, the RealCost simulation will not function!

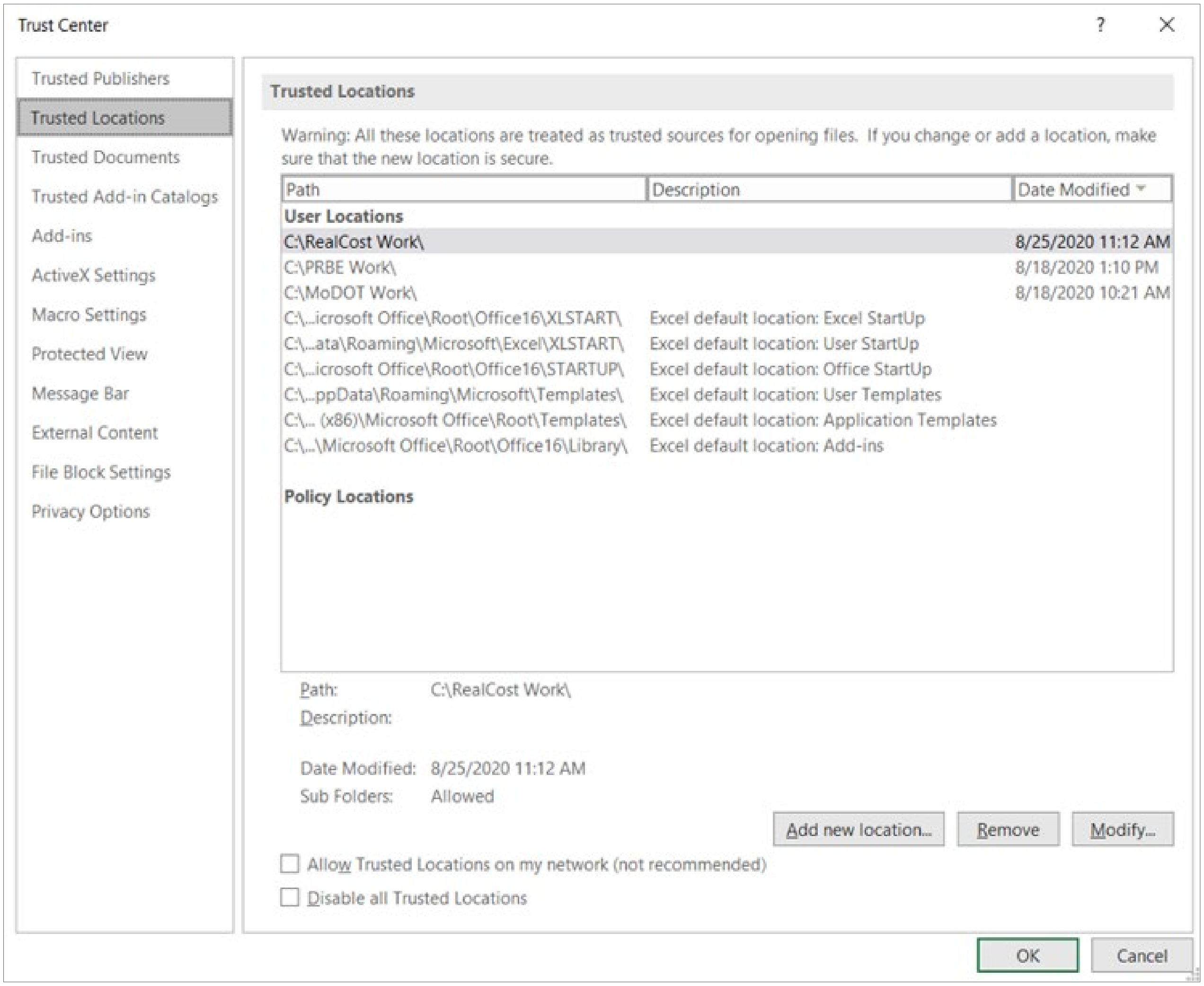
Open Excel, and start a new blank worksheet file. Then, use the following steps and figure 5 through figure 7 to set this working folder as a trusted folder by Excel:

1. Click File/Options.
2. Select Trust Center and click the Trust Center Settings.
3. Select Trusted Locations.



Source: FHWA.

Figure 5. Screenshot. RealCost working folder setup—Excel/Options/Trust Center/Trust Center Settings.

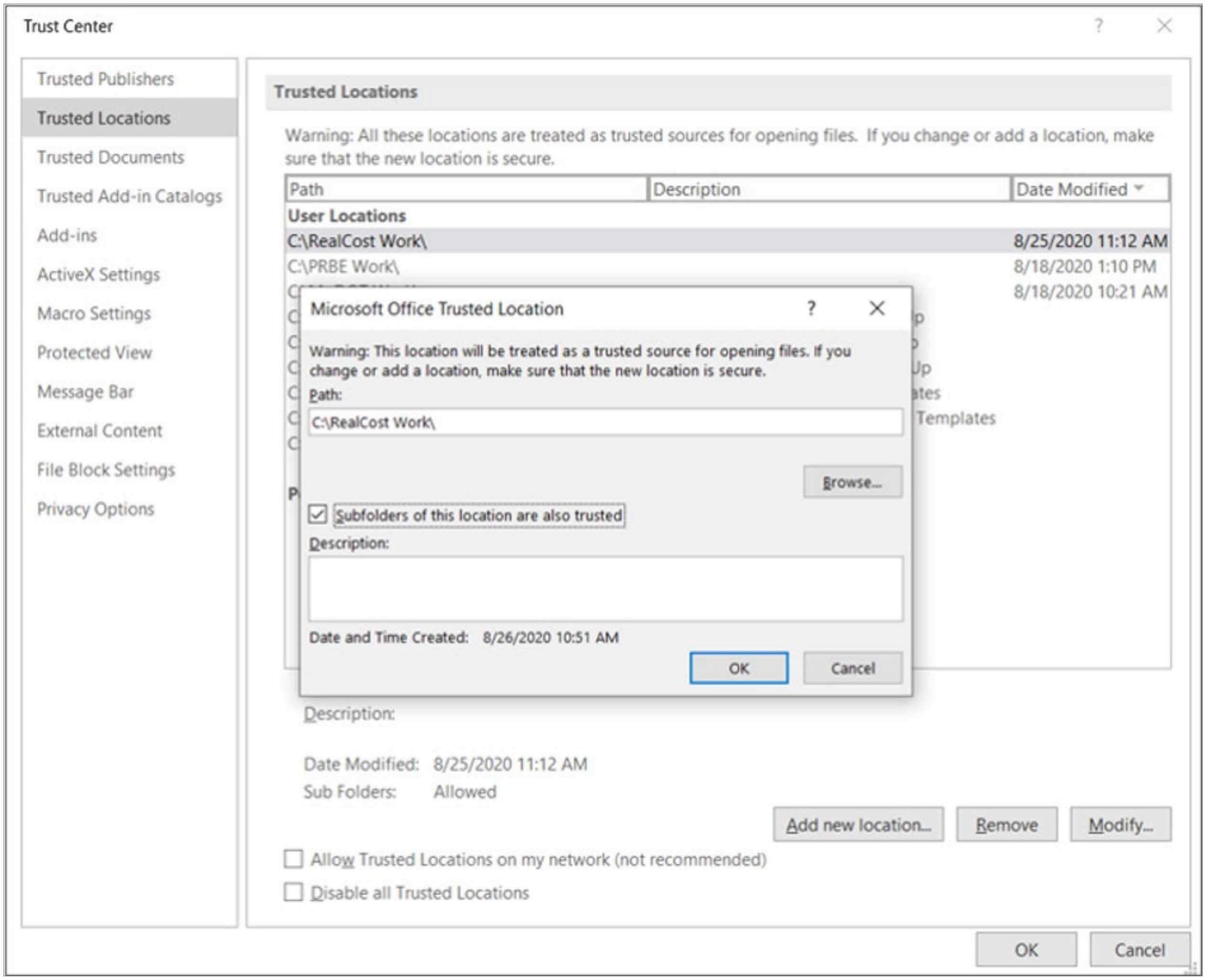


Source: FHWA.

Figure 6. Screenshot. RealCost working folder setup—Excel/Options/Trust Center/Trust Center Settings/Trusted Locations.

Click the Add new location button and navigate to your RealCost working folder (e.g., C:\RealCost work).

Check the box next to "Subfolders of this location are also trusted," and click OK. Then, click OK on the subsequent windows to exit.

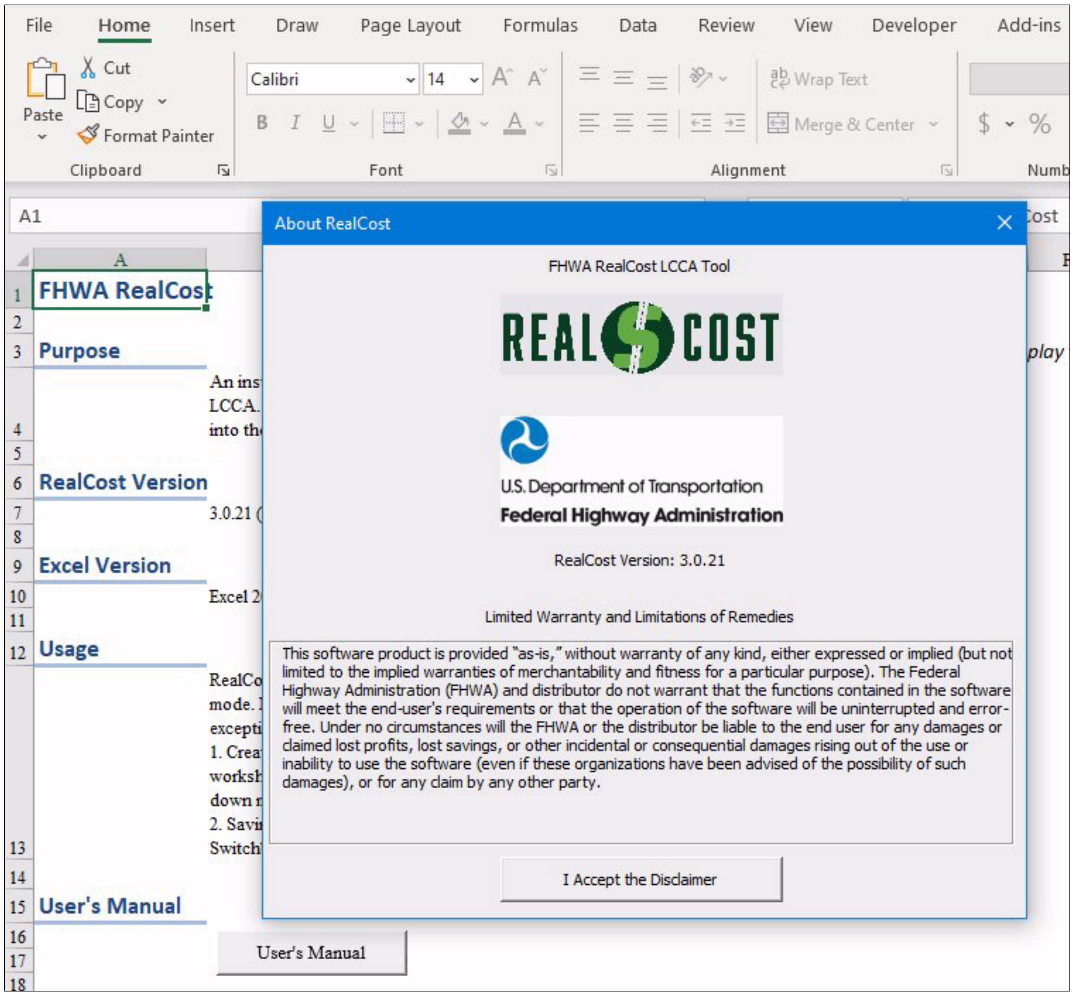


Source: FHWA.

Figure 7. Screenshot. RealCost working folder setup—Excel/Options/Trust Center/Trust Center Settings/Trusted Locations/Add New Location.

Starting RealCost

Once the working folder setup is complete, make a copy of the file to preserve the original copy. Then, start Excel and open the copied RealCost file. A dialog box with the FHWA disclaimer will pop up (figure 8). Click the I Accept the Disclaimer button. This action needs to be done only once for a given version. Save the file.

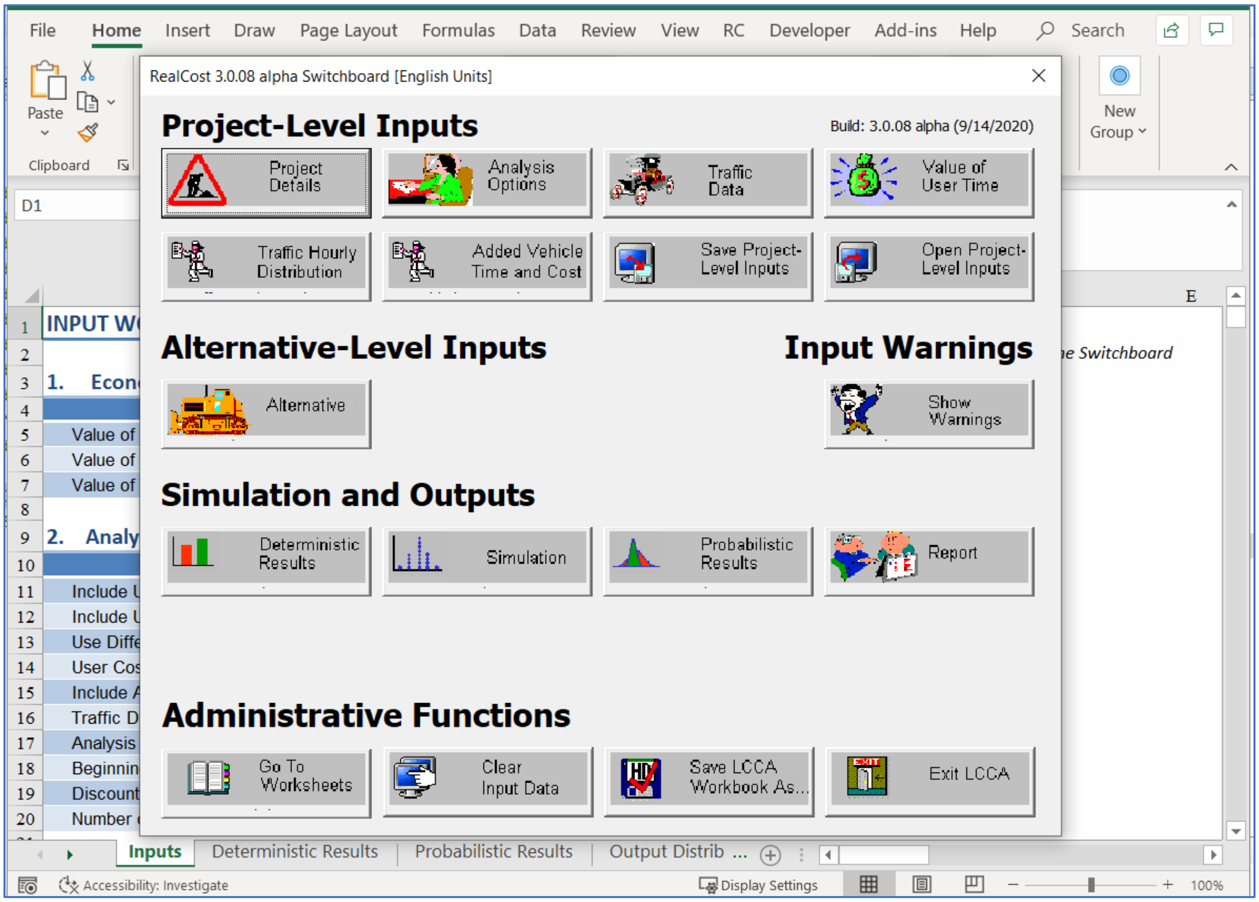


Source: FHWA.

Figure 8. Screenshot. The opening screen of RealCost.

Moving Between the Switchboard and Worksheets

Upon activation, RealCost opens to the Inputs worksheet. Users can work on the worksheets or use the Add-ins menu and Switchboard to navigate among worksheets. The Switchboard is a menu screen superimposed on an Excel worksheet that serves as a navigational tool (see figure 9). The Switchboard buttons provide access to almost all the program's functionality—data entry, analysis, reports, and utilities. These capabilities are discussed in more detail in the section titled "RealCost Switchboard Functions." Basic navigation and the Administrative Functions are described here.



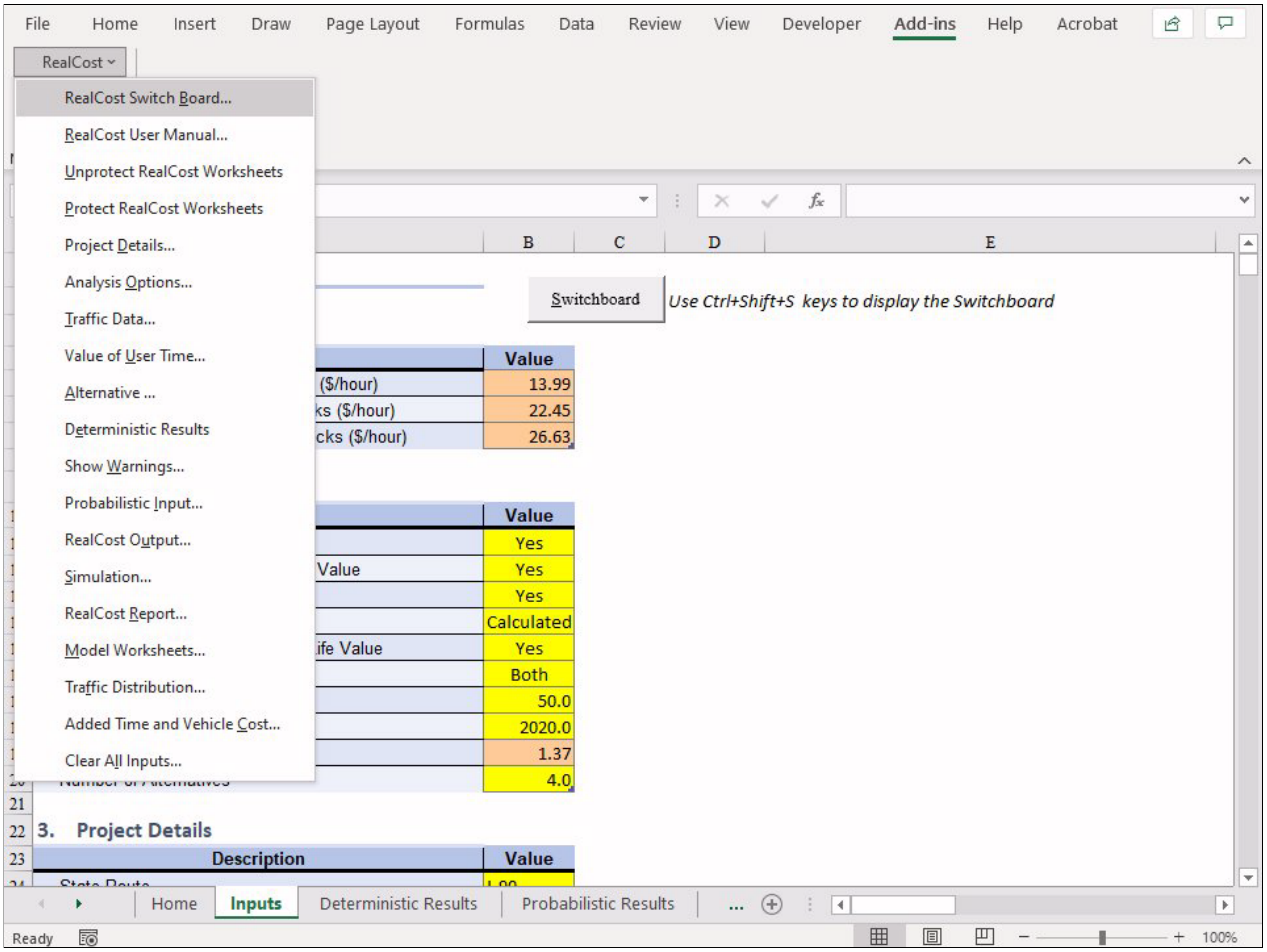
Source: FHWA.

Figure 9. Screenshot. The RealCost Switchboard overlaid on the worksheets.

The visibility of the Switchboard screen and the underlying Excel sheets is mutually exclusive, i.e., when the Switchboard is active, the underlying Excel worksheets that capture the data entered through the Switchboard input screens and the Excel menu bar are not accessible. To close the RealCost Switchboard, the user must switch to the worksheet mode using one of two options:

- Use the Go to Worksheets button in the Administrative Functions section of the Switchboard to display and select from a list of worksheets.
- Use the Switchboard's X button (located in the upper right-hand corner of the menu screen) to close the Switchboard.

To reopen the Switchboard from a worksheet, use the Add-ins menu from the Excel menu bar and the RealCost drop-down menu and select RealCost Switchboard (figure 10) or click the Switchboard button on the Inputs sheet.



Source: FHWA.

Figure 10. Screenshot. Opening the Switchboard from the RealCost menu.

Most functions can be performed in either mode, with the following exceptions:

- Creating a new probabilistic input or an LCCA output requires working in worksheet mode and using the respective options on the RealCost drop-down menu.
- Saving data input files for design strategy alternatives requires using the Switchboard.

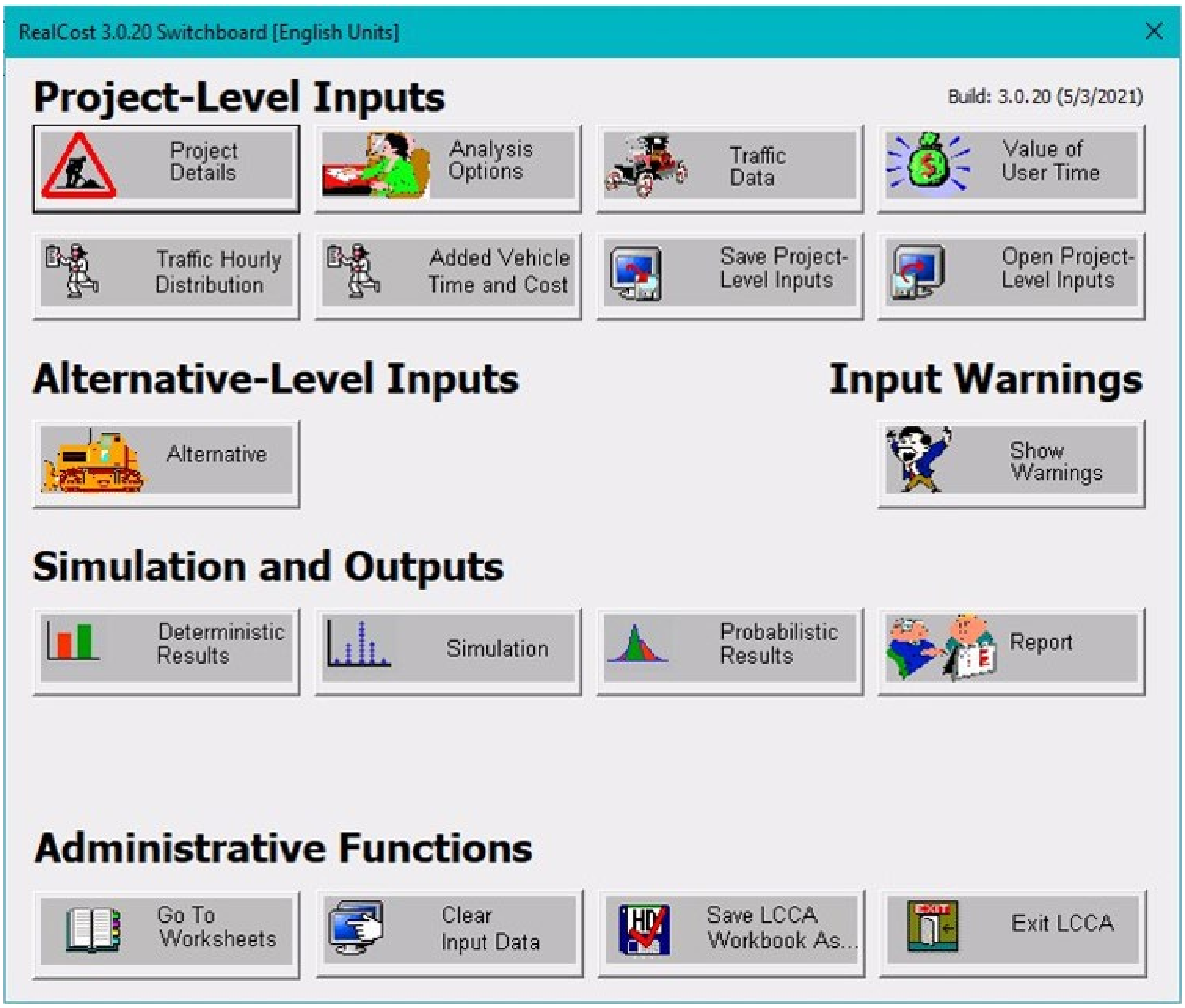
Should the Add-ins or RealCost menu disappear from the Excel menu bar (which may occur if another application or file is opened while RealCost is running), the user can retrieve the menu through the Excel View menu.

On the Excel menu bar:

View >> Macros >> View Macros >> AddLCCAMenu (i.e., run that specific macro)

RealCost Switchboard Functions

As shown in figure 11, the RealCost Switchboard has five operational categories. Brief descriptions of each category and the 18 Switchboard command buttons arranged under the various categories are provided in table 2. Detailed discussions regarding data input and using the RealCost features as part of the LCCA process are given in the next chapter.



Source: FHWA.

Figure 11. Screenshot. The five operational categories of the RealCost Switchboard.

Table 2. RealCost Switchboard command buttons and their functions.

Command Buttons	Functionality
Project Details	Stores descriptive data about the project. LCCA assumptions and other information concerning the analysis can and should be recorded here.
Analysis Options	Project-level data that apply to all alternatives being considered (e.g., analysis period, discount rate, costing options).
Traffic Data	Existing normal operations traffic data, such as the amount of traffic, vehicle types, and capacity.
Value of User Time	Hourly value of user time for three basic vehicle types.
Traffic Hourly Distribution	Distribution of annual average daily traffic (AADT) throughout the day, with separate data fields for rural and urban traffic patterns.
Added Vehicle Time and Cost	Cost and time to slow or stop, by vehicle type. Provides for cost escalation.
Save Project-Level Inputs	Saves the project-level data to an *.LCC file.
Open Project-Level Inputs	Retrieves project-level data from an *.LCC file.
Alternative	All alternative data, such as alternative-level agency activity cost, service life, construction duration, and work zone data. Each alternative includes commands to save and recall individual alternative data sets.
Show Warnings	Identifies suspect data values and errors due to missing or out-of-bounds data. Warnings are displayed on the Simulation Warnings worksheet. It should be noted that "warnings" call attention to certain inputs that fall out of expected ranges and do not necessarily indicate input errors, whereas "errors" are fatal inputs that will prevent the program from running and providing LCCA results.
Deterministic Results	Calculates and displays deterministic LCCA results based upon input parameters represented by a single value (i.e., a mean or most likely value).
Simulation	Performs simulation with probabilistic inputs.
Probabilistic Results	Displays probabilistic results. Allows access to probabilistic results worksheets.

Command Buttons	Functionality
Report	Produces a printable report that shows inputs and results.
Go to Worksheets	Allows direct access to specific worksheets within the workbook. To close the Switchboard and choose from a list of individual worksheets, use the Go to Worksheets button. The user can also access the worksheet that is currently active by clicking on the X in the upper right-hand corner of the Switchboard.
Clear Input Data	Deletes all project-level data, alternative-level data, and computation outputs. Creates a “clean slate.”
Save LCCA Workbook As…	Saves the entire Excel workbook, including both inputs and results worksheets. Saving a workbook is the only way to save analysis results. Typically, an analysis file containing the simulation results using 2,000 iterations is 6 MB in size.
Exit LCCA	Closes RealCost. The software will ask the user whether the file should be saved. The exit command on the Excel File menu and the RealCost menu present the same save options. As noted in the preceding row, to save the analysis results, it is necessary to save the entire Excel workbook. Because an analysis file is usually around 6 MB in size, saving can take several seconds. However, data input can be saved via *.LCC (project-level inputs) and *.LCA (alternative-level inputs) files without saving the entire workbook.

Saving and Exiting Via the Switchboard

RealCost can be closed by using the Exit LCCA button in the Administrative Functions section of the Switchboard. When exiting, however, it is necessary to save the entire workbook to retain analysis results. The Exit LCCA button prompts the user to save the workbook. The Save RealCost button can be used to save the workbook at any time. Both the Exit and Save buttons prompt for a file name and location.

TIP

Analysis results can only be saved by saving the RealCost workbook, either through the Switchboard Save LCCA Workbook As button or the Excel menu bar. This file should be saved with a descriptive name.

Saving and Exiting Via Worksheets

To save a workbook and exit while in worksheet mode, it is advisable to use the Save As option on the Excel menu before closing. Saving under an appropriate name will preserve the analysis results. If the user saves a file in the RealCost workbook, the data will need to be cleared before analyzing another project. This step can be done with the Clear Input Data option in the Administrative Functions part of the RealCost Switchboard.

CHAPTER 3. USING REALCOST IN LCCA

This chapter elaborates on the functioning of the RealCost tool by discussing the various sections within it and providing examples.

ENTERING, SAVING, AND LOADING DATA

RealCost's data needs are compliant with the data requirements discussed in FHWA's best practice LCCA process (Walls and Smith 1998). RealCost produces the lifecycle costs by performing the necessary functions once the user enters the required input data. Furthermore, the software permits the analyst to quickly consider modifications to the data that result from the analysis of earlier LCCA iterations. The LCCA steps and their corresponding data input and output screens are listed in table 3.

Table 3. LCCA steps and corresponding RealCost forms.

FHWA LCCA Steps	RealCost Data Input and Output Screens
1. Establish design strategy alternatives	Project Details Analysis Options Traffic Data Value of User Time Traffic Hourly Distribution Added Vehicle Time and Cost
2. Determine activity timing	Alternative
3. Estimate agency and user costs	Alternative
4. Compute lifecycle costs	Deterministic Results Simulation
5. Analyze the results	Deterministic Results Probabilistic Results

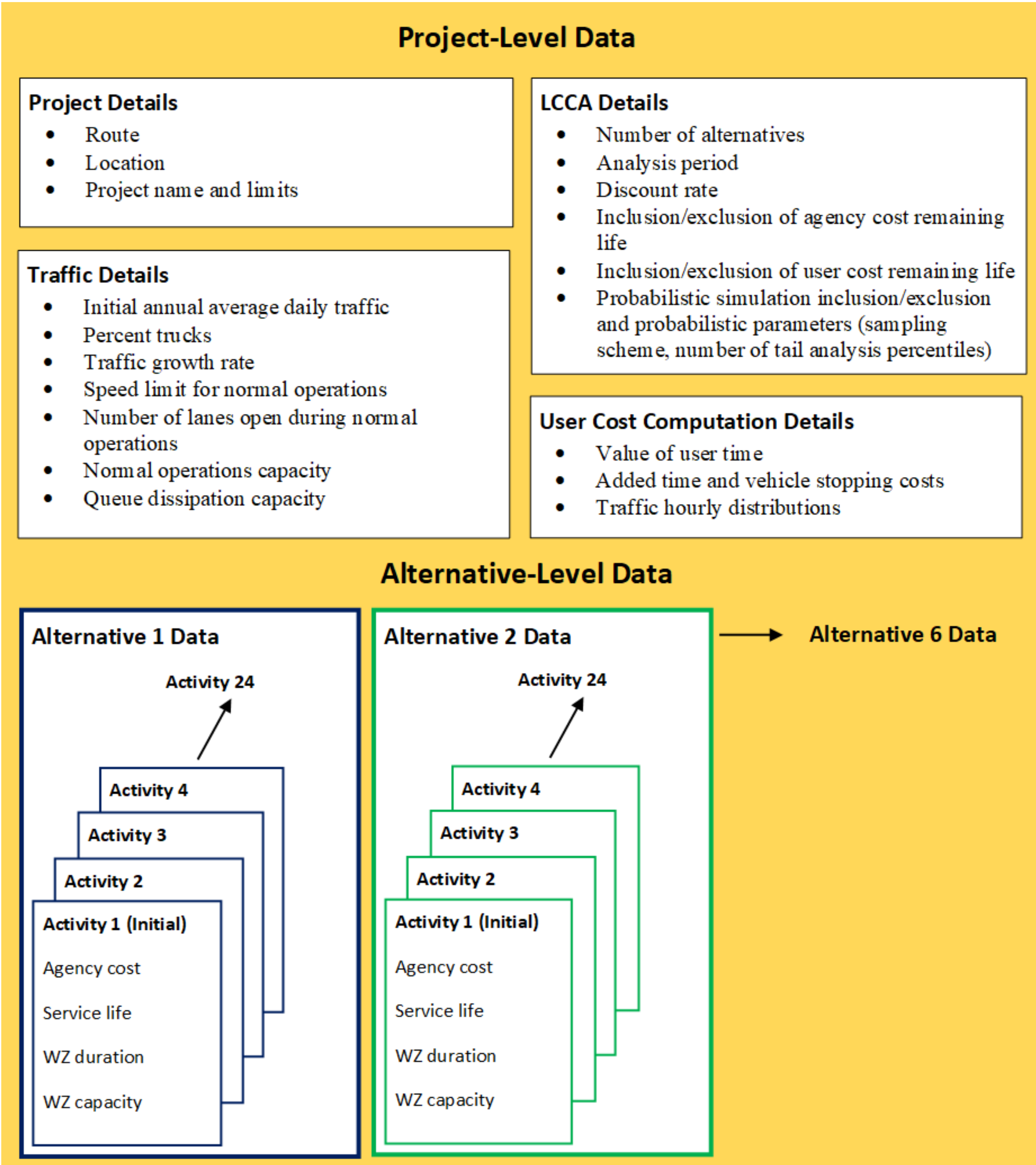
Project-Level Versus Alternative-Level Data

The LCCA process requires two levels of input data: data about the proposed project and data defining the design strategy alternatives that are being considered for accomplishing the project.

Project-level data apply to all strategic alternatives being considered for the project at hand. FHWA's best practice LCCA methodology requires the analysis period, discount rate, normal operations traffic data, and normal operations roadway geometry to be the same for all strategic alternatives.

Alternative-level data define the differences between strategy alternatives. These differences emerge in agency costs, activity types, timings, and work zone traffic flow characteristics. RealCost models work zone traffic flow restrictions with the user cost methodology described in FHWA's *Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin* (Walls and Smith 1998).

RealCost requires that project-level data be entered separately from alternative-level data to emphasize the difference between the two types of inputs. The division between project-level and alternative-level data provides a consolidated view of the data needs of RealCost (figure 12).



Source: FHWA.
WZ = work zone.

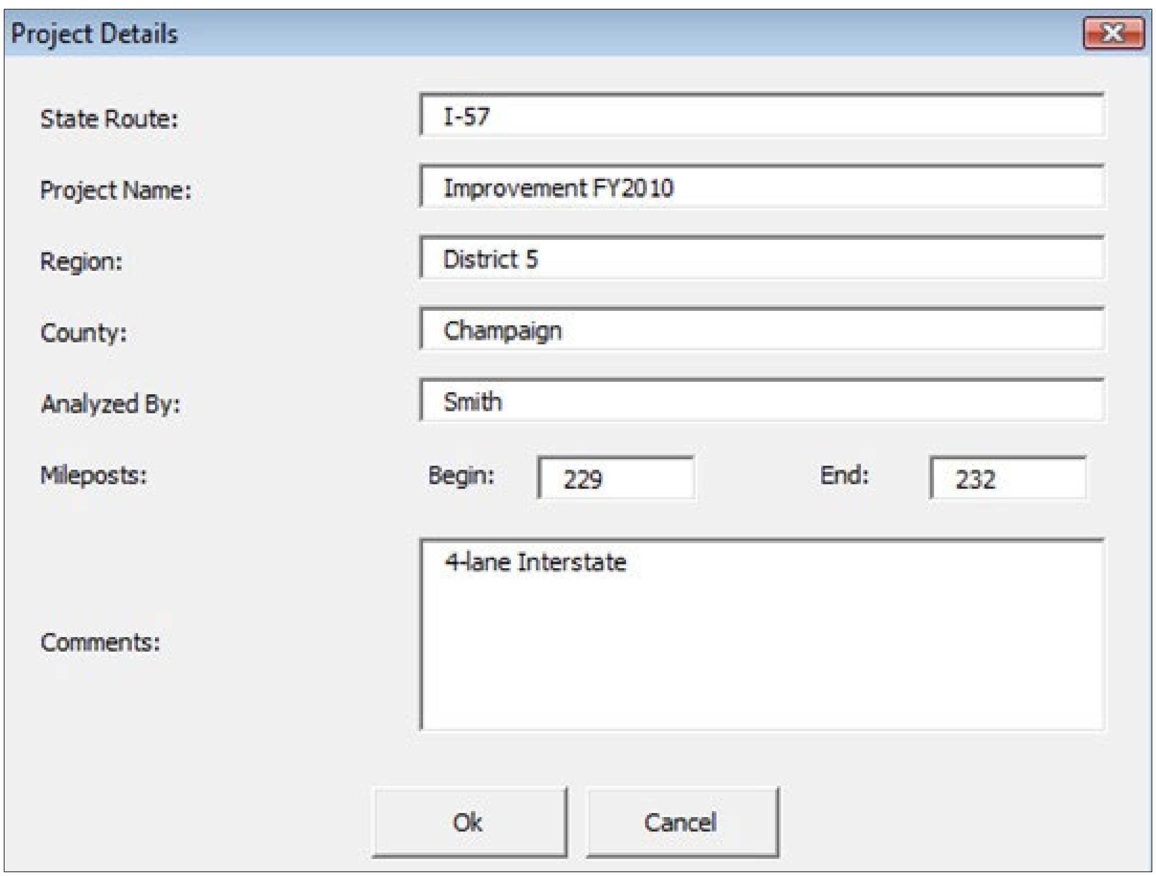
Figure 12. Illustration. The hierarchy of project-level and alternative-level data.

Project-Level Data Inputs

The options selected and data entered in the project-level data input screens (or worksheets) apply to all strategic alternatives being considered to fulfill the performance requirements of a single project. If the project-level data or options are changed, all alternatives must be reconsidered with the new data and options appropriately compared. Alternatives analyzed using different project-level options cannot be directly compared in LCCA.

Project Details

The Project Details input screen (figure 13) is used to name and define the project in terms of its location (route, region, county) and limits (beginning and ending mileposts) and to identify the analyst. Data entered via this screen are not used in the analysis but can be included in the output report. The analyst may enter a project's metadata within the Project Details screen according to the field names on the screen. The analyst may use the other fields to include project documentation details, such as the type of facility on which the project is located and assumptions used in conducting the LCCA. It should be noted that although the beginning and ending mileposts are not used in any of the RealCost calculations, this information is often helpful to the user in terms of developing pay item quantities and costs associated with individual work activities.



Source: FHWA.

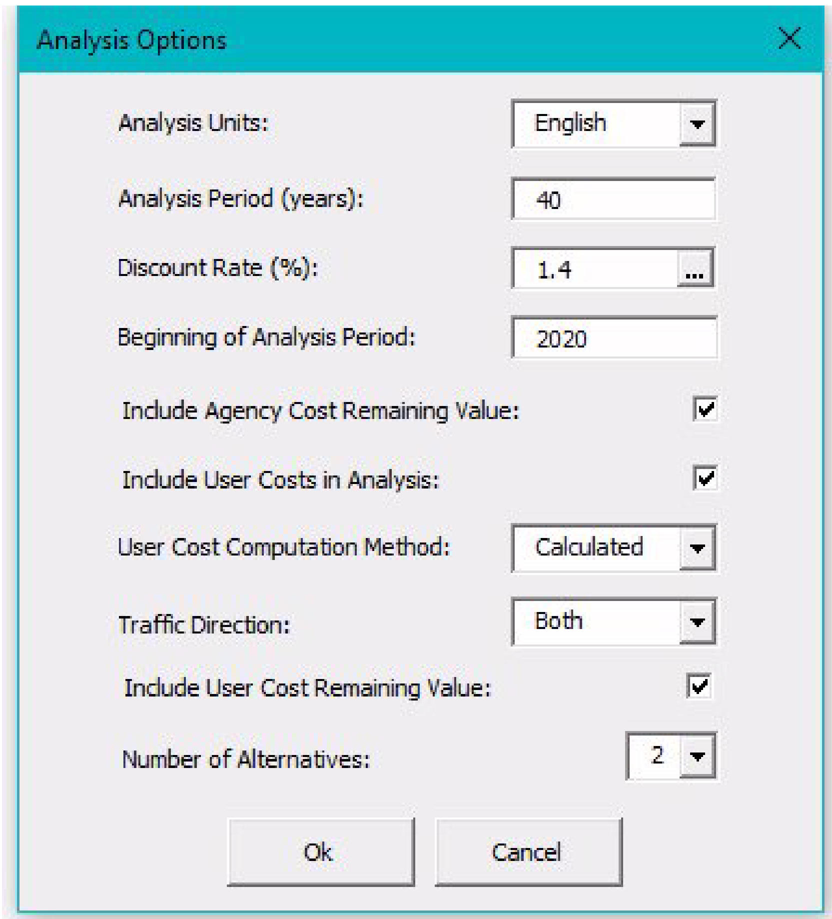
Figure 13. Screenshot. Project Details input screen.

Analysis Options

Generally, analysis options are decided by agency policy rather than the design decisionmaker. Options defined in the Analysis Options input screen include the analysis units (English or metric), analysis period, discount rate, beginning year, the inclusion of agency cost and user cost remaining values, the treatment of user costs in the LCCA, and the number of strategic alternatives being evaluated (see figure 14). A checked box equals "yes," an unchecked box equals "no." The data inputs and analysis options available on this screen are discussed in table 4, with FHWA's recommendations as reported in *Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin* (Walls and Smith 1998).

TIP

LCCA requires that all alternatives in an analysis produce the same benefits. If project-level data or options are changed, all alternatives must be reconsidered using the new data and options.



Source: FHWA.

Figure 14. Screenshot. Analysis Options input screen.

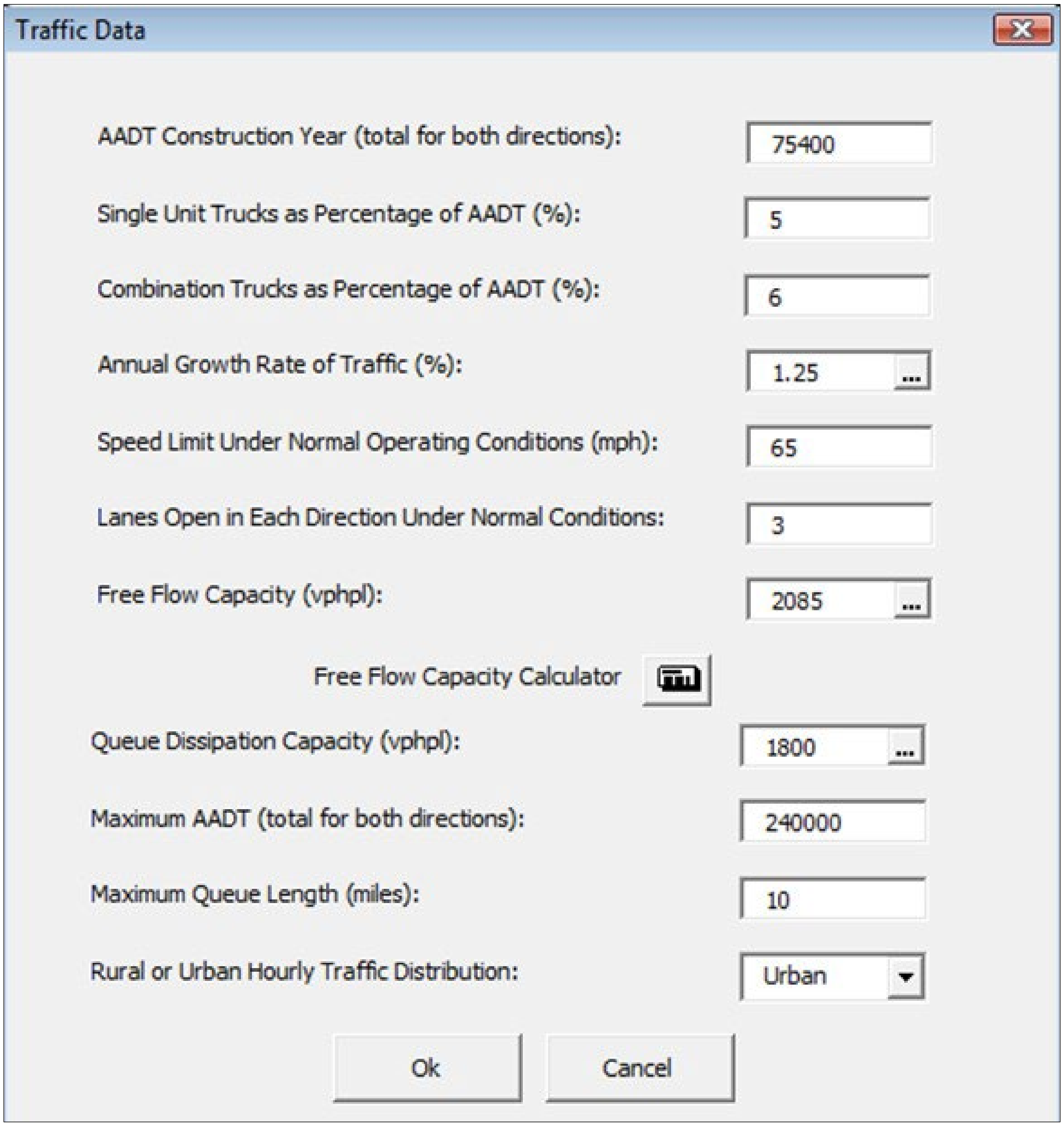
Table 4. Analysis Options inputs.

Option/Input	Description	FHWA Recommendation
Analysis Period	The number of years over which the strategy alternatives will be compared.	35–40 yr[a]
Discount Rate	The rate by which future expenditures will be discounted to present value. This information is entered as a decimal number.	Real discount rate of 2–4 percent[a]
Beginning of Analysis Period	Sets the first year of the analysis period. RealCost expenditure diagrams draw their dates from this field and the analysis period field. The beginning year can also be referred to as the base year for the analysis.	The year when the initial activity will be completed and open to traffic.
Include Agency Cost Remaining Value	Indicates whether the agency cost calculation incorporates a prorated share of agency costs as a credit for the remaining life if the structural or service life of activity extends beyond the analysis period.	Checked (yes)
Include User Costs in Analysis	Indicates whether user costs will be included in the analysis and displayed in the results.	Checked (yes)
User Cost Computation Method	Directs RealCost to either calculate user costs ("Calculated") based upon input data following best-practice methods or utilize inputted user costs ("Specified") values when calculating user lifecycle cost.	Calculated
Traffic Direction	Directs RealCost to calculate user costs for the inbound lanes (i.e., lanes leading into a city or morning peak hour), the outbound lanes (i.e., lanes leading away from a city or evening peak hour), or both lanes.	—
Include User Cost Remaining Value	Indicates whether the user cost calculation incorporates a prorated share of user costs as a credit for the remaining life if the structural or service life of activity extends beyond the analysis period.	Checked (yes)
Number of Alternatives	RealCost allows for up to six strategy alternatives for comparison.	—

[a]Refer to FHWA's *Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin* for the latest recommendation (Walls and Smith 1998).
—The cell is intentionally left blank.

Traffic Data

Highway engineers use traffic data to determine their design parameters. In RealCost, traffic data (figure 15) are used exclusively to calculate the work zone user costs following the method outlined in FHWA's *Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin* (Walls and Smith 1998). The traffic data inputs are described in table 5. If user costs are not included in the analysis and the associated option button in the Analysis Options input screen is left unchecked, traffic data entry is not required.



Source: FHWA.

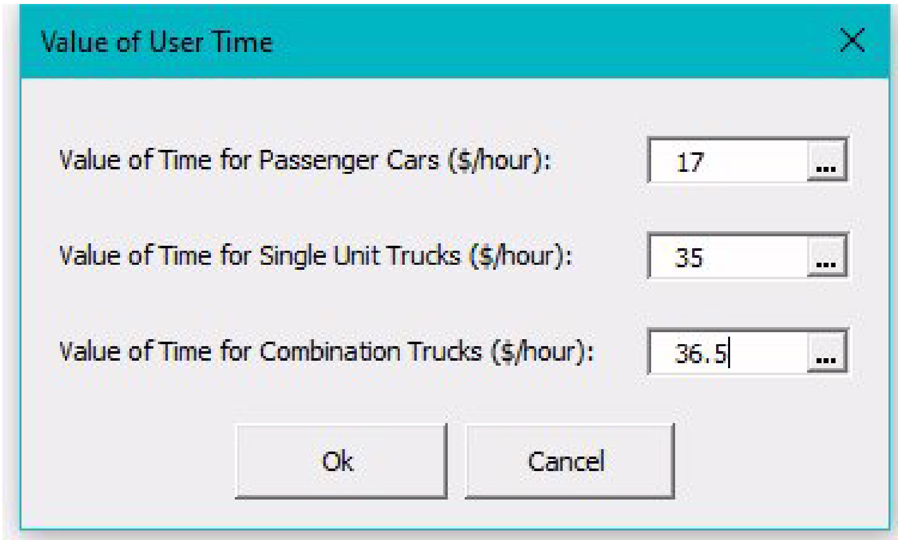
Figure 15. Screenshot. Traffic Data input screen.

Table 5. Traffic Data inputs.

Input	Description
AADT Construction Year	This information is the AADT in the construction or base year of the analysis. This number is the total AADT for both directions.
Single-Unit Trucks	The percentage of the AADT that is single-unit trucks.
Combination Trucks	The percentage of the AADT that is combination trucks.
Annual Growth Rate of Traffic	The percentage by which "AADT in both directions" increases each year (i.e., compound growth). Advanced users can modify the formula in the worksheet to affect a simple traffic growth rate.
Speed Limit Under Normal Operating Conditions	The speed limit that is in effect during the facility's normal operating conditions (i.e., the time between work zones). This number is considered in the user cost computations.
Lanes Open Under Normal Conditions	The number of roadway lanes available to traffic (in each direction) under normal operating conditions.
Free-Flow Capacity	The capacity of each lane under normal operating conditions.
Free-Flow Capacity Calculator	This button opens a screen that calculates free-flow lane capacities based on the *Highway Capacity Manual* (Transportation Research Board (TRB) 1994).
Queue Dissipation Capacity	The capacity of each lane during queue dissipation operating conditions.
Maximum AADT in both Directions	The traffic growth is capped at this number to prevent growth beyond possible capacity. If traffic grows beyond this value, this value is substituted for the computed future AADT value, and future user costs are calculated based upon this maximum AADT value. As a rule, AADT projections should not exceed the observed 24-h traffic volumes contained in the *Highway Capacity Manual* (TRB 1994).
Maximum Queue Length	The effects of self-imposed detours are modeled (i.e., traffic exiting from the work zone route yet still incurring some user costs). Queue-related user costs, which are based upon queue length, are calculated with this value instead of the calculated queue length. However, all vehicles, even those that detour, are charged queue costs. This value is State-specific and is best determined by the traffic division.
Rural or Urban Traffic	The choice between two hourly traffic distributions is allowed. Default values (accessible in the software) for these distributions are taken from the Texas Transportation Institute's *MicroBENCOST* software program (McFarland et al. 1993).

Value of User Time

The Value of User Time input screen (figure 16) allows editing of the values applied to an hour of user time. The dollar value of user time differs for each vehicle type and is used to calculate user costs associated with a delay during work zone operations.

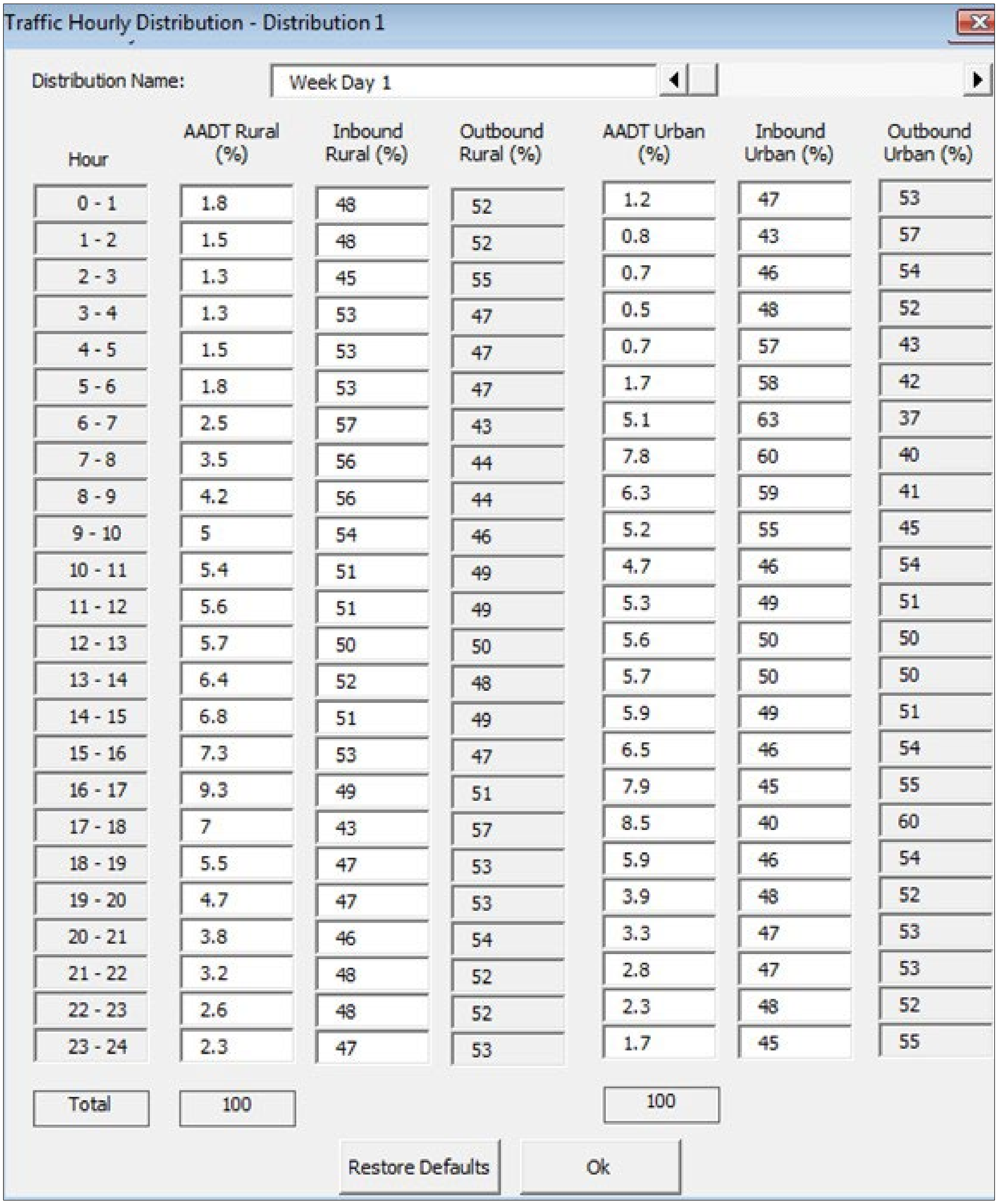


Source: FHWA.

Figure 16. Screenshot. Value of User Time input screen.

Traffic Hourly Distribution

To transform annual average daily traffic (AADT) to an hourly traffic distribution, RealCost includes default Rural and Urban Traffic hourly distributions from MicroBENCOST. The Traffic Hourly Distribution input screen (figure 17, with input descriptions in table 6) allows the user to adjust (or restore) these settings, with the requirement being that the inbound and the outbound distributions sum to 100 percent. As many as four sets of hourly traffic distributions can be established by the user, with each set assigned a distribution name at the top of the screen. Although the default names given to the four groups of traffic distributions are Week Day 1, Week End 1, Week Day 2, and Week End 2, the names can be changed and saved to reflect any 4 hourly distributions (for example, by geographical regions or districts).


Traffic Hourly Distribution - Distribution 1

Distribution Name: Week Day 1

Hour	AADT Rural (%)	Inbound Rural (%)	Outbound Rural (%)	AADT Urban (%)	Inbound Urban (%)	Outbound Urban (%)
0 - 1	1.8	48	52	1.2	47	53
1 - 2	1.5	48	52	0.8	43	57
2 - 3	1.3	45	55	0.7	46	54
3 - 4	1.3	53	47	0.5	48	52
4 - 5	1.5	53	47	0.7	57	43
5 - 6	1.8	53	47	1.7	58	42
6 - 7	2.5	57	43	5.1	63	37
7 - 8	3.5	56	44	7.8	60	40
8 - 9	4.2	56	44	6.3	59	41
9 - 10	5	54	46	5.2	55	45
10 - 11	5.4	51	49	4.7	46	54
11 - 12	5.6	51	49	5.3	49	51
12 - 13	5.7	50	50	5.6	50	50
13 - 14	6.4	52	48	5.7	50	50
14 - 15	6.8	51	49	5.9	49	51
15 - 16	7.3	53	47	6.5	46	54
16 - 17	9.3	49	51	7.9	45	55
17 - 18	7	43	57	8.5	40	60
18 - 19	5.5	47	53	5.9	46	54
19 - 20	4.7	47	53	3.9	48	52
20 - 21	3.8	46	54	3.3	47	53
21 - 22	3.2	48	52	2.8	47	53
22 - 23	2.6	48	52	2.3	48	52
23 - 24	2.3	47	53	1.7	45	55
Total	100			100		

Restore Defaults | Ok

Source: FHWA.

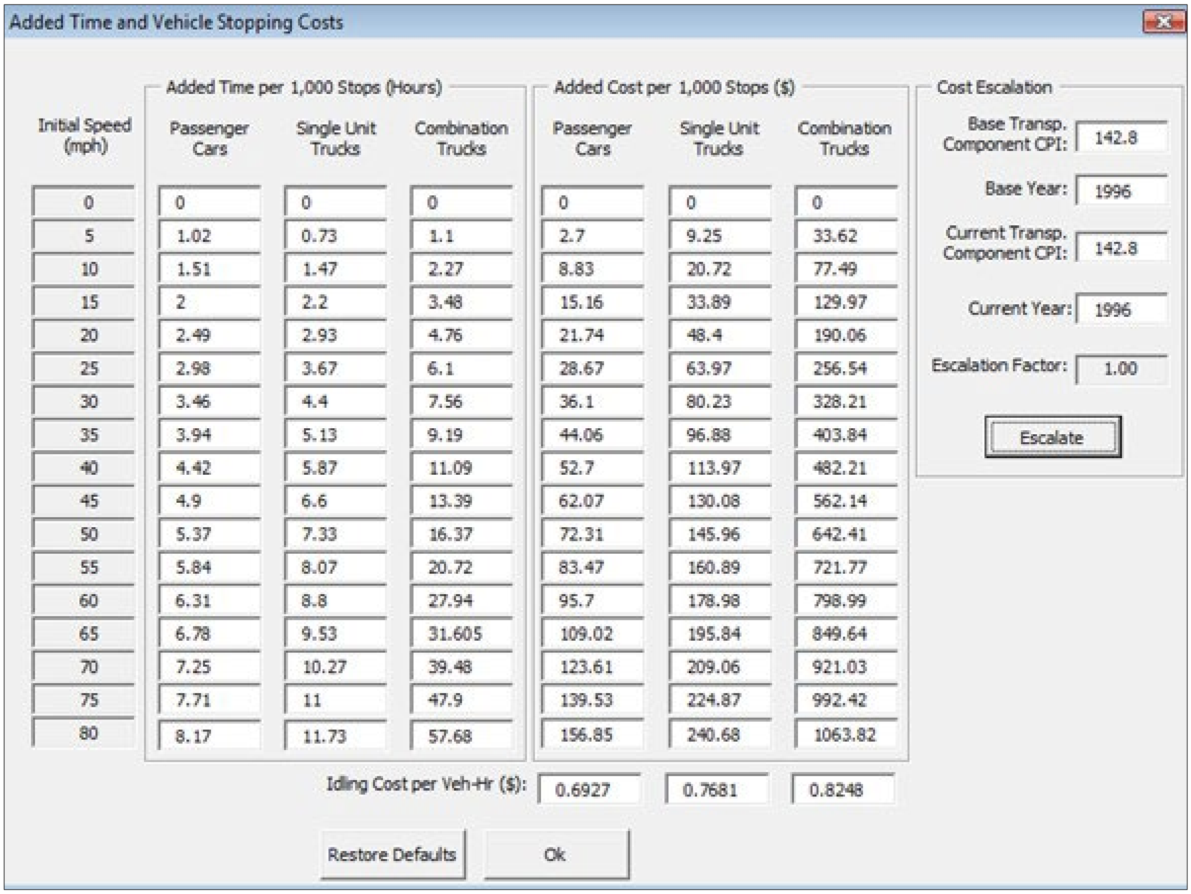
Figure 17. Screenshot. Traffic Hourly Distribution input screen.

Table 6. Traffic Hourly Distribution inputs.

Input	Description
Distribution Name	RealCost allows for defining up to four different traffic hourly distributions—two for weekday representation and two for weekend day representation.
AADT Rural (%) or AADT Urban (%)	The percentage of AADT traveling on the roadway, in both directions, during the indicated hour under the specified (rural or urban, weekday or weekend day) traffic distribution.
Inbound Rural (%) or Inbound Urban (%)	The percentage of that hour's traffic traveling inbound on the route under the specified (rural or urban, weekday or weekend day) traffic distribution. The following formula describes the percentage of the AADT traveling in the inbound direction for the indicated hour: (AADT Rural %) × (Inbound Rural %) or (AADT Urban %) × (Inbound Urban %)
Restore Defaults	Returns all values on this screen to their original, as delivered, default values. Default values for these distributions are taken from the MicroBENCOST software produced by the Texas Transportation Institute. MicroBENCOST, which is used to calculate the benefits and costs of transportation improvements, includes an hourly traffic distribution that has been adopted as a default traffic distribution for RealCost.

Added Time and Vehicle Stopping Costs

Added Time per 1,000 Stops (Hours) and Added Cost per 1,000 Stops ($) values are used to calculate user delay and vehicle operating costs due to speed changes that occur during work zone operations. This input screen (figure 18) is used to adjust the default values for added time and added cost per 1,000 stops. The Idling Cost per Veh-Hr ($) field is used to calculate the additional vehicle operating costs that result from traversing a traffic queue under stop-and-go conditions. The costs and times are different for each vehicle type (i.e., passenger cars, single-unit trucks, combination trucks) (Walls and Smith 1998).



Added Time and Vehicle Stopping Costs

Initial Speed (mph)	Added Time per 1,000 Stops (Hours): Passenger Cars	Single Unit Trucks	Combination Trucks	Added Cost per 1,000 Stops ($): Passenger Cars	Single Unit Trucks	Combination Trucks
0	0	0	0	0	0	0
5	1.02	0.73	1.1	2.7	9.25	33.62
10	1.51	1.47	2.27	8.83	20.72	77.49
15	2	2.2	3.48	15.16	33.89	129.97
20	2.49	2.93	4.76	21.74	48.4	190.06
25	2.98	3.67	6.1	28.67	63.97	256.54
30	3.46	4.4	7.56	36.1	80.23	328.21
35	3.94	5.13	9.19	44.06	96.88	403.84
40	4.42	5.87	11.09	52.7	113.97	482.21
45	4.9	6.6	13.39	62.07	130.08	562.14
50	5.37	7.33	16.37	72.31	145.96	642.41
55	5.84	8.07	20.72	83.47	160.89	721.77
60	6.31	8.8	27.94	95.7	178.98	798.99
65	6.78	9.53	31.605	109.02	195.84	849.64
70	7.25	10.27	39.48	123.61	209.06	921.03
75	7.71	11	47.9	139.53	224.87	992.42
80	8.17	11.73	57.68	156.85	240.68	1063.82
Idling Cost per Veh-Hr ($):				0.6927	0.7681	0.8248

Cost Escalation

Base Transp. Component CPI: 142.8

Base Year: 1996

Current Transp. Component CPI: 142.8

Current Year: 1996

Escalation Factor: 1.00

Escalate

Restore Defaults

Ok

Source: FHWA.

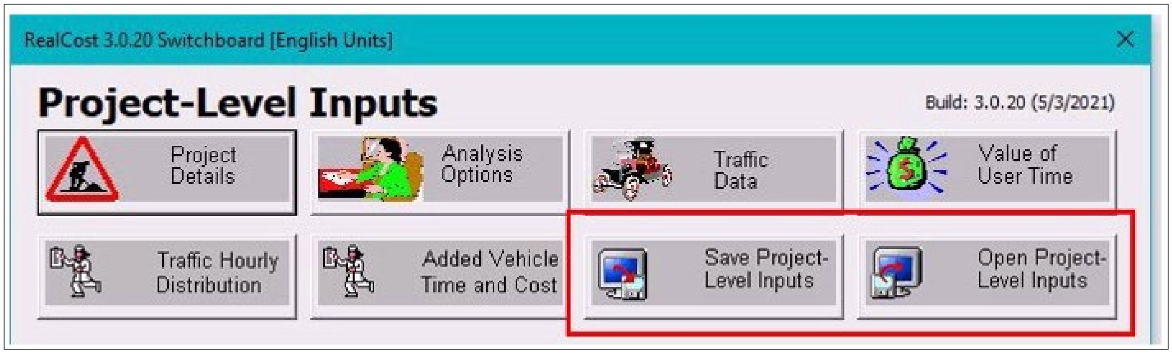
CPI = Consumer Price Index; Transp. = transportation; Veh-Hr = vehicle hour.

Figure 18. Screenshot. Added Time and Vehicle Stopping Costs input screen.

The default values for Added Time, Added Cost, and Idling Cost are derived from NCHRP Report 133, *Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects* (Curry and Anderson 1972). The Added Cost and Idling Cost default values represent 1996 values developed using an escalation factor of the transportation component of the Consumer Price Index (CPI) (U.S. Bureau of Labor Statistics 2021). A cost escalation function is available on the right side of the form to allow the analyst to update those 1996 values to current-year values. The user enters the current transportation component of the CPI and the current year and clicks on the Escalate button. The Restore Defaults button at the bottom of the screen functions much like it does on the Traffic Hourly Distribution input screen.

Saving and Loading Project-Level Data

The last two buttons in the Project-Level Inputs section of the Switchboard are used to save and retrieve (load) project-level inputs (figure 19). The project-level inputs are saved in a small, comma-delimited file, which allows for quick retrieval of the data for use in future LCCA sessions. This file may be named via ordinary Windows conventions and is automatically saved with the *.LCC extension. Changing the file extension will prevent RealCost from recognizing the file. In addition, the user is cautioned that opening a *.LCC file will overwrite data in the Project-Level Inputs section.



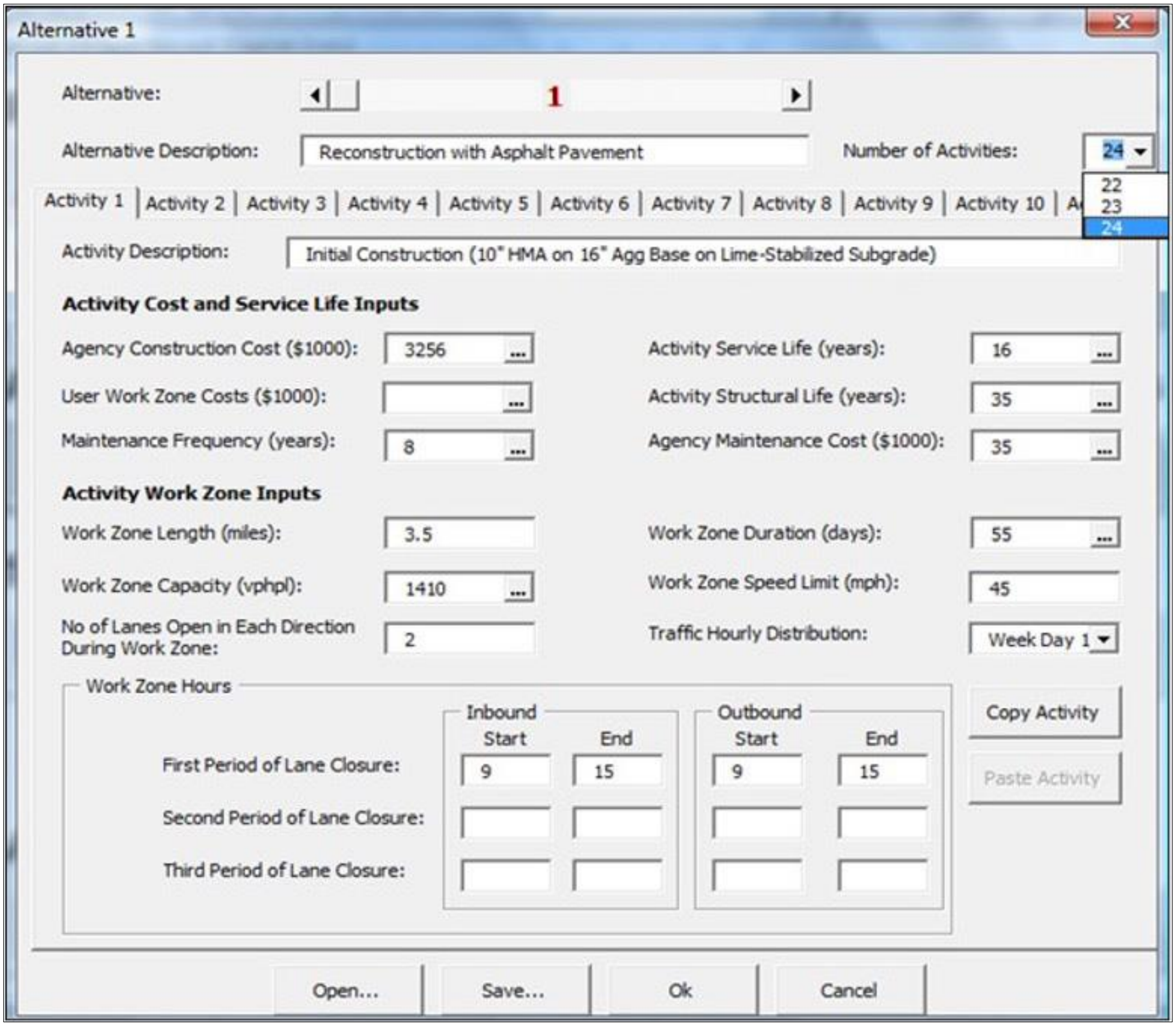
Source: FHWA.

Figure 19. Screenshot. Switchboard buttons to save and open project-level inputs.

Alternative-Level Data Inputs

Data that define the differences between strategy alternatives (i.e., the agency costs and work zone specifics for component activities of each alternative) are alternative-level inputs. Each alternative for a project can have up to 24 activities covering the selected analysis period. The activities defined by the analyst are performed in sequence (i.e., activity 1 precedes activity 2, activity 2 precedes activity 3, and so on). Data describing these activities are entered for each of the strategy alternatives (maximum of six) being compared.

The input screen for defining strategy alternatives and their sequence of activities is the Alternative screen. The Switchboard button for opening this screen is located under the Alternative-Level Inputs section of the Switchboard. At the top of the Alternative input screen (figure 20), a scroll bar allows the analyst to navigate between alternatives to define alternative-level inputs. The number of alternatives available for use is based on the number of alternatives specified earlier by the user in the Analysis Options input screen. A field is also provided for naming the strategy alternative (e.g., Asphalt Pavement or Steel Bridge).



Source: FHWA.

Figure 20. Screenshot. Alternative input screen.

The number of activities for the alternative at hand is defined using the drop-down list at the top right corner of the form. Again, up to 24 activities per alternative can be defined. Once the number of activities is selected, a series of Activity tabs appear across the top of the input screen. Each tab accesses a different activity. For instance, in figure 20, the Activity 1 tab has been accessed and is the currently active tab. The user can provide a short description of the activity in the field below the series of Activity tabs.

The remaining parts of the Alternative input screen allow the user to enter agency and user costs (if the specified option was selected in the Analysis Option input screen), service life, and maintenance inputs for each activity of a particular strategy alternative, as well as the work zone inputs associated with the activity. The data entered in this screen are used to calculate the agency and user lifecycle costs that are ultimately used to compare the economics of each strategy alternative. The construction cost to be entered is the overall cost for the activity. An activity typically consists of two or more individual pay items (e.g., a hot-mix asphalt (HMA) overlay might consist of a tack coat, an HMA binder course, and an HMA surface course) covering the chosen analysis length (e.g., entire project length, 1-mi unit length).

The service life of activity represents the expected functional performance of the asset item as a result of conducting the activity, where the time-series trends of surface properties define functional performance (e.g., smoothness, friction, noise, and aesthetics). Functional activities are localized thin repairs/treatments that do not add to the load-carrying capacity of the asset item. Pavement examples include preventive maintenance treatments, like crack/joint sealing, chip seals, thin HMA overlays, and friction restoration treatments, like diamond grinding and microsurfacing.

The structural life of activity represents the period over which the product of the activity can satisfy or contribute to the overall structural, load-carrying requirements of the roadway. Structural activities provide or impart strength-bearing material layers and thicknesses. They have both a defined structural life as well as a functional life. Pavement examples include an initial asphalt or concrete pavement structure, moderate to thick HMA overlays, portland cement concrete (PCC) overlays, and recycled pavements.

RealCost uses activity service life (i.e., functional performance) to define the timings of all future activities for a given alternative. The service life defined by the user for the first activity establishes when the second activity will occur. Likewise, the service life defined for the second activity establishes when the third activity will occur. When summed together, the full sequence of defined activity service lives must extend to or beyond the chosen analysis period. For example, for a 40-yr analysis period, an alternative might consist of two activities, with the service life of the first activity being 25 yr and the service life of the second activity being 15 yr. If the service life for a given activity is left undefined, the sequence of the following activities will initiate the same year as that activity (i.e., a zero-service life will be assigned to that activity).

RealCost uses structural life to help determine the agency cost and user cost remaining life values of each alternative if specified for inclusion by the user in the Analysis Options input screen. Previous versions of RealCost computed remaining life values by prorating the cost of the last activity (i.e., the activity occurring immediately before the end of the analysis period) by its expected unused service life. RealCost v 3.0 uses a structural life depreciation approach to compute the remaining life value for each alternative, which, when discounted, gets factored in as a negative cost (i.e., a benefit) in the lifecycle cost computation. In the case of pavements, newly constructed or reconstructed pavements can be expected to have structural lives between 20 and 40 yr, whereas pavements undergoing major rehabilitation can be expected to have structural lives between 10 and 20 yr. Moreover, for given design traffic, assets with a greater structure (i.e., thicker, stronger materials) can be assigned longer structural lives than those with less structure. It is important to point out that structural life assignments do not influence activity timings. Their influence on lifecycle cost results is only realized when the assigned structural life exceeds the chosen analysis period. Hence, if left undefined, only the remaining life component of the last activity is computed and factored into the total lifecycle cost. Additional descriptions and illustrations of the structural life depreciation approach used in RealCost are available from the FHWA Office of Preconstruction, Construction, and Pavements.

Table 7 provides summary descriptions and useful notes for the various data inputs contained in the Alternative input screen. It is important to distinguish the work zone length input from project length, which is defined by the beginning and ending mileposts in the Project Details input screen, and LCCA length, which is used in computing agency costs for the different activities (based on quantities estimated for a nominal length of the project (typically 1 mi) or the entire project length). Although the value of the work zone length can be the same as the project length or the LCCA length, it is usually different. For example, a project may be 10 mi long, and the activities costs may be based (LCCA length) on a 1-mi length or project length, whereas the work zone length for a particular activity may be 2 mi. The work zone duration should match the number of days needed to complete the activity for the LCCA length.

Table 7. Alternative inputs.

Input	Description	Notes
Alternative	Strategy alternative number.	Up to six possible
Alternative Description	Name of the strategy alternative.	—
Number of Activities	The number of activities defining a given alternative over the chosen analysis period.	Up to 24 possible
Activity Description	Name of the activity.	—
Agency Construction Cost	Agency costs that will be included in the LCCA for a given activity comprising a given alternative.	Thousands of dollars
Service Life	The service life of the activity in terms of functional performance. This field defines how many years after a certain activity the next activity will take place.	Years
Structural Life	Structural life of the activity (if any) in terms of load-carrying capacity. This field helps determine remaining life values at the end of the chosen analysis period.	Years
User Work Zone Costs	This field allows direct entry of user costs. It is accessible only when the User Cost Computation Method field on the Analysis Options input screen is set to Specified. When this field is set to Calculated, it will be presented in gray font and will not be accessible.	1. Thousands of dollars. 2. Inaccessible if User Cost is set to Calculated.
Maintenance Cost	Cost of minor, scheduled maintenance performed between major activities. These minor activities incur no user costs. Their purpose is to allow for the inclusion of the agency costs of minor activities such as preventive maintenance. To remove minor routine maintenance from the analysis, set the value of this field to zero (0).	1. Thousands of dollars. 2. Enter zero (0) if not being used.

Input	Description	Notes
Maintenance Frequency	Cyclical frequency of minor maintenance. This frequency only applies during the service life of the specific major activity that it is described for and expires as soon as the next major activity begins.	Enter zero (0) if not being used.
Work Zone Length	Length of the actual work zone, measured from the beginning to the end of the reduced-speed area (where the work zone speed limit is in effect).	Miles
Work Zone Duration	Number of days that the work zone will affect traffic flow. For example, if the work zone is in effect 5 d a week for 3 w this value would be 15.	Days
Work Zone Capacity	The vehicular capacity of one lane of the work zone for 1 h.	Vehicles per hour per lane
Work Zone Speed Limit	The posted speed limit within the work zone.	Miles per hour
Lanes Open in Each Direction During Work Zone	The number of open lanes in the work zone area, when in effect. The number of lanes open applies to each direction.	—
Work Zone Hours	The period during the day for which a work zone is in effect. During these hours, capacity is limited to Work Zone Capacity. Work zone timing may be modeled separately for inbound and outbound traffic. Up to three separate periods of work zone can be modeled for each day. For example, a work zone in effect from 9 a.m. to 3 p.m. and from 8 p.m. to 5 a.m., would use the following numbers: 09 to 15, 20 to 24, and 00 to 05.	Military time (0-24 h)

—The cell is intentionally left blank.

Saving and Loading Alternative-Level Data

The Open and Save buttons at the bottom of the Alternative input screen are used to open and save alternative-level data. These data files may be named via ordinary Windows conventions and are automatically saved with the *.LCA extension. Each strategy alternative can be saved and opened separately, which allows for quick retrieval of the data for use in future LCCA sessions. A name that is descriptive of the strategy alternative at hand should be used. The saved *.LCA file includes all data entered for the alternative, including its activities.

Saving alternatives individually allows different alternatives to be loaded, analyzed, and stored for use in future analyses. Users are cautioned that opening an *.LCA file overwrites all existing data for the alternative that is in active memory. To avoid losing data, the user should save new data to an *.LCA file before loading another alternative.

The Copy Activity and Paste Activity buttons allow data to be copied from one activity to another within the same alternative. In this case, the user should begin at the activity that has the data to be copied, press the Copy button, move to the activity that is to receive the data, and then press the Paste button. All existing data in the receiving activity will be overwritten.

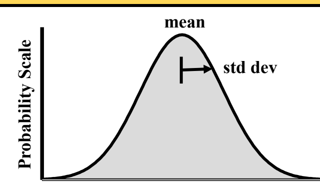
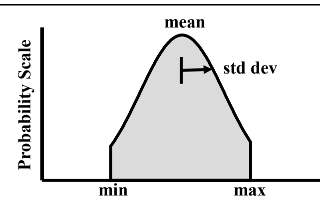
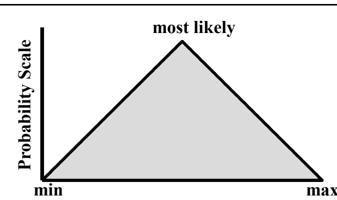
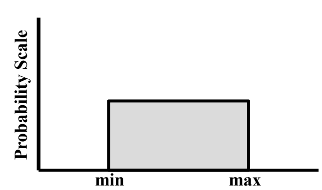
Probabilistic Input

RealCost encourages the consideration of variability (i.e., uncertainty) in analysis inputs. Therefore, input variability can be addressed by using probabilistically defined inputs.

Probability Functions

The most commonly used probabilistic distribution functions and how they are defined (e.g., mean, standard deviation, minimum, maximum, most likely values) are displayed in table 8. More information on the use of probability distributions is provided in FHWA's *Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin* (Walls and Smith 1998).

Table 8. Examples of input probability distributions typically used in RealCost.

Distribution Type	Spreadsheet Formula	Illustration
Normal	lccanormal (mean, std dev)	
Truncated Normal	lccatnormal (mean, std dev, lower bound, upper bound)	
Triangular	lccatriang (minimum, most likely, maximum)	
Uniform	lccauniform (minimum, maximum)	

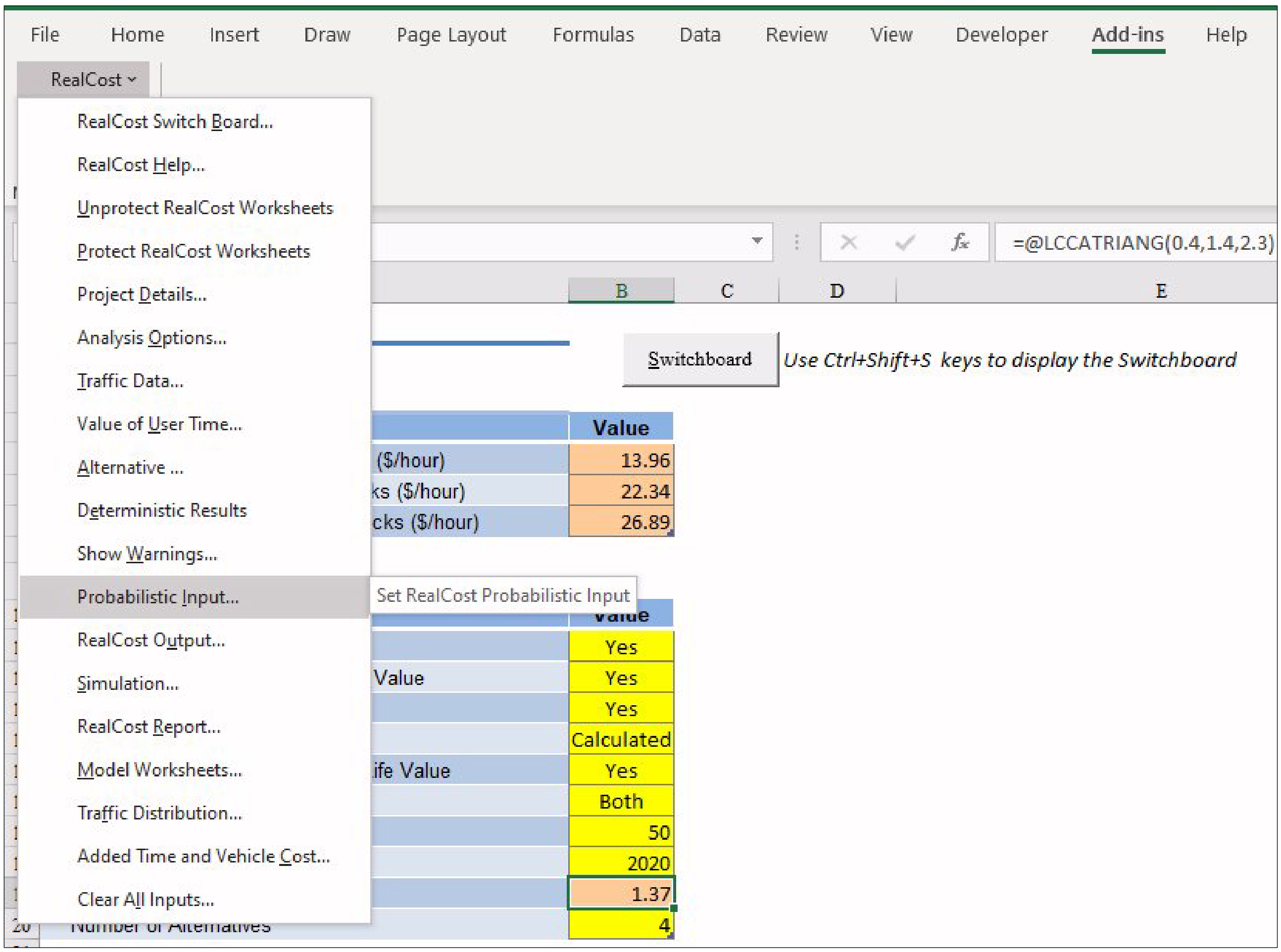
Source: FHWA.
std dev = standard deviation.

Probability Input Methods

Users can make probabilistic input in two ways:

- Via the Probabilistic Input Add-in menu on the input worksheet.
- Via the Switchboard input screens.

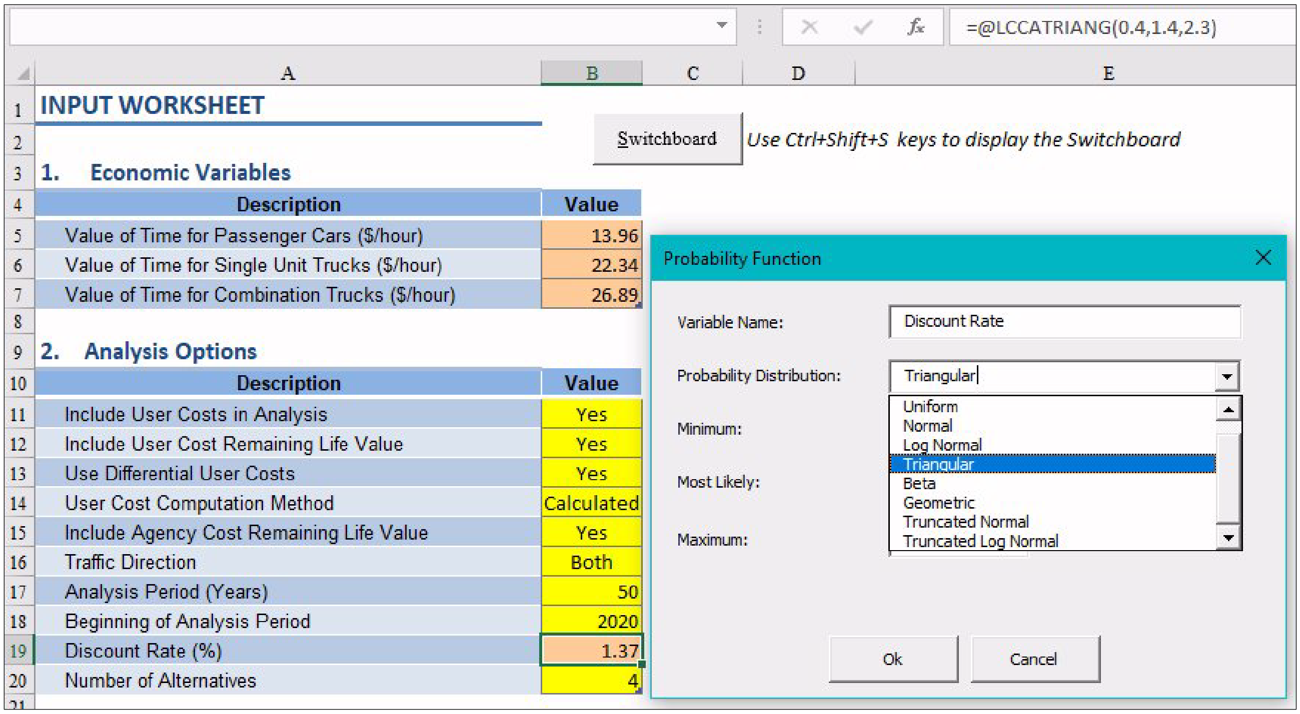
Figure 21 shows an example of defining the discount rate as a probabilistic input on the input worksheet. Users can place the cursor on the input cell and select the Probabilistic Input from the RealCost Add-ins menu.



Source: FHWA.

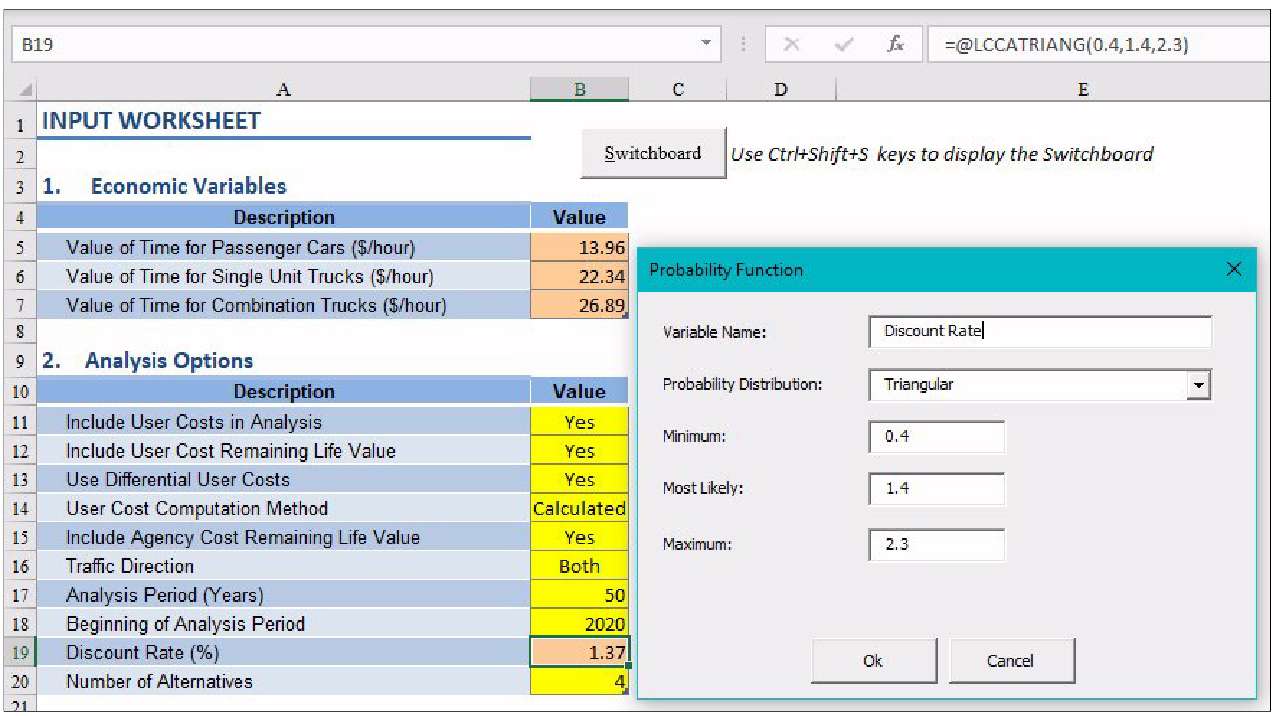
Figure 21. Screenshot. Probabilistic Input Add-in menu on the input worksheet.

Users can select a desired probabilistic function in the Probabilistic Function user form (figure 22) then input the required function parameters for the selected function (figure 23).



Source: FHWA.

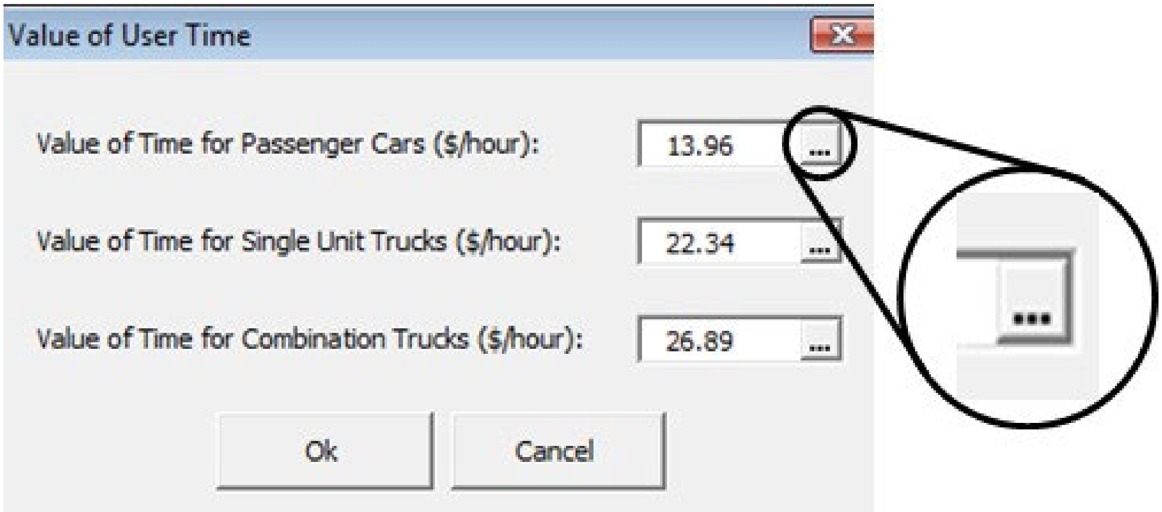
Figure 22. Screenshot. Probabilistic distribution selection.



Source: FHWA.

Figure 23. Screenshot. Input parameters for a probabilistic function.

The example in figure 24 shows the process of changing the value of user time for passenger-car vehicles from a deterministic value to a normal distribution, using the Switchboard input screens. Most data inputs can be assigned a probabilistic function.

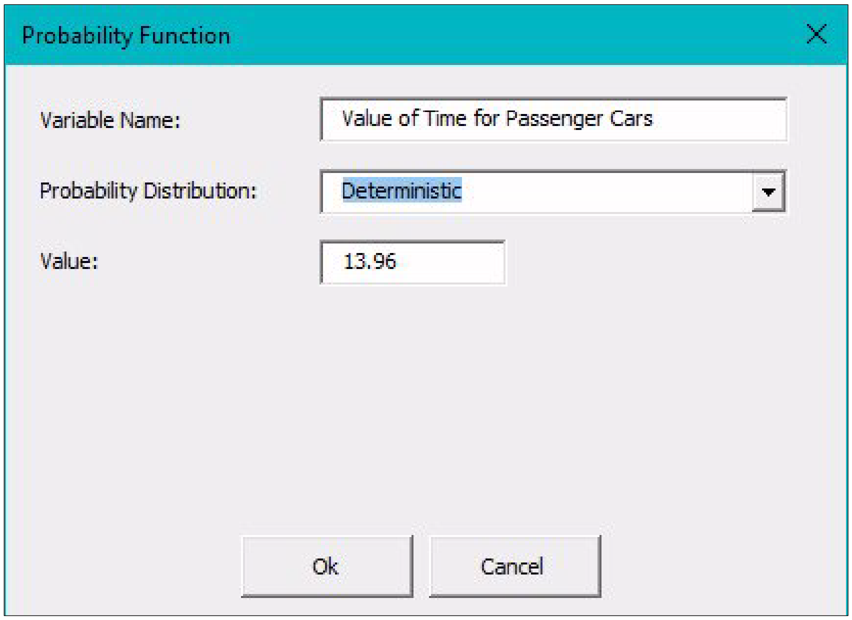


Source: FHWA.

Figure 24. Screenshot. The ellipsis button accesses probabilistic inputs for the specific data element.

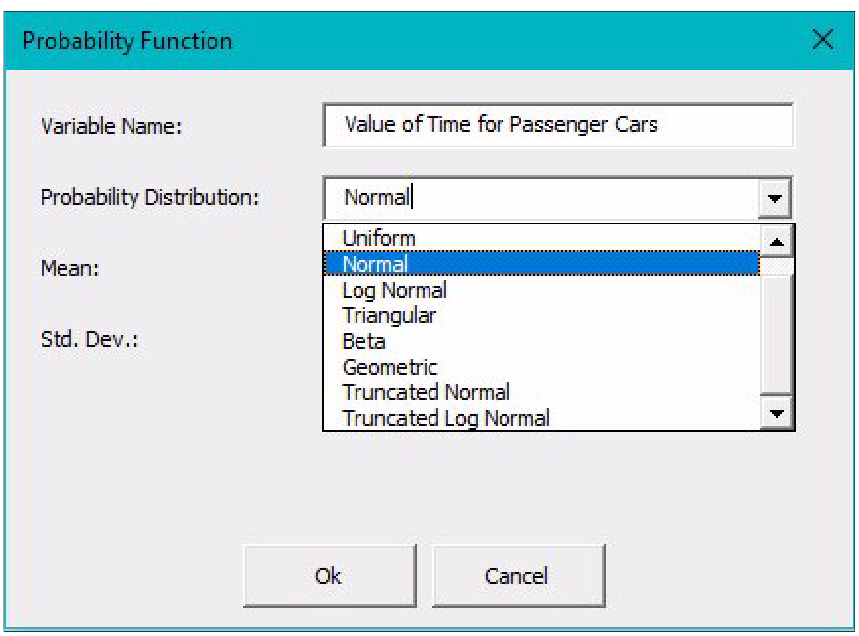
Several inputs on the Project-Level and Alternative-Level input screens can be described either by deterministic values (single or point values) or by probabilistic values (value ranges and likelihoods of occurrence). The default value for all data is deterministic. The probabilistic inputs are identified by the small ellipsis button to the right of the data input field. For example, in figure 24, the ellipsis button for the value of user time for passenger cars is circled.

Clicking an ellipsis button (figure 24) opens a probability function input screen with the deterministic input as default (figure 25) and the variable name included from the previous screen. Users can change the default deterministic to one of seven probability functions—normal, truncated normal, triangular, uniform, beta, geometric, and log-normal—to describe the input data (figure 26). Then, users can enter the parameters for the assigned function (figure 27).



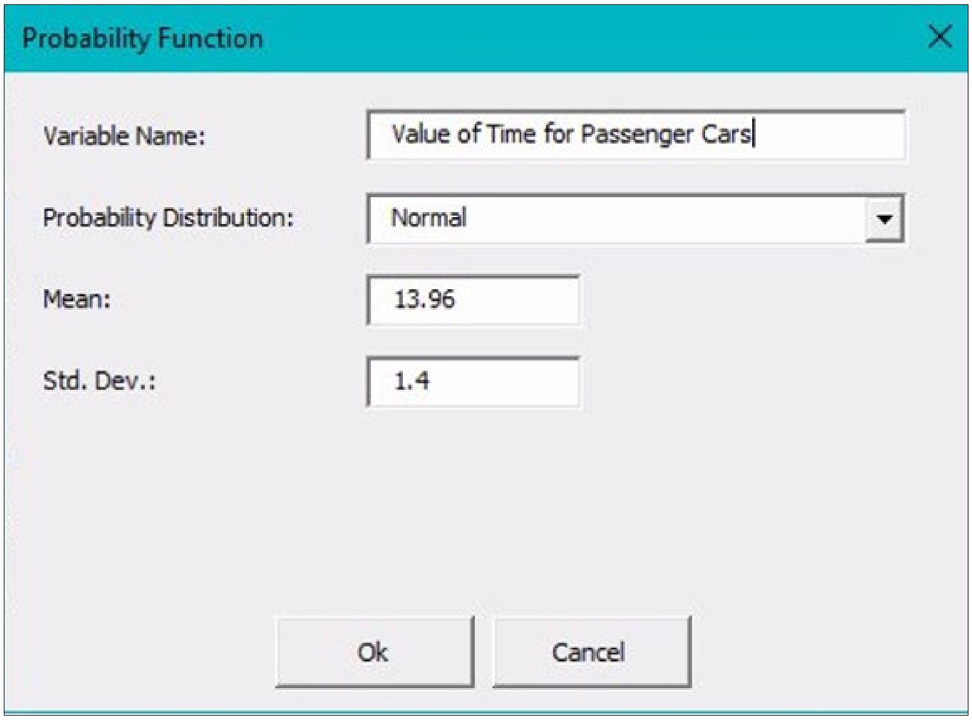
Source: FHWA.

Figure 25. Screenshot. Creating a probabilistic input—default is deterministic.



Source: FHWA.

Figure 26. Screenshot. Creating a probabilistic input—assign a probabilistic function.



Source: FHWA.

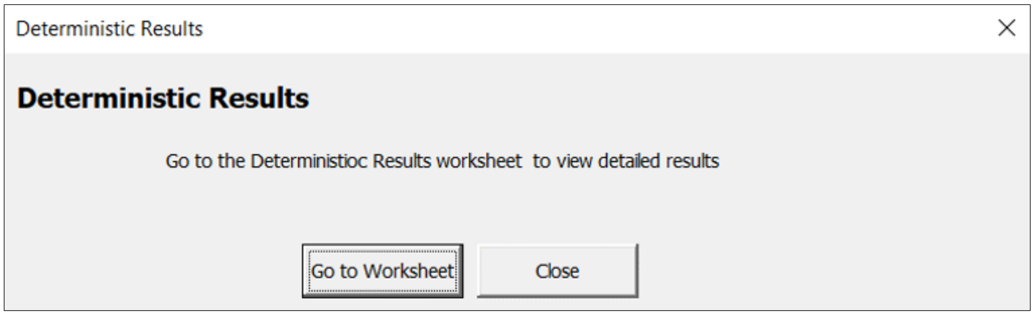
Figure 27. Screenshot. Creating a probabilistic input—enter the parameters for a probabilistic function.

SIMULATION AND OUTPUTS

The Simulation and Outputs section of the Switchboard is where deterministic lifecycle costs and simulations of probabilistic lifecycle costs are performed. The deterministic analysis is conducted using the most likely input from a probabilistic list of inputs.

Deterministic Results

The Deterministic Results output screen, shown in figure 28, calculates deterministic present-worth values for both agency and user costs and displays those values. The lowest cost strategy alternatives for both agency and user are labeled. The screen also provides a direct link to the Deterministic Results Excel worksheet, which contains all the information required to investigate deterministic results.



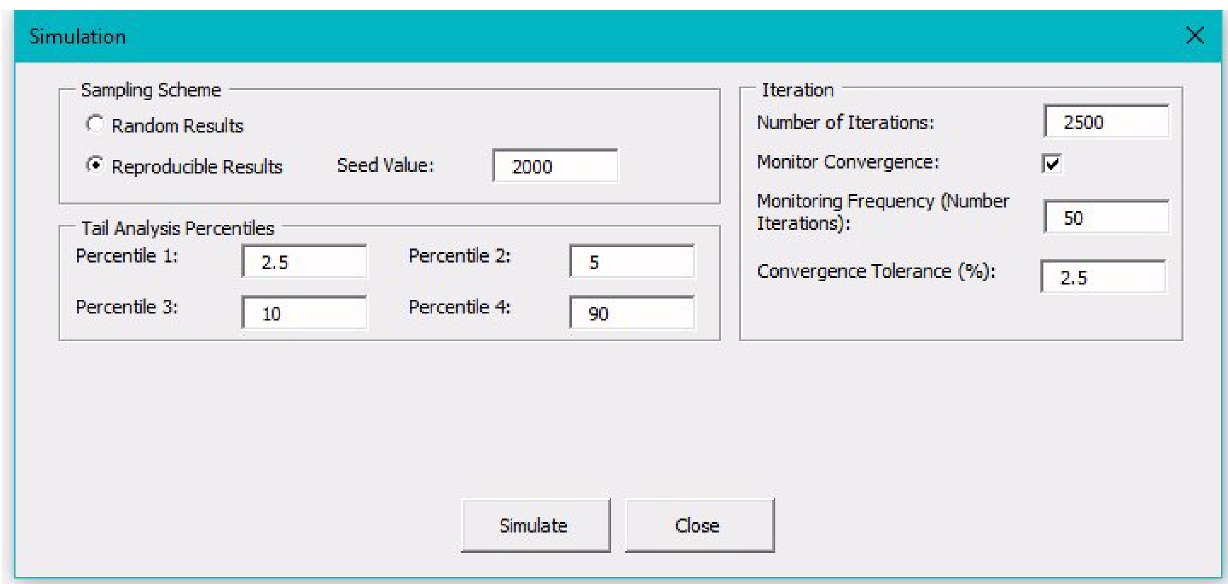
Source: FHWA.

Figure 28. Screenshot. Deterministic Results output screen.

Probabilistic Analysis

Running the Simulation

Running a simulation is a necessary step toward performing a probabilistic analysis. To conduct probabilistic analysis, RealCost uses the Monte Carlo simulation technique, which allows modeling of the uncertainty or variability associated with a particular probabilistic input. Monte Carlo simulation involves random sampling of inputs and calculating the potential range and likelihood of output values. The simulation produces the probabilistic outputs; without running a simulation, such probabilistic outputs are not available. The Simulation input screen is shown in figure 29.



Source: FHWA.

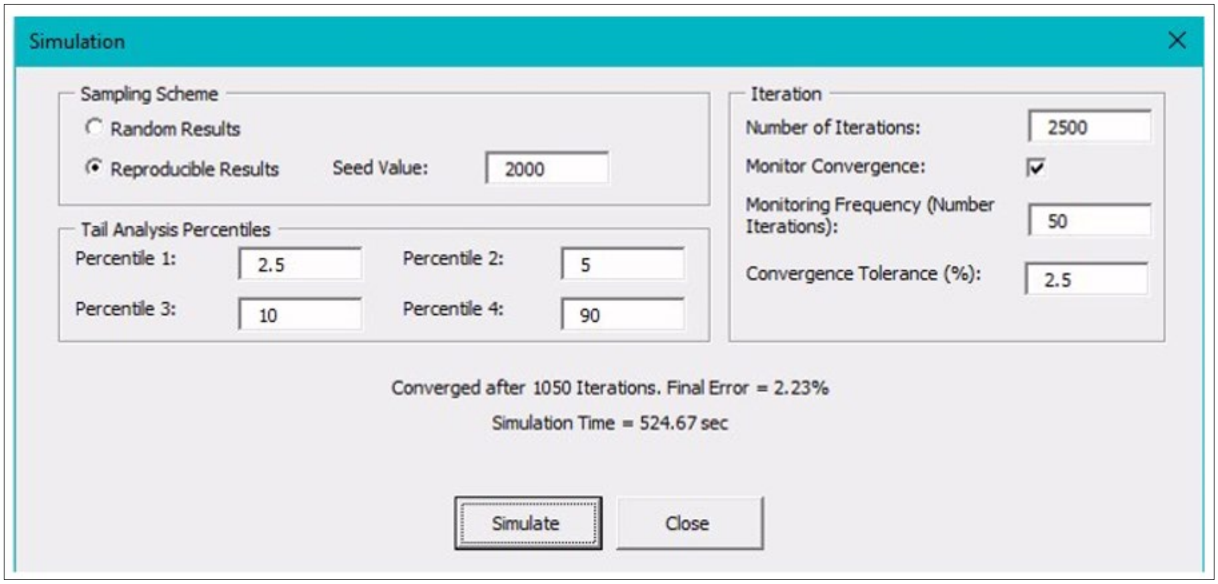
Figure 29. Screenshot. Simulation input screen.

The Sampling Scheme section of the Simulation input screen determines from where the software will draw its simulation numbers. The Random Results option causes the simulation seed value (where the simulation starts) to come from the computer's internal clock. While not truly random, this seed value cannot be influenced by the software user, and it produces different values with each simulation. The Reproducible Results option allows the analyst to specify the seed value to be used in all simulations, which causes the same set of random numbers to be generated from the pseudo-random number generator. Choosing Reproducible Results allows the user to perform separate simulation runs to compare multiple alternatives, knowing that variations from run to run will be caused by actual input changes and not variability associated with different seed values.

Tail Analysis Percentiles are used to analyze the lifecycle cost probability distributions generated by RealCost. Percentile values should be entered in ascending order.

The Iteration section is used to determine the number of iterations to be performed and whether the simulation will be monitored for convergence. Output convergence can be used by the analyst to determine that a simulation has run enough iterations to properly define its outputs. Convergence is monitored by checking the change in the cumulative outputs of each of six lifecycle cost statistics (mean, standard deviation, 10th, 25th, 75th, and 90th percentile) each time a specified number of iterations is completed (specified in the Monitoring Frequency box). Once the maximum change falls below the specified Convergence Tolerance, RealCost will end the simulation run without completing any remaining iterations—yielding probabilistic results while significantly shortening the time it takes to complete the analysis. The number of iterations should be 2,000 at a minimum. Fewer iterations (e.g., 250 to 500) are appropriate for preliminary runs intended to ensure the proper operation of the program or to check for the reasonableness of outputs. Monitoring Frequency is adequate at 100 iterations, and, when used, a Convergence Tolerance of 2.5 (percent) should provide appropriate probabilistic outputs.

Figure 30 shows a simulation that ended due to simulation convergence of less than 2.5 percent. Note that the convergence error is listed at the bottom of the screen. This convergence error is monitored and reported during the simulation.

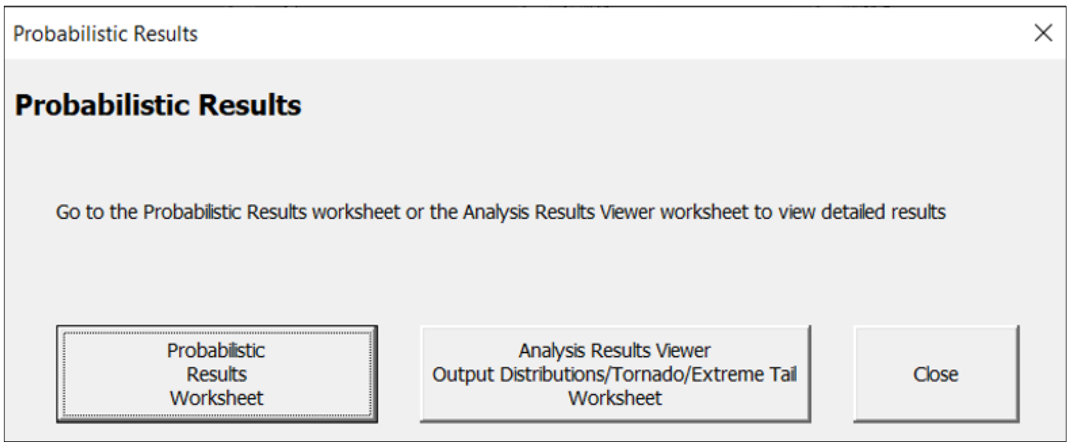


Source: FHWA.

Figure 30. Screenshot. Simulation input screen at the conclusion of a simulation run.

Analyzing Probabilistic Results

After a simulation is run, probabilistic results are recorded and made available for examination and analysis. A simulation must be run before viewing probabilistic results. The simulation results for both agency costs and user costs (if included) are kept separate, per the recommendation of *Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin* (Walls and Smith 1998). After the simulation run, the user needs to close the simulation screen and return to the Switchboard. After this step, the user needs to click on the Probabilistic Results button within the Switchboard, and the following screen shown in figure 31 will appear.



Source: FHWA.

Figure 31. Screenshot. Probabilistic Results output screen.

Figure 32 shows the statistical results of a probabilistic simulation involving four alternatives (recall that up to six alternatives can be analyzed simultaneously as part of one simulation). The results are presented in tabular form in the Probabilistic Results output screen.

Table 3. Total Cost

Total Cost (Present Value)	Alternative 1: Agency Cost ($1000)	Alternative 1: User Cost ($1000)	Alternative 2: Agency Cost ($1000)	Alternative 2: User Cost ($1000)	Alternative 3: Agency Cost ($1000)	Alternative 3: User Cost ($1000)	Alternative 4: Agency Cost ($1000)	Alternative 4: User Cost ($1000)
Mean	$2,749.65	$374.90	$2,883.49	$32.76	$3,835.99	$501.47	$4,049.81	$22.43
Standard Deviatio	$229.78	$53.80	$232.78	$5.48	$349.76	$94.87	$370.10	$2.87
Minimum	$2,027.88	$228.90	$2,060.93	$18.88	$2,762.78	$200.76	$2,868.46	$14.56
Maximum	$3,464.84	$572.89	$3,602.59	$51.14	$5,029.89	$857.29	$5,258.89	$31.64

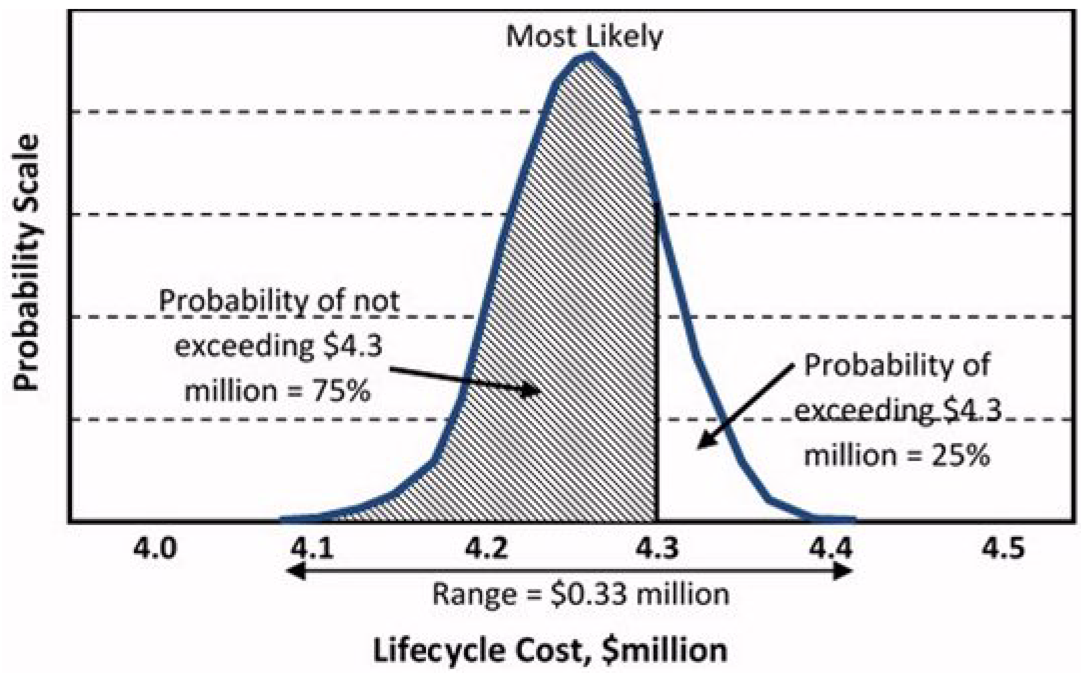
Source: FHWA.

Figure 32. Screenshot. Statistical results of a probabilistic simulation.

The Analysis Results viewer worksheet provides a selection to view the Output Distribution, Tornado Graphs Analysis, and Extreme Tail Analysis. The Output Distributions provide the probability density and cumulative distribution functions that directly compare the strategic alternatives. The Tornado Graphs Analysis and the Extreme Tail Analysis provide additional information for assessing the simulation results for each alternative. Discussions of these analysis techniques using RealCost are provided in the following paragraphs.

Comparison of Probability Distribution Curves

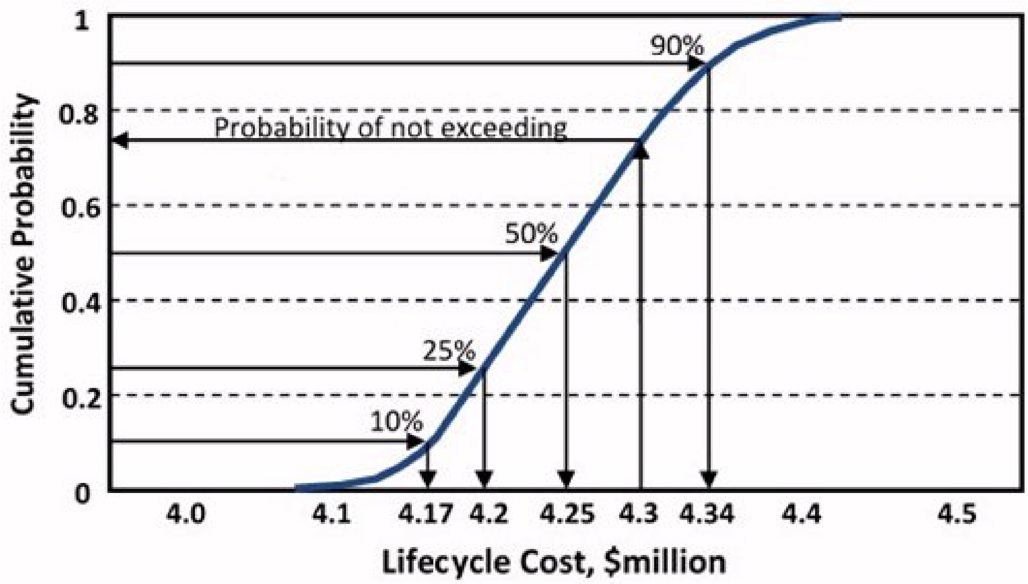
The probability density function identifies both the range and likelihood of possible lifecycle cost values (figure 33) for a design strategy alternative. The curve itself identifies the probability of any cost occurring. The area bounded by the curve and to the left of a specified value (e.g., $4.3 million) indicates the probability that the projected lifecycle cost will not exceed that value (i.e., 75 percent). Alternatively, the area bounded by the curve and to the right of the specified value indicates the probability that the projected lifecycle cost will not be lower than the specified value (i.e., 25 percent). The total area under the curve will always sum to 1.0 or 100 percent.



Source: FHWA.

Figure 33. Graph. Probability density function.

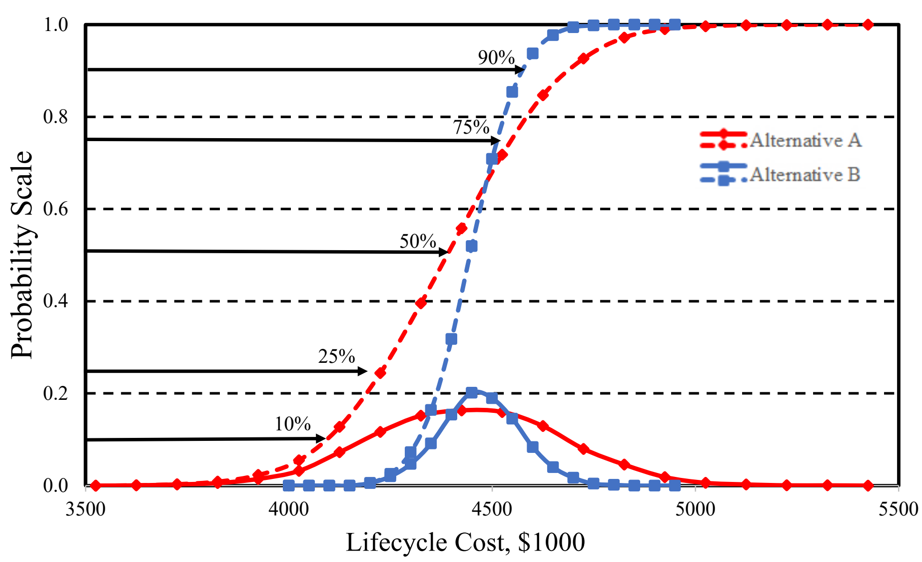
The cumulative distribution function is the "area so far" function of the probability density function. It is the summation of area (i.e., sum probability) under the probability density curve as a function of the projected lifecycle costs. Mathematically, a probabilistic density function is a derivative of the cumulative distribution function. The conversion of the probability density curve in figure 33 yields the cumulative distribution shown in figure 34. This figure more clearly shows a 75 percent probability that the projected lifecycle cost of the strategic alternative will be less than or equal to $4.3 million. It also shows the projected lifecycle costs corresponding to the 10, 25, 50, and 90 percent probability levels. For instance, there is a 25-percent likelihood of the cost being less than or equal to $4.2 million.



Source: FHWA.

Figure 34. Graph. Cumulative distribution function.

Analyzing the lifecycle cost results of two or more alternatives requires more than just comparing the mean costs to determine which one is the lowest. It requires an examination of both the mean and the variation of the costs. Furthermore, while an overlay of the probability density functions of the various alternatives can provide a general understanding of the mean and variation, a simpler and better understanding is achieved through an overlay of the cumulative distribution curves, as illustrated in figure 35.



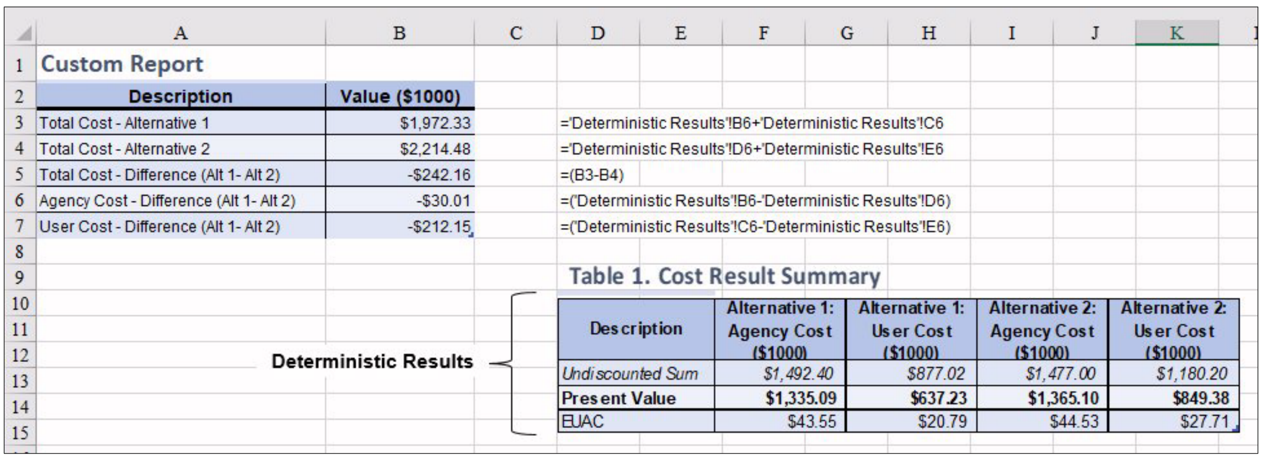
Source: FHWA.

Figure 35. Graph. Cumulative distribution curves for two design strategy alternatives.

In this figure, Alternative A has a lower mean lifecycle cost than Alternative B, and at the 10- and 25-percent probability levels, the costs for Alternative A are also considerably lower.

However, at the 75- and 90-percent probability levels, the costs for Alternative B are less than those for Alternative A. The lower standard deviation for agency cost of Alternative B makes it the more economically attractive option at the higher reliability levels.

Alternatives can also be compared via the difference distribution curve. This type of analysis can be used to determine the true assessment of the probabilities associated with the lowest cost alternative. Although not a standard feature in RealCost, the difference distribution analysis can be conducted by creating a new worksheet within RealCost that includes equations for determining the cost difference between competing alternatives. For example, figure 36 illustrates an inserted worksheet for calculating the total, agency, and user cost differences between alternatives 1 and 2. The equations used in column B are shown adjacent to the corresponding cell.



Custom Report

Description	Value ($1000)	
Total Cost - Alternative 1	$1,972.33	='Deterministic Results'!B6+'Deterministic Results'!C6
Total Cost - Alternative 2	$2,214.48	='Deterministic Results'!D6+'Deterministic Results'!E6
Total Cost - Difference (Alt 1- Alt 2)	-$242.16	=(B3-B4)
Agency Cost - Difference (Alt 1- Alt 2)	-$30.01	=('Deterministic Results'!B6-'Deterministic Results'!D6)
User Cost - Difference (Alt 1- Alt 2)	-$212.15	=('Deterministic Results'!C6-'Deterministic Results'!E6)

Deterministic Results

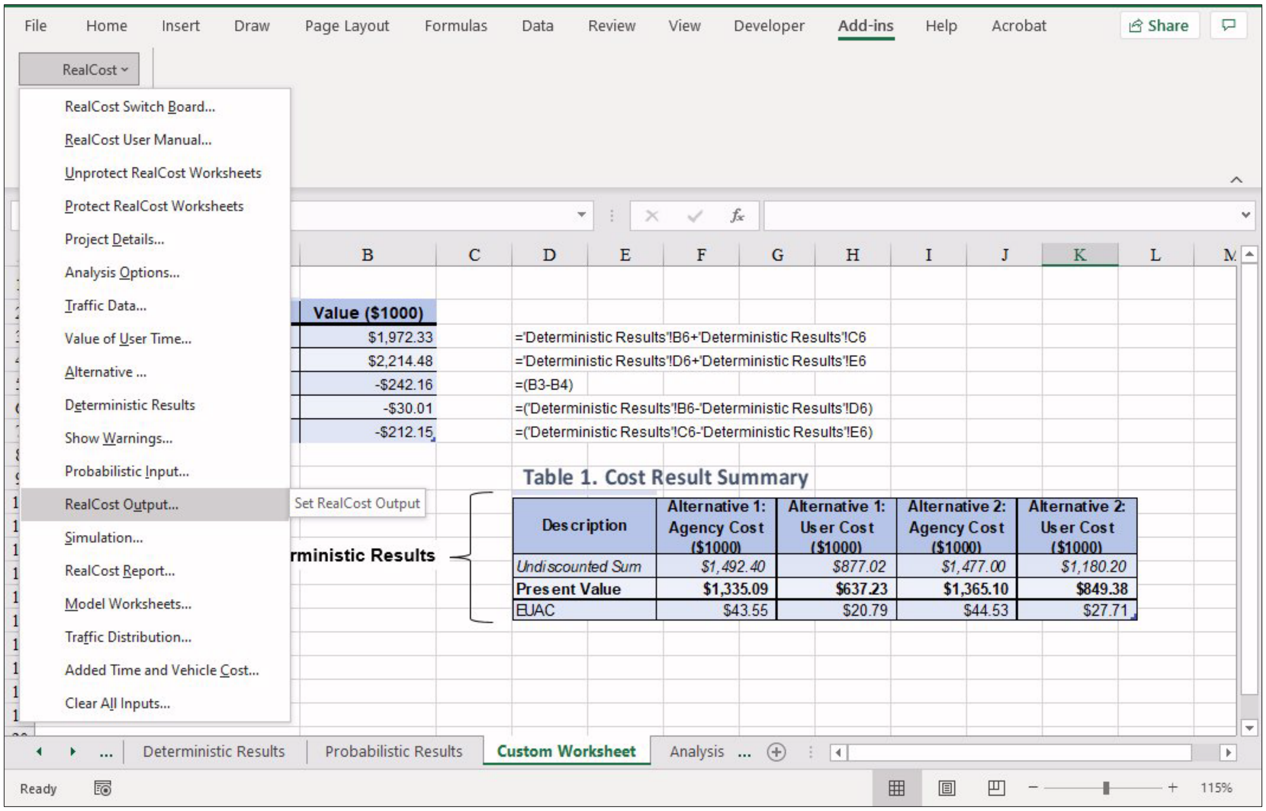
Table 1. Cost Result Summary

Description	Alternative 1: Agency Cost ($1000)	Alternative 1: User Cost ($1000)	Alternative 2: Agency Cost ($1000)	Alternative 2: User Cost ($1000)
Undiscounted Sum	*$1,492.40*	*$877.02*	*$1,477.00*	*$1,180.20*
Present Value	**$1,335.09**	**$637.23**	**$1,365.10**	**$849.38**
EUAC	$43.55	$20.79	$44.53	$27.71

Source: FHWA.

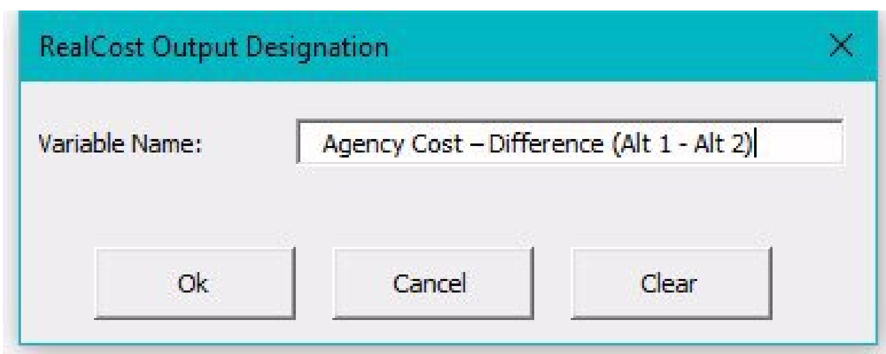
Figure 36. Screenshot. Worksheet for calculating difference distribution.

Each cell must also be characterized as a RealCost output to be included in the probabilistic analysis process. To complete this step, users select RealCost Output for each cell from the RealCost menu command, as shown in figure 37 and figure 38.



Source: FHWA.

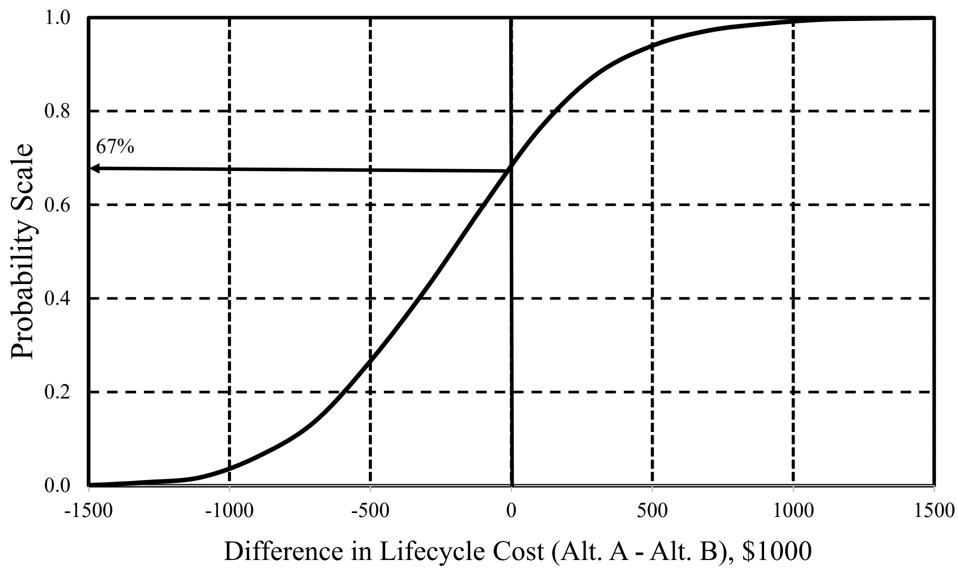
Figure 37. Screenshot. Establishing a cell as a RealCost Output—Step 1.



Source: FHWA.

Figure 38. Screenshot. Establishing a cell as a RealCost Output—Step 2.

The resulting difference distribution curve simplifies the comparison of cumulative distribution curves by associating a level of reliability with the difference between the two alternatives. Figure 39 shows the difference distribution curve for the two alternatives compared in Figure 35, where approximately two-thirds of the simulation outcomes for Alternative A are less than Alternative B. It should be noted that different distribution curves that are symmetric about zero have balanced risk between alternatives.

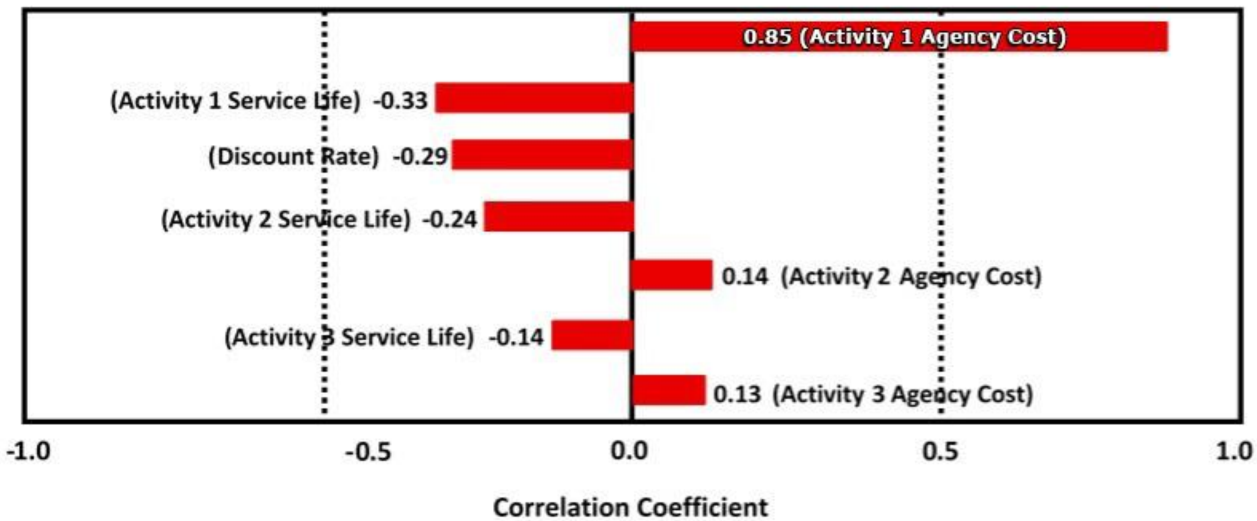


Source: FHWA.

Figure 39. Graph. Difference distribution curve for two design strategy alternatives.

The Tornado Graphs Analysis worksheet contains correlation sensitivity plots in the form of tornado graphs that display the significance of model inputs on the lifecycle cost output distribution for each alternative. The significance is measured by the correlation coefficient, which is indicated by the bar length in a tornado graph (figure 40). The higher the degree of correlation between the input and output, the more the input variable is affecting the output. A correlation coefficient of 1 indicates a perfect positive correlation between variables, a value of 0 indicates no correlation, and a value of −1 indicates a complete inverse correlation. In the tornado graph, the input variables are plotted top-down in the decreasing order of correlation, giving rise to the funnel shape.

The correlation coefficient implies that if the input variables' mean is changed by 1 standard deviation of the input, the output mean will be changed by X times the standard deviation of the output, with X being the correlation coefficient value. Hence, in figure 42, if the mean value of the most influential input parameter (Activity 1 Agency Cost) is increased by 1 standard deviation, then the mean lifecycle cost will be increased by 0.85 times the standard deviation lifecycle cost. And, if the mean value of the second most influential parameter (Activity 1 Service Life) is increased by 1 standard deviation, then the mean lifecycle cost will be decreased by 0.33 times the standard deviation lifecycle cost.



Source: FHWA.

Figure 40. Chart. Correlation sensitivity plot ("tornado graph").

Extreme Tail Analysis

The Extreme Tail Analysis worksheet provides insight into the sensitivity of the lifecycle cost outputs to a combination of inputs. Particular emphasis is given to the tails of the distribution, which encompass the most extreme outcomes encountered in the analysis. As mentioned in the Running Simulation section, the analyst may enter four Tail Analysis Percentiles to define the areas of the tails of most interest. RealCost demonstrates how various inputs act together to produce these four defined tail areas.

In the extreme tail analysis, key inputs are identified by evaluating the relationship between inputs and simulation results for the area or "tail" of interest in the output distribution. The analysis hinges on the computation of an alpha (α) value, which is computed as the difference between the median of the input subset (i.e., the area or tail of interest) and all values, divided by the standard deviation for all input values. Alpha values greater than 0.5 or less than −0.5 indicate the input is a significant driver in the output extremes. Conversely, alpha values between (and inclusive of) 0.5 and −0.5 indicate the input is not a significant driver in the output extremes.

RealCost computes and displays the alpha values for each input from the four defined tail areas. Table 9 illustrates the Extreme Tail Analysis worksheet following the completion of a simulation. In this table, only the variable Alternative 1 Activity 1 Agency Cost is shown to be a significant driver in the lifecycle cost extremes. The cells shaded in red ($\alpha < -0.5$) indicate that the lower portion of the input distribution curve is significant in forcing the output distribution curve outward. The blue-shaded cells ($\alpha > 0.5$) indicate that the upper portion of the input distribution curve is significant in forcing the output distribution curve outward.

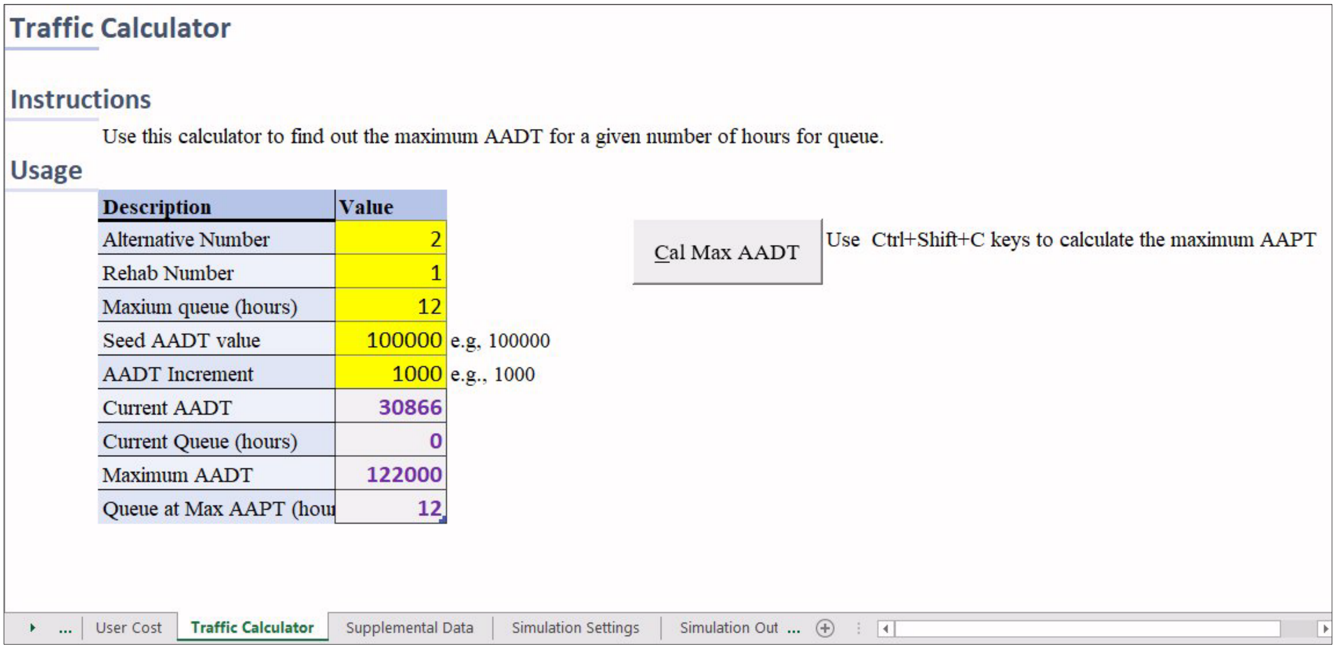
Table 9. Example of RealCost Extreme Tail Analysis Results—Alternative 1 Agency Cost.

Input Variable	5th Percentile	10th Percentile	90th Percentile	95th Percentile
Discount Rate	0.07	0.11	−0.10	−0.08
Alternative 1: Activity 1: Agency Cost	−1.83[a]	−1.61[a]	1.63[b]	1.96[b]
Alternative 2: Activity 1: Agency Cost	−0.21	−0.18	0.01	0.03
Alternative 1: Activity 1: Service Life	0.40	0.26	−0.31	−0.37
Alternative 2: Activity 1: Service Life	−0.08	−0.09	−0.09	−0.09
Alternative 1: Activity 2: Agency Cost	−0.13	−0.17	0.23	0.09
Alternative 2: Activity 2: Agency Cost	0.00	0.00	−0.11	−0.06
Alternative 1: Activity 2: Service Life	0.02	0.06	−0.09	−0.07
Alternative 2: Activity 2: Service Life	0.18	0.07	−0.11	−0.12
Alternative 1: Activity 3: Agency Cost	−0.27	−0.20	0.16	0.24
Alternative 2: Activity 3: Agency Cost	−0.07	−0.05	0.06	−0.02
Alternative 1: Activity 3: Service Life	0.18	0.07	−0.08	−0.12
Alternative 2: Activity 3: Service Life	0.00	0.07	−0.07	−0.03
Alternative 1: Activity 4: Agency Cost	−0.21	−0.25	0.11	0.19
Alternative 1: Activity 4: Service Life	−0.03	0.06	−0.14	−0.14

[a]Highlights cells that are shaded in red, indicating that the lower portion of the input distribution curve is significant in forcing the output distribution curve outward.
[b]Highlights cells that are shaded in blue, indicating that the upper portion of the input distribution curve is significant in forcing the output distribution curve outward.

TRAFFIC CALCULATOR

The Traffic Calculator is a utility tool to find the maximum AADT for a given number of hours for queues. The tool is located on the Traffic Calculator worksheet (figure 41).



Source: FHWA.
Cal = calculate.

Figure 41. Screenshot. The Traffic Calculator worksheet.

The user inputs in the Traffic Calculator include:

- Alternative Number—input the desired alternative number (e.g., 4).
- Rehab Number—input the desired rehabilitation number (e.g., 1).
- Maximum queue (hours)—input the desired maximum queue hours (e.g., 12).
- Seed AADT value—input the desired starting AADT for the computation (e.g., 100,000).
- AADT Increment—input the desired AADT increment for the computation (e.g., 1,000).

After the inputs, users can click the Cal Max AADT button to start the computation. A progress bar will be shown until the computation is complete. The tracking and outputs include:

- Current AADT—tracking current AADT input.
- Current Queue (hours)—tracking current Queue input.
- Maximum AADT—the computed maximum AADT.
- Queue at Max AADT (hours)—the queue hours at the maximum AADT.

APPENDIX A. REALCOST EXAMPLE EXERCISES

This appendix presents four example exercises to familiarize the reader with the application and use of RealCost. Each exercise is derived from actual projects in which a probabilistic LCCA was performed to help the owner agency choose the appropriate strategy alternative for implementation. The number of strategic alternatives evaluated and compared in each example varies.

Three of the four examples are pavement LCCAs that represent a range of conditions (setting, traffic, project type) encountered frequently by most highway agencies. The first example involved a new construction project located in a rural setting with moderate traffic volume. The second example consisted of a reconstruction project located in an urban setting with high traffic volume. The third example involved a reconstruction project located in a rural setting with moderately low traffic. In each example, both deterministic and probabilistic computations and results are provided for illustration. Example 2 also included further discussion on tornado graphs and extreme tail analysis, while example 3 included customizations of RealCost using difference distribution and bid-item level probabilistic inputs.

The fourth example exercise is for a bridge LCCA project. The example involved the replacement of two adjacent bridges located on a rural highway with moderately low traffic. Both deterministic and probabilistic computations are included, and work zone user costs are considered.

PAVEMENT LCCA EXAMPLE 1—RURAL NEW CONSTRUCTION

The project featured in this example involves the 2020 construction of a new four-lane divided highway facility in a largely rural location. The project will create a new 6-mi long, east-west connection between an interstate and a key State route. The highway will consist of four 12-ft-wide lanes, a 46-ft-wide median, 4-ft-wide inside shoulders, and 10-ft-wide outside shoulders. The project was designed to provide for future high occupancy vehicle lanes in the median. The two-way AADT has been estimated to be 30,866 vehicles per day (vpd).

Two different pavement designs were developed for the project, one a conventional asphalt pavement and the other a PCC pavement. The asphalt pavement consisted of 9.5 inches of HMA placed on 8 inches of the crushed aggregate base (CAB). The inside shoulder used the same design, while the outside shoulder consisted of 3 inches of HMA placed on a 14.5-inch CAB. The PCC pavement consisted of 12 inches of doweled, jointed concrete placed on top of 3.5 inches of HMA base and 3.5 inches of CAB. Both shoulders were designed to consist of 4 inches of HMA on 15 inches of CAB. The subgrade for both designs consisted of a well to poorly graded gravelly sand.

The two designs are to be evaluated on a probabilistic lifecycle cost basis using a 50-yr analysis period (a deterministic analysis will also be performed with a discount rate of 1.37 percent). A triangular distribution is assumed for the discount rate, with the minimum, most likely, and maximum values being 0.4, 1.4, and 2.3 percent, respectively. Both daytime and nighttime construction scenarios are to be considered in the LCCA, resulting in four unique pavement alternatives: HMA (day work), HMA (night work), PCC (day work), and PCC (night work). Lifecycle cost computations for each alternative are to be based on a 1-mi long "typical" section of roadway.

LCCA Inputs

The following summarizes the RealCost inputs related to traffic, pavement performance, agency costs, and work zone user costs.

Traffic

The following lists the traffic data inputs used in the simulation. They include the base year AADT, the traffic growth rate estimate, and the percentage of trucks and automobiles.

- Initial AADT (both directions)—30,866 vpd.
- Traffic Growth Rate—1.9 percent (deterministic).
- Percent Automobiles—90 percent.
- Percent Trucks—10 percent (4 percent single units and 6 percent combination units).

Pavement Performance and Activity Timing

The historical pavement performance data on similar highways in the vicinity of the proposed project provided the estimated values for service life and timing of rehabilitation activities (i.e., HMA overlays, PCC diamond grinding). The analysis period for the asphalt design includes two thin resurfacings with 12- and 13-yr functional lives and a third rehabilitation. The two thin-resurfacings after the initial construction account for 40-yr structural life, and the last portion of the analysis period is covered by the structural overlay at year 40.

For the PCC design, a 50-yr structural life is anticipated. However, a rehabilitation treatment in the form of concrete pavement restoration (CPR) is forecasted at year 30 to address roughness and friction issues. The service life of the CPR is estimated to be 20 yr.

For probabilistic simulation, a normal distribution will be applied to the service lives of the original structures and the future rehabilitation treatments (and, consequently, the timings of the future rehabilitation treatments). A summary of each design's construction and expected rehabilitation treatments are provided in table 10 and table 11.

Table 10. Summary of activities and service life—rural new construction (HMA pavement (day work and night work)).

Activity	Pavement Structure	Service Life, Years[a]—Mean	Service Life, Years[a]—Std Dev
New construction (40-yr structural life)	9.5-inch HMA over 8.0 inches of CAB (mainline and inside shoulder), 3.0-inch HMA on 14.5 inches of CAB (outside shoulder)	15.0	1.5
Rehabilitation 1 (functional)	1.75-inch HMA overlay (mainline and shoulders)	13.0	1.3
Rehabilitation 2 (functional)	1.75-inch mill and HMA inlay (mainline) and chip seal shoulders	12.0	1.2
Rehabilitation 3 (15-yr structural life)	3.0-inch HMA overlay (mainline and shoulders)	15.0	1.5

[a]Normal probability distribution assumed.

Table 11. Summary of activities and service life—rural new construction (PCC pavement (day work and night work)).

Activity	Pavement Structure	Service Life, Years[a]—Mean	Service Life, Years[a]—Std Dev
New construction (50-yr structural life)	12.0-inch PCC over 3.5-inch HMA and 3.5-inch CAB and 4.0-inch HMA on 15.0-inch CAB (shoulders)	30.0	3.0
Rehabilitation 1 (functional)	CPR (patching, grinding, and joint resealing) (mainline) and chip seal shoulders	20.0	2.0

[a]Normal probability distribution assumed.

Agency Costs

The per-mile unit length costs for new construction and future rehabilitation are computed by using the estimated quantities and historical unit cost data for these actions and all associated traffic control costs, mobilization costs, and engineering costs. These costs, expressed in terms of means and standard deviations (normal probability distribution), are listed in table 12 through table 15. For both the HMA and PCC alternatives, it was assumed that the cost of construction/rehabilitation was 5 percent higher for night work compared to day work.

Table 12. Agency cost input values—rural new construction with HMA Pavement (day work).

Activity	Year	Cost ($[a]) for 1-mi length (Mean)	Cost ($[a]) for 1-mi length (Standard Deviation)
New construction	0	1,985,000	198,500
Rehabilitation 1: HMA overlay	15	327,000	32,700
Rehabilitation 2: mill and HMA overlay	28	391,000	39,100
Rehabilitation 3: HMA overlay	40	550,000	55,000

[a]Normal probability distribution assumed.

Table 13. Agency cost input values—rural new construction with HMA pavement (night work).

Activity	Year	Cost ($[a]) for 1-mi length (Mean)	Cost ($[a]) for 1-mi length (Standard Deviation)
New construction	0	2,084,000	208,400
Rehabilitation: HMA overlay	15	343,000	34,300
Rehabilitation: mill and HMA overlay	28	411,000	41,100
Rehabilitation: HMA overlay	40	578,000	57,800

[a]Normal probability distribution assumed.

Table 14. Agency cost input values—rural new construction with PCC pavement (day work).

Activity	Year	Cost ($[a]) for 1-mi length (Mean)	Cost ($[a]) for 1-mi length (Standard Deviation)
New construction	0	3,465,000	346,500
Rehabilitation: CPR	30	600,000	60,000

[a]Normal probability distribution assumed.

Table 15. Agency cost input values—rural new construction with PCC pavement (night work).

Activity	Year	Cost ($[a]) for 1-mi length (Mean)	Cost ($[a]) for 1-mi length (Standard Deviation)
New construction	0	3,638,000	363,800
Rehabilitation: CPR	30	630,000	63,000

[a]Normal probability distribution assumed.

Work Zone User Costs

Since the new construction will not have traffic, no user costs for this event will be assessed. However, work zone user costs can and will be calculated for each future rehabilitation treatment applied. Each work zone setup will require closing one of two lanes per direction. Expected work zone hours of operation are as follows:

- Daytime construction scenario:
    - HMA Rehabilitations 1, 2, and 3—9 a.m.–5 p.m. (inbound) and 6 a.m.−3 p.m. (outbound).
    - PCC Rehabilitation 1—9 a.m.–5 p.m. (inbound) and 6 a.m.–3 p.m. (outbound).
- Nighttime construction scenario:
    - HMA Rehabilitations 1, 2, and 3—7 p.m.–5 a.m. (inbound and outbound).
    - PCC Rehabilitation 1—7 p.m.–5 a.m. (inbound and outbound).

Table 16 summarizes key aspects of each work zone and lists the values of time for the three vehicle types.

Table 16. Work zone details—the rural new construction.

Detail	HMA Pavement Rehabilitations 1, 2, and 3	PCC Pavement Rehabilitation 1—CPR
Work zone operation (one direction)	1 of 2 lanes open	1 of 2 lanes open
Approach speed (mph)	60	60
Work zone speed (mph)	40	40
Work zone hours of operation—Daytime Scenario	9 a.m.–5 p.m. (in) 6 a.m.–3 p.m. (out)	9 a.m.–5 p.m. (in) 6 a.m.–3 p.m. (out)
Work zone hours of operation—Nighttime Scenario	7 p.m.–5 a.m. (in) 7 p.m.–5 a.m. (out)	7 p.m.–5 a.m. (in) 7 p.m.–5 a.m. (out)
Construction Duration—Daytime Scenario (days)	3	9
Construction Duration—Nighttime Scenario (days)	3	9
Value of time of passenger vehicles ($/h/vehicle)	13.96 (mean) 1.40 (std dev)	13.96 (mean) 1.40 (std dev)
Value of time of single-unit trucks ($/h/vehicle)	22.34 (mean) 2.23 (std dev)	22.34 (mean) 2.23 (std dev)
Value of time of combination trucks ($/h/vehicle)	26.89 (mean) 2.69 (std dev)	26.89 (mean) 2.69 (std dev)

Additional inputs established for the computation of work zone user costs are as follows:

- Free-flow capacity—2,137 vehicles per hour per lane (vphpl) (based on the Transportation Research Board's (TRB's) *Highway Capacity Manual* (1994)).
- Queue dissipation capacity—1,818 passenger cars per lane per hour (for all rehabilitation activities).
- Maximum AADT (two-way)—140,000 vpd (based on selected design hourly volume and adjustments for the percentage of trucks and other traffic flow factors).
- Maximum queue length—2.0 mi (based on the distance to upstream detour exit).
- Work zone capacity—1,340 vphpl.
- Transportation Component CPI (Base Year 2009)—205.

Lifecycle Cost Computation

Both deterministic- and probabilistic-based LCCAs were performed, the results of which are described in the following sections.

Deterministic Results

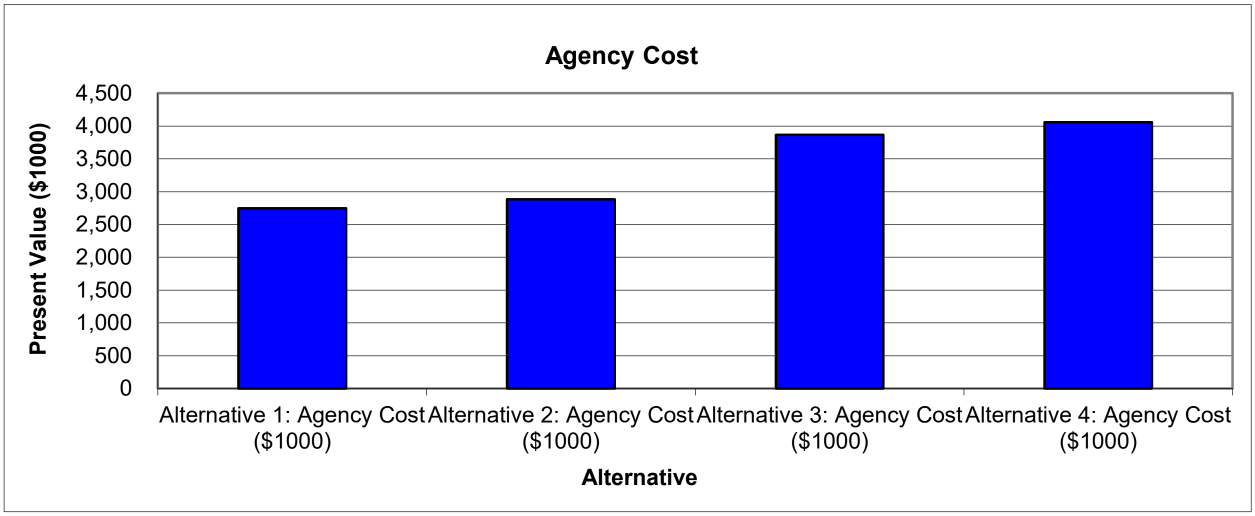
Table 17 and table 18 present the results of the deterministic analysis. Both the agency costs and user costs for each of the four alternatives are listed in terms of net present value (NPV) and equivalent uniform annual cost (EUAC). Figure 42 and figure 43 provide graphical displays of the NPV results. Based on the input values described previously, the HMA (day work) and HMA (night work) alternatives resulted in the lowest agency lifecycle cost, a difference of 29 percent lower than the two PCC alternatives.

Table 17. Deterministic LCCA results—rural new construction example (1/2).

Total Cost	Alternative 1: HMA Pavement (Day Work) Agency Cost ($1,000)	Alternative 1: HMA Pavement (Day Work) User Cost ($1,000)	Alternative 2: HMA Pavement (Night Work) Agency Cost ($1,000)	Alternative 2: HMA Pavement (Night Work) User Cost ($1,000)	Alternative 3: PCC Pavement (Day Work) Agency Cost ($1,000)	Alternative 3: PCC Pavement (Day Work) User Cost ($1,000)	Alternative 4: PCC Pavement (Night Work) Agency Cost ($1,000)	Alternative 4: PCC Pavement (Night Work) User Cost ($1,000)
NPV	2,745.69	379.06	2,882.95	32.59	3,864.30	551.71	4,057.26	22.87
EUAC	76.16	10.51	79.96	0.90	107.18	15.30	112.54	0.63

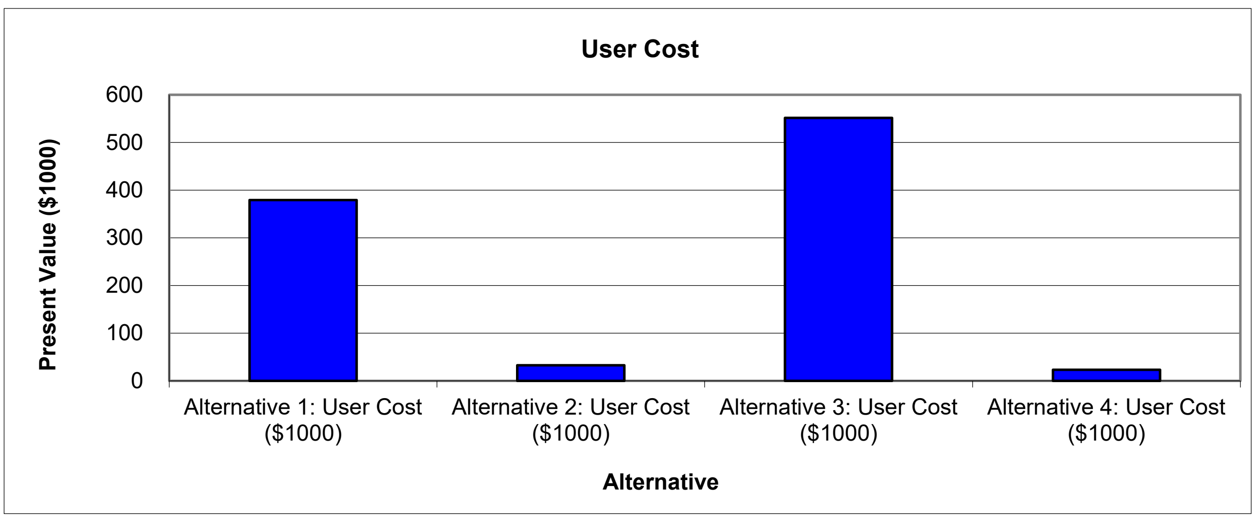
Table 18. Deterministic LCCA results—rural new construction example (2/2).

Description	Alternatives
Lowest present value agency cost	Alternative 1: HMA pavement (day work)
Lowest present value user cost	Alternative 4: PCC pavement (night work)



Source: FHWA.

Figure 42. Graph. Present value agency costs—new construction example.



Source: FHWA.

Figure 43. Graph. Present value user costs—new construction example.

Concerning user costs, the PCC (night work) alternative resulted in the lowest lifecycle cost, a difference of nearly 30 percent lower than the next lowest alternative (HMA (night work)). For both pavement types, the use of night work results in significantly reduced user costs. This reduced cost is because fewer vehicles are on the roadway during nighttime hours, which results in fewer user delays. If the agency and user lifecycle costs are added together, the alternative with the lowest total cost is the HMA (night work) alternative ($2,916,000).

Probabilistic Results

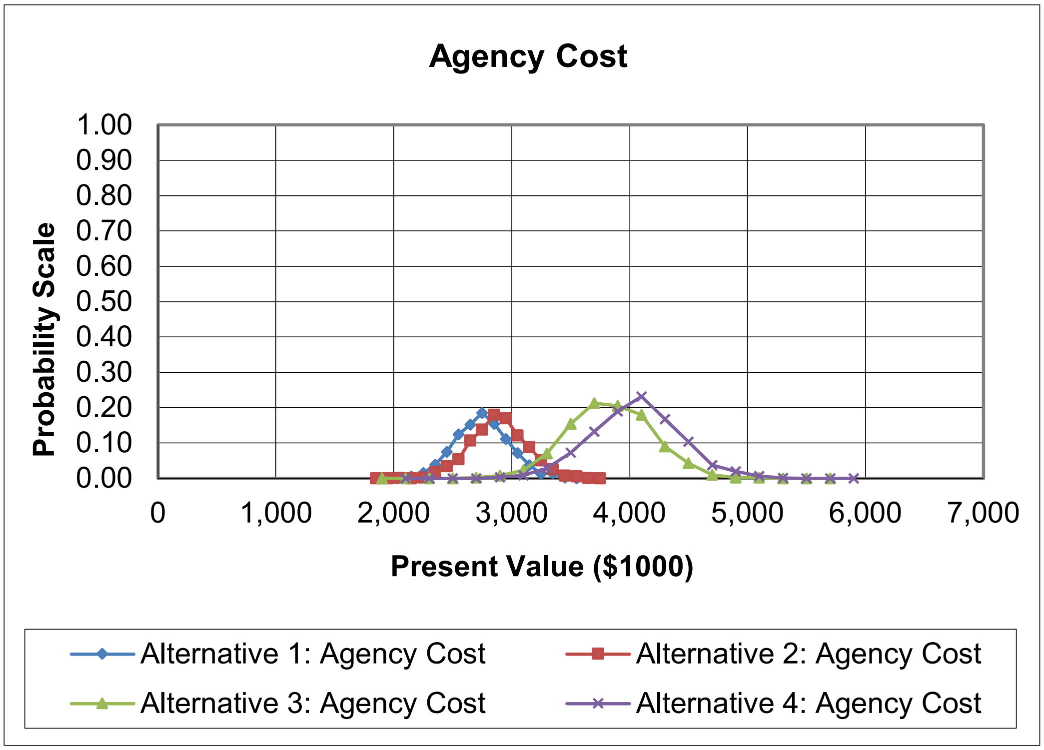
A probabilistic simulation was performed using 2,500 iterations (computational time = 947 s[1]). The resulting agency- and user-cost NPV statistics (mean, standard deviation, minimum, maximum) are summarized in table 19. The frequency and cumulative distribution curves are illustrated in figure 44 through figure 47. As shown, the mean agency costs from the probabilistic analysis are very similar to the values from the deterministic analysis (table 19). Because the HMA alternatives' mean costs are substantially lower than the PCC alternatives and the cost standard deviations for the three HMA alternatives are considerably lower than the corresponding PCC alternatives, the HMA alternatives have the lower lifecycle cost over the entire probability range. Similarly, comparing the HMA (day work) and HMA (night work) results show that the former alternative has a lower agency lifecycle cost over the entire probability range.

In terms of the user lifecycle costs, the two nighttime scenarios provide the lowest costs. There are only minor differences between the HMA (night work) alternative and the PCC (night work) alternative. Because the PCC alternative has a lower mean cost and a slightly lower standard deviation, it maintains lower user lifecycle costs over the entire probability range.

[1]The computation time may vary, depending on the computer's hardware and software.

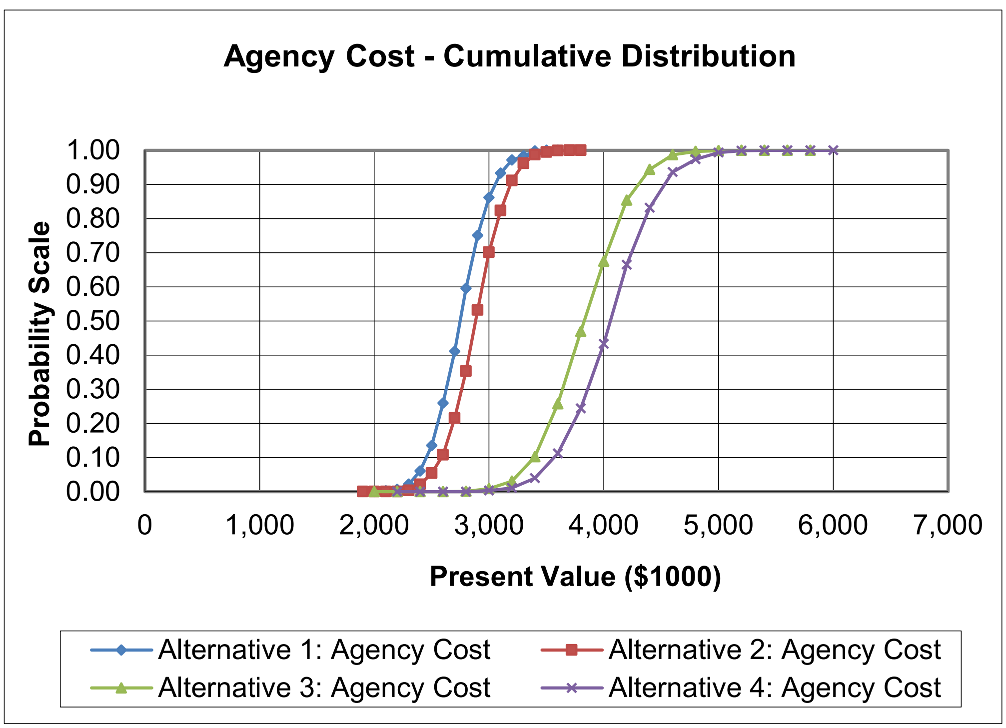
Table 19. Probabilistic LCCA results—rural new construction example.

Total Cost (Present Value)	Alternative 1: HMA Pavement (Day Work) Agency Cost ($1,000)	Alternative 1: HMA Pavement (Day Work) User Cost ($1,000)	Alternative 2: HMA Pavement (Night Work) Agency Cost ($1,000)	Alternative 2: HMA Pavement (Night Work) User Cost ($1,000)	Alternative 3: PCC Pavement (Day Work) Agency Cost ($1,000)	Alternative 3: PCC Pavement (Day Work) User Cost ($1,000)	Alternative 4: PCC Pavement (Night Work) Agency Cost ($1,000)	Alternative 4: PCC Pavement (Night Work) User Cost ($1,000)
Mean	2,749.65	374.90	2,883.49	32.76	3,835.99	501.47	4,049.81	22.43
Standard deviation	229.78	53.80	232.78	5.48	349.76	94.87	370.10	2.87
Minimum	2,027.88	228.90	2,060.93	18.88	2,762.78	200.76	2,868.46	14.56
Maximum	3,464.84	572.89	3,602.59	51.14	5,029.89	857.29	5,258.89	31.64



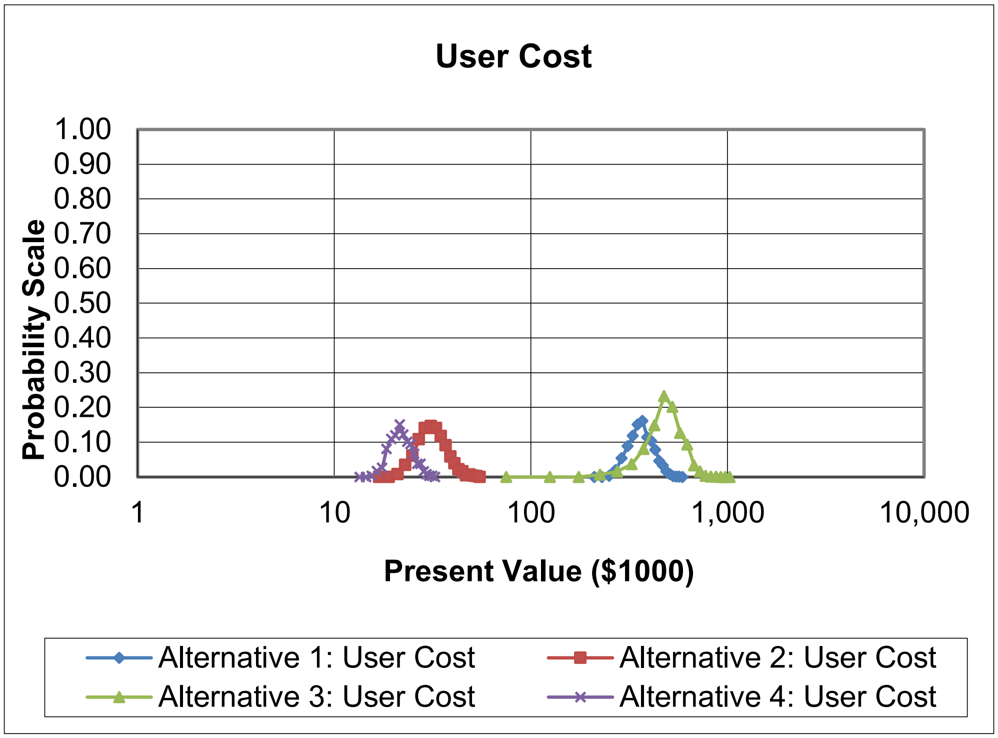
Source: FHWA.

Figure 44. Graph. Probability distribution of agency costs—rural new construction.



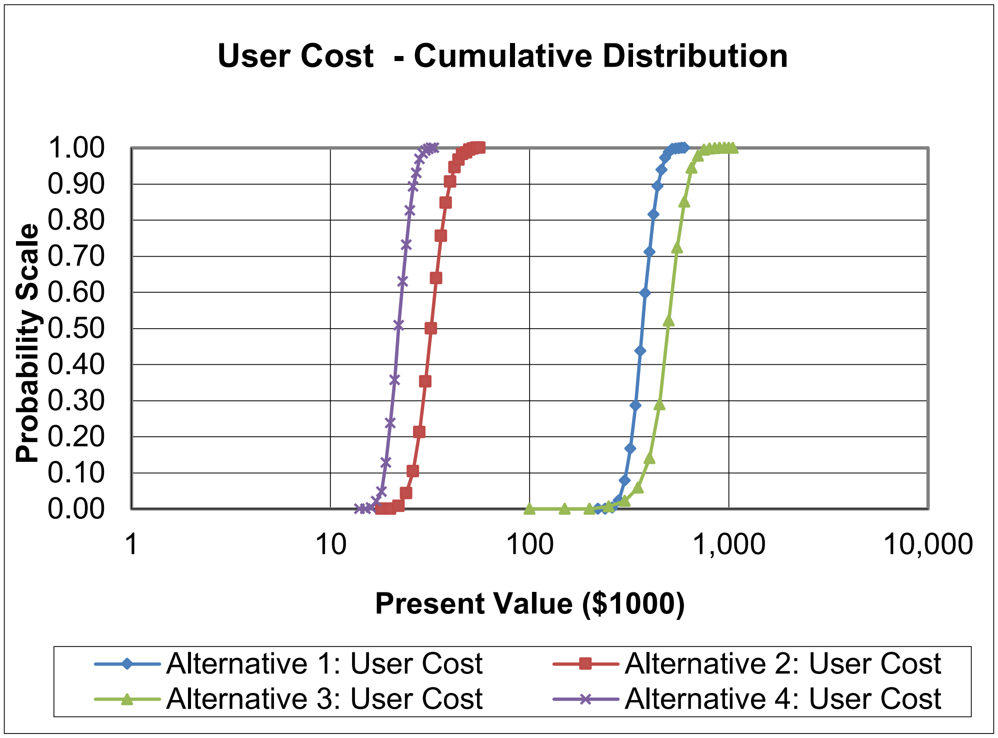
Source: FHWA.

Figure 45. Graph. Cumulative probability distribution of agency costs—rural new construction.



Source: FHWA.

Figure 46. Graph. Probability distribution of user costs—rural new construction.



Source: FHWA.

Figure 47. Graph. Cumulative probability distribution of user costs—rural new construction.

Preferred Alternative

The deterministic and probabilistic analyses indicate that the HMA (day work) alternative yields the lowest total agency lifecycle cost. A final selection of an alternative would naturally consider a variety of other monetary and nonmonetary factors.

PAVEMENT LCCA EXAMPLE 2—URBAN RECONSTRUCTION

The project featured in this example involves the 2020 reconstruction and widening of an existing four-lane divided highway facility in an urban location. The project will create an eight-lane interstate facility that is 7.0-mi long. The highway will consist of eight 12-ft-wide lanes, 10-ft-wide inside shoulders, and 12-ft-wide outside shoulders (which may be used in the future as an additional general-purpose lane). The two-way AADT has been estimated to be 72,000 vpd.

Two pavement designs were developed for the project, asphalt pavement and a PCC pavement. The asphalt pavement consists of 10.0 inches of HMA placed on 5.4 inches of CAB. The shoulders will be constructed with the same pavement section as specified for the mainline. The PCC pavement consists of 12.0 inches of doweled, jointed concrete placed over a 2.4-inch HMA base and 3.0 inches of CAB. Shoulders will be constructed with the same section as specified for the mainline. The subgrade for both designs consist of a glacial till.

The two designs will be evaluated on both a deterministic and probabilistic lifecycle cost basis using a 50-yr analysis period. A triangular distribution is assumed for the discount rate, with the minimum, most likely, and maximum values being 0.4, 1.4, and 2.3 percent, respectively. Both daytime and nighttime construction scenarios will be considered in the LCCA, resulting in four unique pavement alternatives: HMA daytime, PCC daytime, HMA nighttime, and PCC nighttime. Lifecycle cost computations for each alternative are to be based on a 1-mi long "typical" section of roadway.

LCCA Inputs

The following summarizes the RealCost inputs related to traffic, pavement performance, agency costs, and work zone user costs.

Traffic

The following list contains the traffic data inputs to be used in the simulation. They include the base year AADT, the traffic growth rate estimate, and the percentage of trucks and automobiles.

- Initial AADT (both directions)—72,000 vpd.
- Traffic Growth Rate—2.5 percent most likely (triangular distribution, with 2.0 percent minimum and 3.0 percent maximum).
- Percent Automobiles—90 percent.
- Percent Trucks—10 percent (5.2 percent singles and 4.8 percent combinations).

Pavement Performance and Activity Timing

Each proposed initial structure's service life was estimated using historical pavement performance data on similar highways in the vicinity of the proposed project and the life of each appropriate form of rehabilitation (i.e., HMA overlays, PCC diamond grinding). For the asphalt pavement design, an initial life of 14 yr and an 8-yr rehabilitation cycle is considered to represent the best expected performance. For the PCC design, a rehabilitation treatment in the form of major CPR is forecasted to occur after 25 yr. For probabilistic simulation, a triangular distribution will be applied to the timings of future rehabilitation treatments. A summary of each design's construction and expected rehabilitation treatments are provided in table 20 and table 21.

Table 20. Summary of construction and future rehabilitation treatments—urban reconstruction with HMA pavement (day work and night work).

Activity	Pavement Structure	Service Life, Years[a]—Most Likely	Service Life, Years[a] Minimum, Maximum
Reconstruction (50-yr structural life)	12.0-inch HMA over 5.4-inch CAB (mainline and shoulders)	14.0	12.0, 16.0
Rehabilitation 1 (functional)	1.75-inch mill and HMA inlay (mainline only) fog seal shoulders	8.0	6.0, 10.0
Rehabilitation 2 (functional)	1.75-inch mill and HMA inlay (mainline only), fog seal shoulders	8.0	6.0, 10.0
Rehabilitation 3 (functional)	1.75-inch HMA overlay (mainline only)	8.0	6.0, 10.0
Rehabilitation 4 (functional)	1.75-inch mill and HMA inlay (mainline only) fog seal shoulders	8.0	6.0, 10.0
Rehabilitation 5 (functional)	1.75-inch mill and HMA inlay (mainline only) fog seal shoulders	8.0	6.0, 10.0

[a]Triangular probability distribution assumed.

Table 21. Summary of construction and future rehabilitation treatments—urban reconstruction with PCC pavement (day work and night work).

Activity	Pavement Structure	Service Life, Years[a]—Most Likely	Service Life, Years[a] Minimum, Maximum
Reconstruction (50-yr structural life)	12.0-inch PCC over 2.4-inch HMA and 3.0-inch CAB (mainline and shoulders)	25.0	20.0, 30.0
Rehabilitation 1 (functional)	CPR (patching, grinding, and joint resealing) (mainline) fog seal shoulders	25.0	20.0, 30.0

[a]Triangular probability distribution assumed.

Agency Costs

Using estimated quantities and historical unit cost data for these actions, as well as all associated traffic control costs, mobilization costs, and engineering costs, the 1-mi unit length costs for each action were computed for reconstruction and future rehabilitation. These costs, expressed in terms of means and standard deviations (normal probability distribution), are listed in table 22 through table 25. For both the HMA and PCC alternatives, it was assumed that the cost of construction/rehabilitation was 2.5 percent higher for night work compared to day work.

Table 22. Agency cost input values—urban reconstruction with HMA pavement (day work).

Activity	Year	Cost ($[a]) for 1-mi length (Mean)	Cost ($[a]) for 1-mi length (Standard Deviation)
Reconstruction	0	5,118,491	511,849
Rehabilitation 1: mill and HMA inlay	14	660,776	66,078
Rehabilitation 2: mill and HMA inlay	22	660,776	66,078
Rehabilitation 3: HMA overlay	30	838,509	83,851
Rehabilitation 4: mill and HMA inlay	38	660,776	66,078
Rehabilitation 5: mill and HMA inlay	46	660,776	66,078

[a]Normal probability distribution assumed.

Table 23. Agency cost input values—urban reconstruction with HMA pavement (night work).

Activity	Year	Cost ($[a]) for 1-mi length (Mean)	Cost ($[a]) for 1-mi length (Standard Deviation)
Reconstruction	0	5,246,453	524,645
Rehabilitation 1: mill and HMA inlay	14	677,295	67,730
Rehabilitation 2: mill and HMA inlay	22	677,295	67,730
Rehabilitation 3: HMA overlay	30	859,472	85,947
Rehabilitation 4: mill and HMA inlay	38	677,295	67,730
Rehabilitation 5: mill and HMA inlay	46	677,295	67,730

[a]Normal probability distribution assumed.

Table 24. Agency cost input values—urban reconstruction with PCC pavement (day work).

Activity	Year	Cost ($[a]) for 1-mi length (Mean)	Cost ($[a]) for 1-mi length (Standard Deviation)
Reconstruction	0	5,639,715	563,972
Rehabilitation 1: CPR	25	1,294,717	129,472

[a]Normal probability distribution assumed.

Table 25. Agency cost input values—urban reconstruction with PCC Pavement (night work).

Activity	Year	Cost ($[a]) for 1-mi length (Mean)	Cost ($[a]) for 1-mi length (Standard Deviation)
Reconstruction	0	5,780,708	578,071
Rehabilitation 1: CPR	25	1,327,085	132,709

[a]Normal probability distribution assumed.

Work Zone User Costs

As part of this project, several bridges and structures will be reconstructed and that will control the reconstruction schedule. It is assumed that the reconstruction of either the HMA or PCC pavement option will require the same construction duration. Therefore, no difference in user costs is associated with reconstruction between the alternatives. Work zone user costs will be calculated for each future rehabilitation treatment. Each work zone setup will require closing one lane per direction. Expected work zone hours of operation are as follows:

- Daytime construction scenario:
  - HMA rehabilitation—9 a.m.–5 p.m. (inbound) and 6 a.m.–3 p.m. (outbound).
  - PCC rehabilitation—9 a.m.–5 p.m. (inbound) and 6 a.m.–3 p.m. (outbound).
- Nighttime construction scenario:
  - HMA rehabilitation—7 p.m.–6 a.m. (inbound) and 7 p.m.–6 a.m. (outbound).
  - PCC rehabilitation—7 p.m.–6 a.m. (inbound) and 7 p.m.–6 a.m. (outbound).

Table 26 summarizes key aspects of each work zone and lists the values of time for the three vehicle types.

Table 26. Work zone details—urban reconstruction.

Detail	HMA Pavement Rehabilitations 1–5	PCC Pavement Rehabilitation 1
Work zone operation (one direction)	3 of 4 lanes open	3 of 4 lanes open
Approach speed (mph)	65	65
Work zone speed (mph)	40	40
Work zone hours of operation—Daytime Scenario	9 a.m.–5 p.m. (in) 6 a.m.–3 p.m. (out)	9 a.m.–5 p.m. (in) 6 a.m.–3 p.m. (out)
Work zone hours of operation—Nighttime Scenario	7 p.m.–6 a.m. (in) 7 p.m.–6 a.m. (out)	7 p.m.–6 a.m. (in) 7 p.m.–6 a.m. (out)
Construction Duration—Daytime Scenario (days)	8	12
Construction Duration—Nighttime Scenario (days)	8	12
Value of time of passenger vehicles ($/h/vehicle)	13.96 (most likely) 12.00 (minimum) 16.00 (maximum)	13.96 (most likely) 12.00 (minimum) 16.00 (maximum)
Value of time of single-unit trucks ($/h/vehicle)	22.34 (most likely) 20.00 (minimum) 24.00 (maximum)	22.34 (most likely) 20.00 (minimum) 24.00 (maximum)
Value of time of combination trucks ($/h/vehicle)	26.89 (most likely) 25.00 (minimum) 29.00 (maximum)	26.89 (most likely) 25.00 (minimum) 29.00 (maximum)

Additional inputs established for the computation of work zone user costs are as follows:

- Free-flow capacity—2,158 vphpl (based on the 1994 *Highway Capacity Manual* (TRB 1994)).
- Queue dissipation capacity—1,818 passenger cars per lane per hour (for all rehabilitation activities).
- Maximum AADT (two way)—140,000 vpd.
- Maximum queue length—3.5 mi.
- Work zone capacity—1,490 vphpl.
- Transportation component CPI (base year 2009)—205.

Lifecycle Cost Computation

Both deterministic- and probabilistic-based LCCAs were performed, the results of which are further described in the following sections.

Deterministic Results

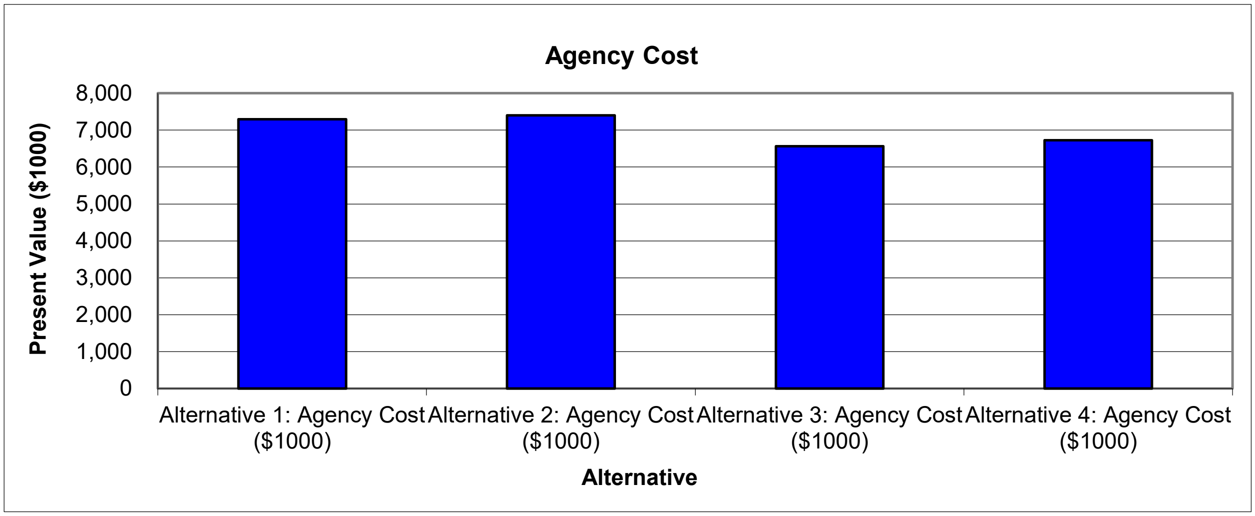
The results of the deterministic analysis are summarized in table 27 and table 28. One of the primary methods for reporting pavement LCCA results is NPV; the agency and user cost results are further illustrated in figure 48 and figure 49, respectively.

Table 27. Deterministic results—urban reconstruction (1/2).

Total Cost	Alternative 1: HMA Pavement (Day Work) Agency Cost ($1,000)	Alternative 1: HMA Pavement (Day Work) User Cost ($1,000)	Alternative 2: HMA Pavement (Night Work) Agency Cost ($1,000)	Alternative 2: HMA Pavement (Night Work) User Cost ($1,000)	Alternative 3: PCC Pavement (Day Work) Agency Cost ($1,000)	Alternative 3: PCC Pavement (Day Work) User Cost ($1,000)	Alternative 4: PCC Pavement (Night Work) Agency Cost ($1,000)	Alternative 4: PCC Pavement (Night Work) User Cost ($1,000)
NPV	7,293.91	523.12	7,400.93	183.94	6,561.85	192.24	6,725.90	68.67
EUAC	202.31	14.51	205.28	5.10	182.00	5.33	186.55	1.90

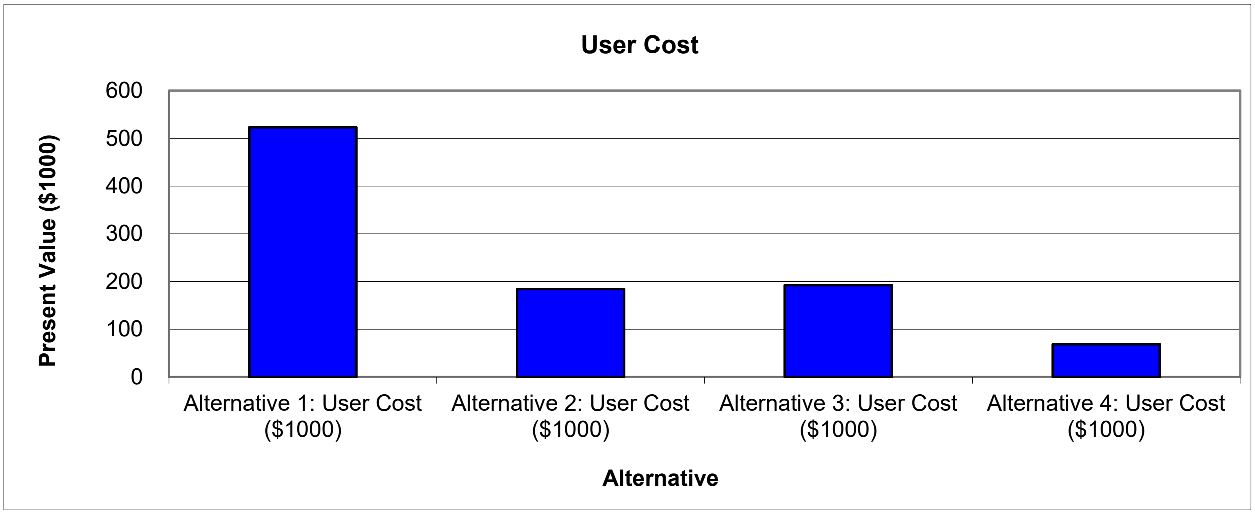
Table 28. Deterministic results—urban reconstruction (2/2).

Description	Alternatives
Lowest NPV agency cost	Alternative 3: PCC pavement (day work)
Lowest NPV user cost	Alternative 4: PCC pavement (night work)



Source: FHWA.

Figure 48. Graph. Present value agency costs—urban reconstruction.



Source: FHWA.

Figure 49. Graph. Present value of user costs—urban reconstruction.

Based on the deterministic analysis, the PCC (day work) alternative results in the lowest present value when only agency costs are considered. As further illustrated in figure 49, the alternatives that include nighttime construction have significantly lower present value user costs. These lower costs are expected due to the lower number of vehicles on the roadway during nighttime hours, resulting in fewer hours of user delay due to construction and lower user costs. When user costs are included in the analysis, the lowest resulting present value occurs with the PCC (night work) alternative.

Probabilistic Results

A probabilistic simulation was performed using 2,500 iterations. The simulation converges after 950 iterations, with the final convergence error of 2.49 percent (simulation time is 796 s.[2]). The resulting agency and user costs are summarized in table 29. This table contains the mean, standard deviation, minimum and maximum agency, and user costs for each of the four alternatives. The agency cost means from the probabilistic analysis are very similar to the deterministic analysis' present value. The probabilistic analysis value is the ability to compare the variability about the mean, shown as the standard deviation. For this example, the standard deviation for all alternatives' agency costs is very similar. For comparison purposes, it does not provide any significant insight for selecting one alternative over another. However, in comparing user costs, the probabilistic analysis shows:

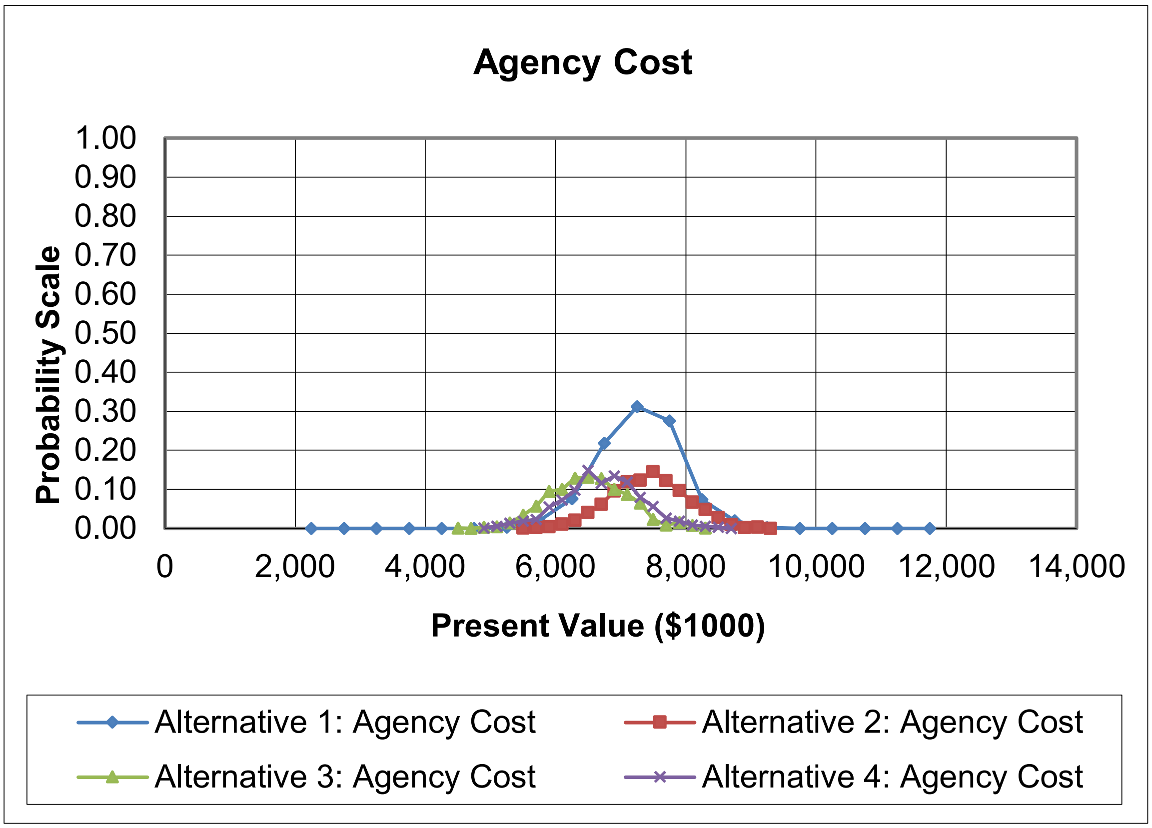
- Less certain (higher variability about the mean) for daytime work than nighttime work.
- Greater potential for the highest NPV with HMA (daytime) alternative.
- Greater potential for the lowest NPV with the PCC (nighttime) alternative.
- Highest certainty for PCC (nighttime) of all the alternatives.

[2]The computation time may vary, depending on users' computer hardware and software.

Table 29. Probabilistic results—urban reconstruction.

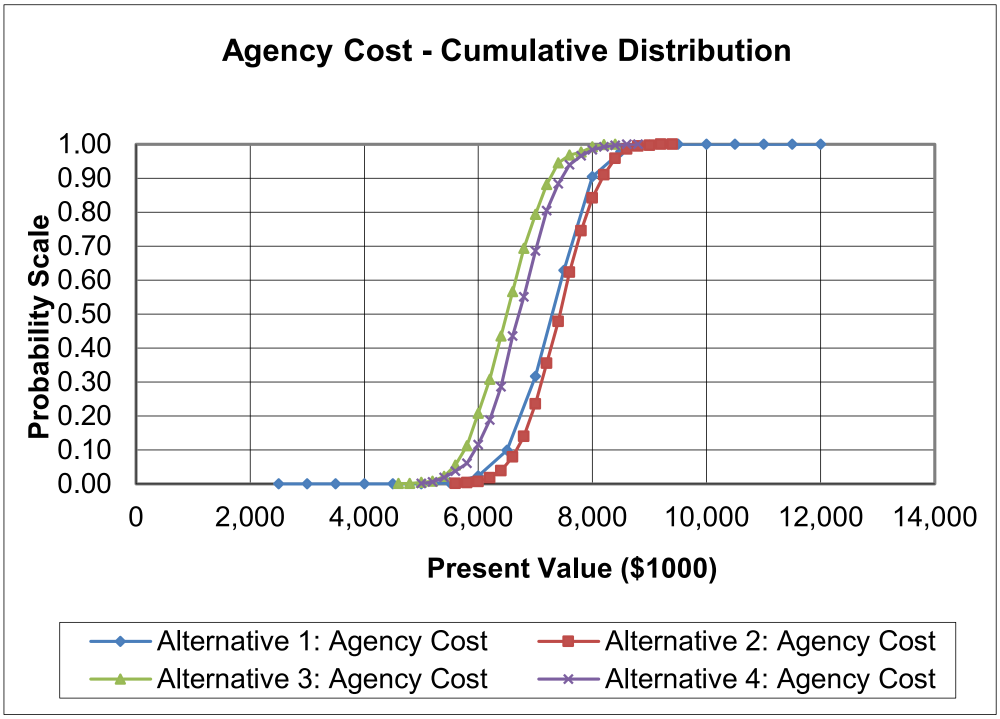
Total Cost (Present Value)	Alternative 1: HMA Pavement (Day Work) Agency Cost ($1,000)	Alternative 1: HMA Pavement (Day Work) User Cost ($1,000)	Alternative 2: HMA Pavement (Night Work) Agency Cost ($1,000)	Alternative 2: HMA Pavement (Night Work) User Cost ($1,000)	Alternative 3: PCC Pavement (Day Work) Agency Cost ($1,000)	Alternative 3: PCC Pavement (Day Work) User Cost ($1,000)	Alternative 4: PCC Pavement (Night Work) Agency Cost ($1,000)	Alternative 4: PCC Pavement (Night Work) User Cost ($1,000)
Mean	7,278.44	528.40	7,417.65	184.04	6,508.02	183.35	6,708.84	65.78
Standard deviation	599.21	69.39	574.24	22.82	585.38	30.56	592.40	7.42
Minimum	5,031.65	366.75	5,592.40	124.30	4,597.69	113.84	4,843.63	47.10
Maximum	9,111.22	761.58	9,126.74	275.16	8,334.89	279.27	8,536.56	91.82

Frequency and cumulative probability distribution curves are shown in figure 50 through figure 53. Figure 50 shows that the mean present value of agency costs for the PCC (day work) alternative is slightly less than the next lowest alternative, the PCC (night work) alternative. It also shows that there is slightly lower variability in agency cost for this alternative. However, figure 51 shows the PCC (day work) alternative maintains the lowest agency lifecycle cost over most of the cumulative probability range (roughly 0 to 90 percent). Figure 52 and figure 53 clearly indicate that the PCC (night work) alternative has the lowest lifecycle user cost.



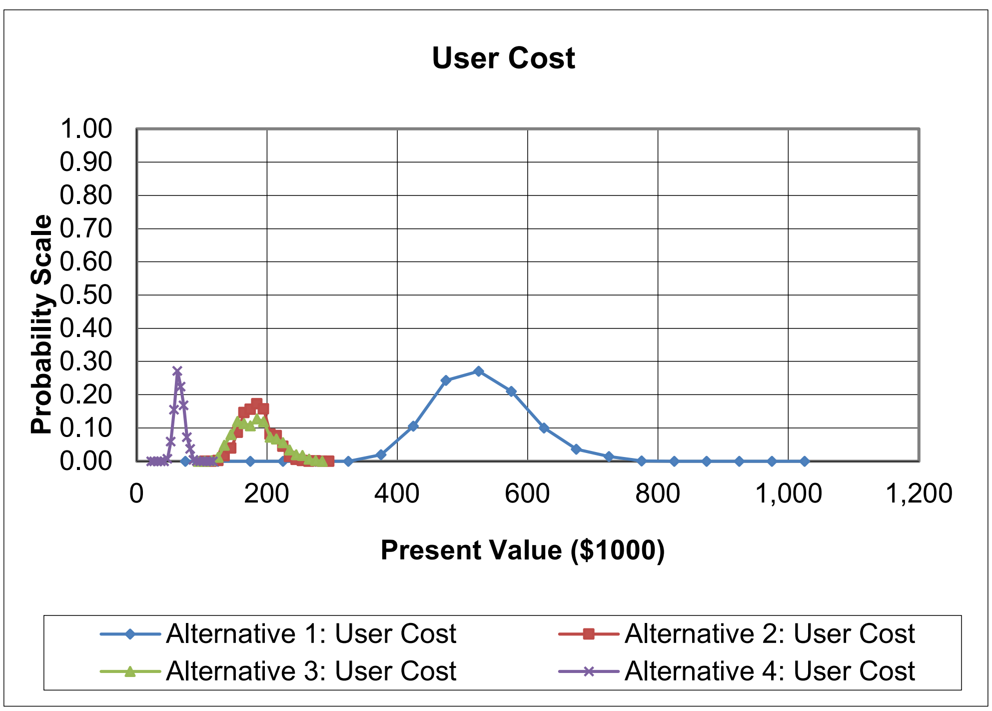
Source: FHWA.

Figure 50. Graph. Probability distribution of agency costs—urban reconstruction.



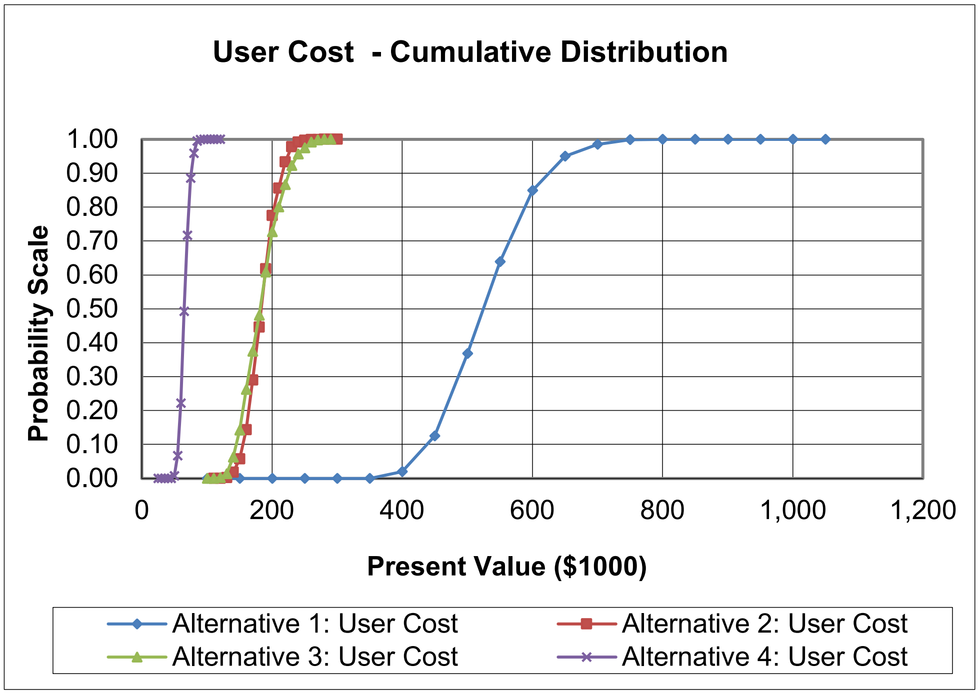
Source: FHWA.

Figure 51. Graph. Cumulative probability distribution of agency costs—urban reconstruction.



Source: FHWA.

Figure 52. Graph. Probability distribution of user costs—urban reconstruction.



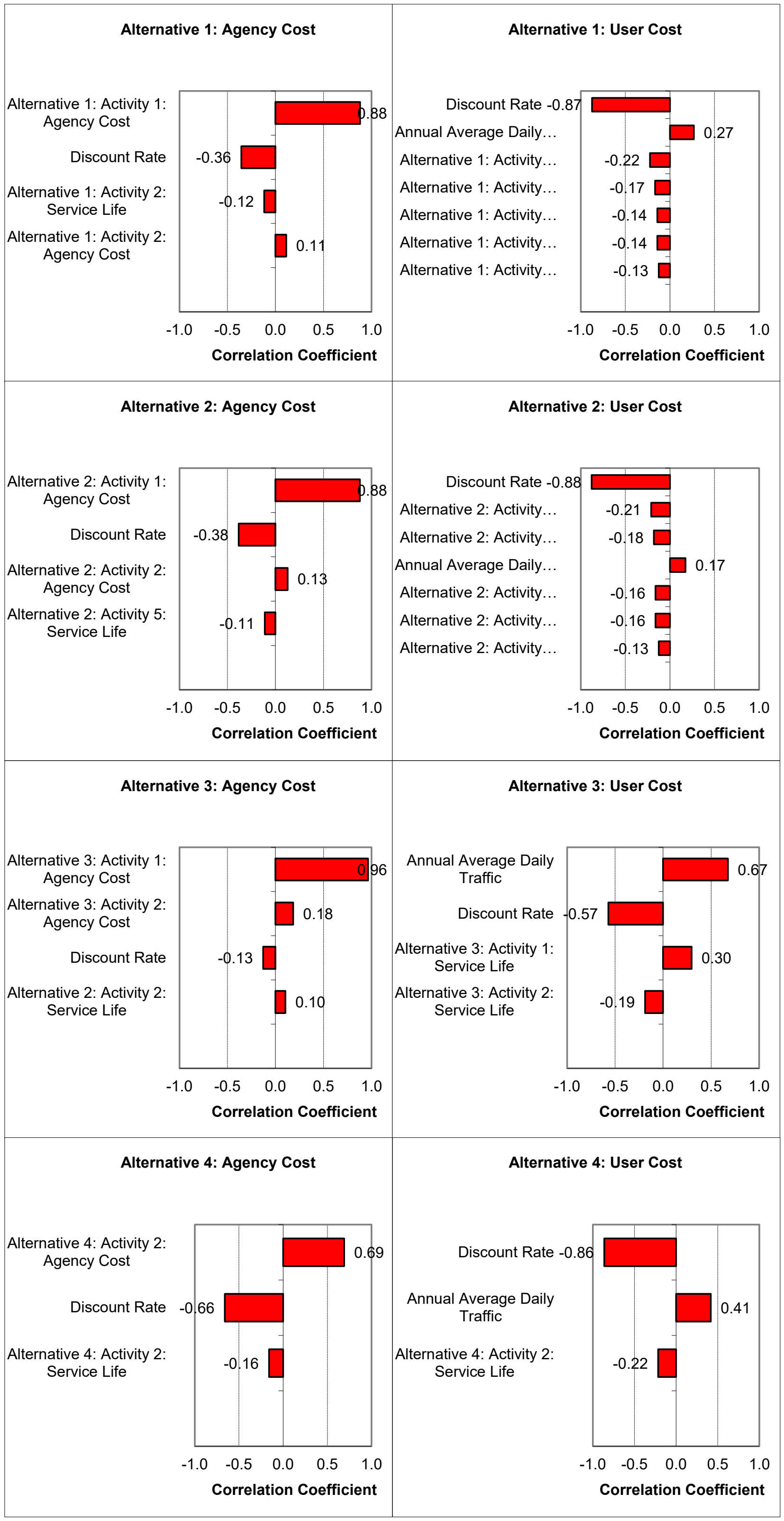
Source: FHWA.

Figure 53. Graph. Cumulative probability distribution of user costs—urban reconstruction.

The results of tornado analyses are shown in figure 54. The tornado graph can be used to identify the effect of the input value's uncertainty on the output distribution mean. The higher the correlation coefficient, the greater the effect the input variable has on the LCCA results. In this manner, the tornado chart can be used by an SHA to identify which inputs have the highest impact so that strategies for mitigating the associated risk and reducing input uncertainty can be addressed.

As shown in figure 54, the key driver in the agency lifecycle cost for this example is the first activity's cost (i.e., the initial construction) for all but PCC (night work). For each alternative, a change of 1 standard deviation in the initial cost causes a change in the lifecycle cost of at least 0.95 of a standard deviation in the same direction. Although not significant, the discount rate had the next most significant influence for all but the PCC (day work) alternative. The discount rate is a key driver for the two HMA alternatives and the PCC (night work) alternative for user lifecycle costs, while AADT is a key driver for the PCC (day work) alternative.

Extreme tail analysis can be used for analyzing the risks associated with extreme events (i.e., the tails of the distribution curve). Results of an extreme tail analysis for this example are shown in table 30, with the alpha values at probability levels of 5, 10, 90, and 95 percent listed for Alternative 1. On that basis, alpha values less than −0.5 (cells shaded in red) or greater than 0.5 (cells shaded in blue) are considered significant. It can be seen that there is a strong relationship between total agency cost and activity 1 agency costs. Also, for user costs, there is a strong relationship with the discount rate. As with the tornado graph, knowing this information, an SHA can focus on these input values to determine if input variation can be reduced.



Source: FHWA.

Figure 54. Screenshot. Tornado graphs—urban reconstruction.

Table 30. Example of the extreme tail analysis—urban reconstruction (Alternative 1).

Input Variable	Agency Cost 5 percent	Agency Cost 10 percent	Agency Cost 90 percent	Agency Cost 95 percent	User Cost 5 percent	User Cost 10 percent	User Cost 90 percent	User Cost 95 percent
Discount Rate	1.03[b]	0.64[b]	−0.72[a]	−1.17[a]	1.49[b]	1.37[b]	−1.57[a]	−1.78[a]
AADT	−0.13	−0.05	0.04	0.15	−0.57[a]	−0.59[a]	0.55[b]	0.53[b]
Alternative 1: Activity 1: Agency Cost	−1.80[a]	−1.59[a]	1.47[a]	1.67[a]	0.23	0.09	0.08	0.09
Alternative 2: Activity 1: Agency Cost	−0.15	−0.09	−0.19	−0.07	0.03	−0.16	−0.13	−0.03
Alternative 3: Activity 1: Agency Cost	0.22	0.32	0.09	0.18	−0.22	−0.11	0.04	0.12
Alternative 1: Activity 1: Service Life	0.24	0.34	−0.23	−0.25	0.29	0.25	−0.33	−0.25
Alternative 2: Activity 1: Service Life	−0.12	0.04	−0.10	−0.26	−0.06	−0.07	0.03	0.09
Alternative 3: Activity 1: Service Life	−0.15	−0.12	0.04	0.38	0.32	0.10	0.16	0.37
Alternative 1: Activity 2: Agency Cost	−0.39	−0.28	0.30	0.42	−0.09	−0.09	0.15	0.17

[a]Highlights the cells that are shaded in red, indicating the values that are less than −0.5.
[b]Highlights the cells that are shaded in blue, indicating the values that are greater than −0.5.

Preferred Alternative

The deterministic and probabilistic analyses indicate that the PCC (day work) alternative yields the lowest agency lifecycle cost. Even when the user lifecycle costs are added directly to the agency lifecycle costs, this alternative still has the lowest combined lifecycle cost, but only by about 1.23 percent at the 50 percent probability level, as compared to the PCC (night work) option. Given the closeness in costs, either alternative could be considered the preferred option, with the final selection based on various other factors.

PAVEMENT LCCA EXAMPLE 3—RURAL RECONSTRUCTION AND WIDENING

The project featured in this example involves the 2020 reconstruction of an existing two-lane highway and two additional lanes to make a new four-lane undivided facility. The project is 4.0 mi long and located in a rural setting. The new highway will consist of four 12-ft-wide lanes and 6-ft-wide shoulders. The AADT construction year (total for both directions) has been estimated to be 21,500 vpd.

Two pavement designs were developed for the project, asphalt pavement and a PCC pavement. The asphalt pavement consists of 10.0 inches of HMA placed over 4.0 inches of CAB. The shoulders will be constructed with 4.0 inches of HMA over 10 inches of CAB. The PCC pavement consists of 10.0 inches of doweled, jointed concrete placed over 4.0 inches of CAB. Shoulders will be constructed with the 4.0-inch HMA over 10 inches of CAB.

The two designs are to be evaluated using both a deterministic and probabilistic lifecycle cost basis using a 40-yr analysis period. A triangular distribution is assumed for the discount rate, with the minimum, most likely, and maximum values being 0.4, 1.4, and 2.3 percent, respectively. Lifecycle cost computations for each alternative are based on a 1-mi long "typical" section of the roadway.

LCCA Inputs

The following summarizes the RealCost inputs related to traffic, pavement performance, agency costs, and work zone user costs.

Traffic

The following list contains the traffic data inputs to be used in the simulation. The inputs include the base year AADT, the traffic growth rate estimate, and the percent of trucks and automobiles:

- Initial AADT (both directions)—21,500 vpd.
- Traffic Growth Rate—3.5 percent.
- Percent Automobiles—93.5 percent.
- Percent Trucks—6.5 percent (3.0 percent single units and 3.5 percent combinations).

Pavement Performance and Activity Timing

The service life of each proposed initial structure was estimated using historical pavement performance data on similar highways in the vicinity of the proposed project and the life of each appropriate form of rehabilitation (i.e., HMA overlays, PCC diamond grinding). For the asphalt pavement design, an initial pavement life of 12 yr is forecasted, followed by a 10-yr rehabilitation cycle involving thin HMA overlay and thin mill-and-inlay. For the PCC design, an initial life of 22 yr is projected, followed by a CPR and then a thin HMA overlay. For probabilistic simulation, a triangular distribution will be applied to the timings of future rehabilitation treatments. A summary of the construction and expected rehabilitation treatments for each design is provided in table 31.

Table 31. Summary of construction and future rehabilitation treatments—rural reconstruction/widening with HMA pavement.

Activity	Pavement Structure	Service Life, Years[a]—Most Likely	Service Life, Years[a] Minimum, Maximum
Reconstruction and new construction (40-yr structural life)	10.0-inch HMA over 4.0-inch CAB (mainline) 4.0-inch HMA over 10.0-inch CAB (shoulders)	12.0	9.0, 15.0
Rehabilitation 1 (functional)	1.75-inch HMA overlay (mainline and shoulders)	10.0	7.0, 13.0
Rehabilitation 2 (functional)	1.75-inch mill and HMA inlay (mainline and shoulders)	10.0	7.0, 13.0
Rehabilitation 3 (functional)	1.75-inch mill and HMA inlay (mainline and shoulders)	10.0	7.0, 13.0

[a]Triangular probability distribution assumed.

Table 32. Summary of construction and future rehabilitation treatments—rural reconstruction/widening with PCC pavement.

Activity	Pavement Structure	Service Life, Years[a]—Most Likely	Service Life, Years[a] Minimum, Maximum
Reconstruction and new construction (40-yr structural life)	10.0-inch PCC over 4.0-inch CAB (mainline) 4.0-inch HMA over 10.0-inch CAB (shoulders)	22.0	19.0, 25.0
Rehabilitation 1 (functional)	CPR (patching, grinding, and joint resealing) (mainline) 1.75-inch mill and HMA inlay (shoulders)	10.0	9.0, 11.0
Rehabilitation 2 (functional)	1.75-inch HMA overlay (mainline and shoulders)	10.0	9.0, 11.0

[a]Triangular probability distribution assumed.

Agency Costs

Using estimated quantities and historical unit cost data for these actions and all associated traffic control costs, mobilization costs, and engineering costs, the 1-mi unit length costs for each action were computed for reconstruction and future rehabilitation. These costs, expressed in terms of means and standard deviations (normal probability distribution), are listed in table 33 and table 34. Because of the recent instability in asphalt prices, a higher standard deviation has been assigned to activities involving HMA compared to those involving PCC.

Table 33. Agency cost input values—rural reconstruction/widening with HMA pavement.

Activity	Year	Cost ($[a]) for 1-mi length (Mean)	Cost ($[a]) for 1-mi length (Standard Deviation)
Reconstruction/new construction	0	877,000	175,000
Rehabilitation 1: HMA overlay	12	160,000	32,000
Rehabilitation 2: mill and HMA inlay	22	253,000	50,600
Rehabilitation 3: mill and HMA inlay	32	253,000	50,600

[a]Normal probability distribution assumed.

Table 34. Agency cost input values—rural reconstruction/widening with PCC pavement.

Activity	Year	Cost ($[a]) for 1-mi length (Mean)	Cost ($[a]) for 1-mi length (Standard Deviation)
Reconstruction/new construction	0	1,082,000	108,200
Rehabilitation 1: CPR	22	267,000	26,700
Rehabilitation 2: HMA overlay	32	160,000	32,000

[a]Normal probability distribution assumed.

Work Zone User Costs

It is assumed that during reconstruction/new construction, the HMA and PCC pavement options will require the same construction duration. Therefore, no difference in user costs is associated with reconstruction between the two alternatives. Work zone user costs will be calculated for each future rehabilitation treatment. Each work zone setup will require closing one lane in each direction. The expected work zone hours of operation are 6 a.m.–6 p.m. (inbound and outbound). Table 35 summarizes each work zone's key aspects and lists the values of time for the three vehicle types.

Table 35. Work zone details—rural reconstruction/widening.

Detail	HMA Pavement Rehabilitations 1–3, PCC Pavement Rehabilitation 2	PCC Pavement Rehabilitation 1
Work zone operation (one direction)	1 of 2 lanes open	1 of 2 lanes open
Approach speed (mph)	45	45
Work zone speed (mph)	30	30
Work zone hours of operation	6 a.m.–6 p.m.	6 a.m.–6 p.m.
Construction duration (days)	10	20
Value of time of passenger vehicles ($/h/vehicle)	13.96 (deterministic)	13.96 (deterministic)
Value of time of single-unit trucks ($/h/vehicle)	22.34 (deterministic)	22.34 (deterministic)
Value of time of combination trucks ($/h/vehicle)	26.89 (deterministic)	26.89 (deterministic)

Additional inputs established for the computation of work zone user costs are as follows:

- Free-flow capacity—1,700 vphpl (based on the 1994 *Highway Capacity Manual* (TRB 1994)).
- Queue dissipation capacity—1,500 passenger cars per lane per hour (for all rehabilitation activities).
- Maximum AADT (two-way)—45,000 vpd.
- Maximum queue length—1.5 mi.
- Work zone capacity—1,340 vphpl.
- Transportation component CPI (base year 2009)—205.

Lifecycle Cost Computation

Both a deterministic- and probabilistic-based LCCA were performed, the results of which are further described in the following sections.

Deterministic Results

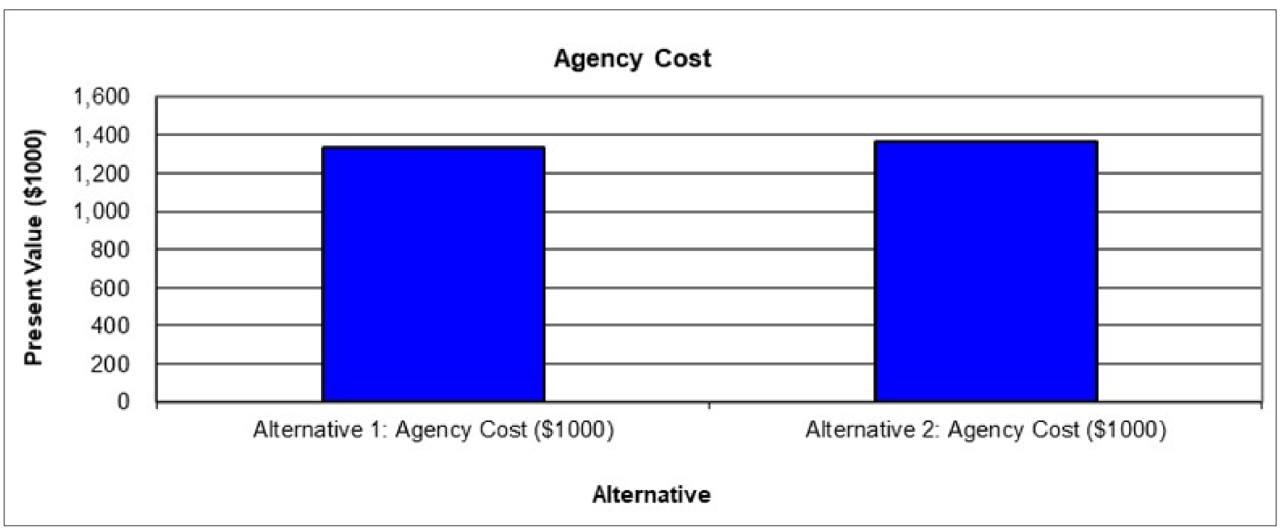
The results of the deterministic analysis are summarized in table 36, table 37, figure 55, and figure 56. The HMA alternative gives the lowest total lifecycle cost for both agency and user costs based on the deterministic analysis.

Table 36. Deterministic results—rural reconstruction/widening (1/2).

Total Cost	Alternative 1: HMA Agency Cost ($1,000)	Alternative 1: HMA User Cost ($1,000)	Alternative 2: PCC Agency Cost ($1,000)	Alternative 1: HMA User Cost ($1,000)
NPV	1,335.09	637.23	1,365.10	849.38
EUAC	43.55	20.79	44.53	27.71

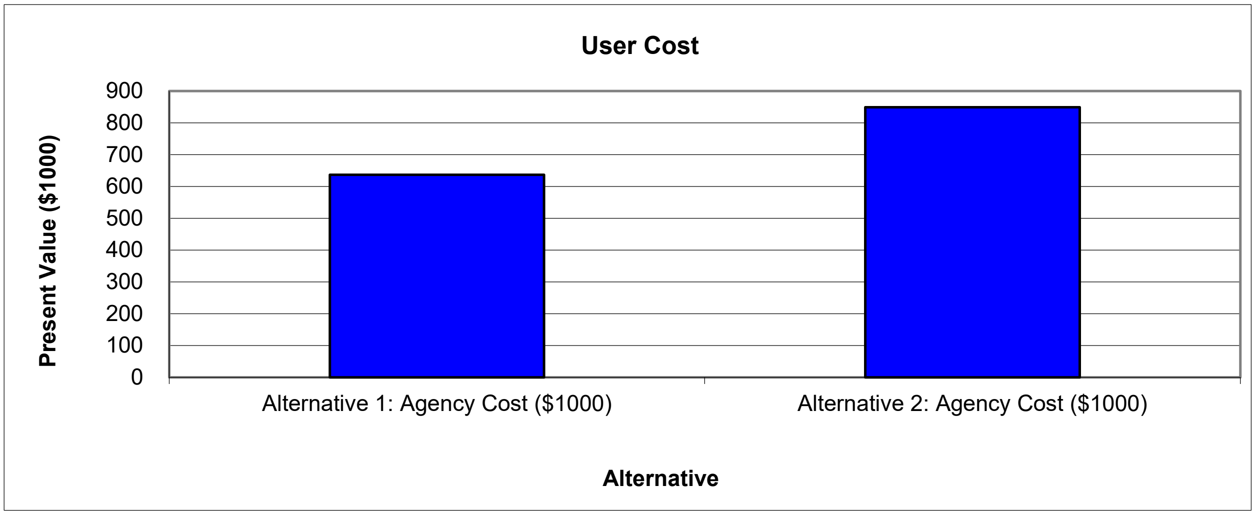
Table 37. Deterministic results—rural reconstruction/widening (2/2).

Description	Alternatives
Lowest NPV agency cost	Alternative 1: HMA
Lowest NPV user cost	Alternative 1: HMA



Source: FHWA.

Figure 55. Graph. Present value agency costs—rural reconstruction/widening.



Source: FHWA.

Figure 56. Graph. Present value of user costs—rural reconstruction/widening.

Probabilistic Results

Analysis 3A

A probabilistic simulation was performed using 2,500 iterations. The simulation converged after 650 iterations with a final convergence error of 2.28 percent (computational time is 367 s[3]). The resulting agency and user costs are summarized in table 38. This table contains the mean, standard deviation, minimum, and maximum agency and user costs for both alternatives. The agency cost means from the probabilistic analysis are very similar to the deterministic analysis' present value.

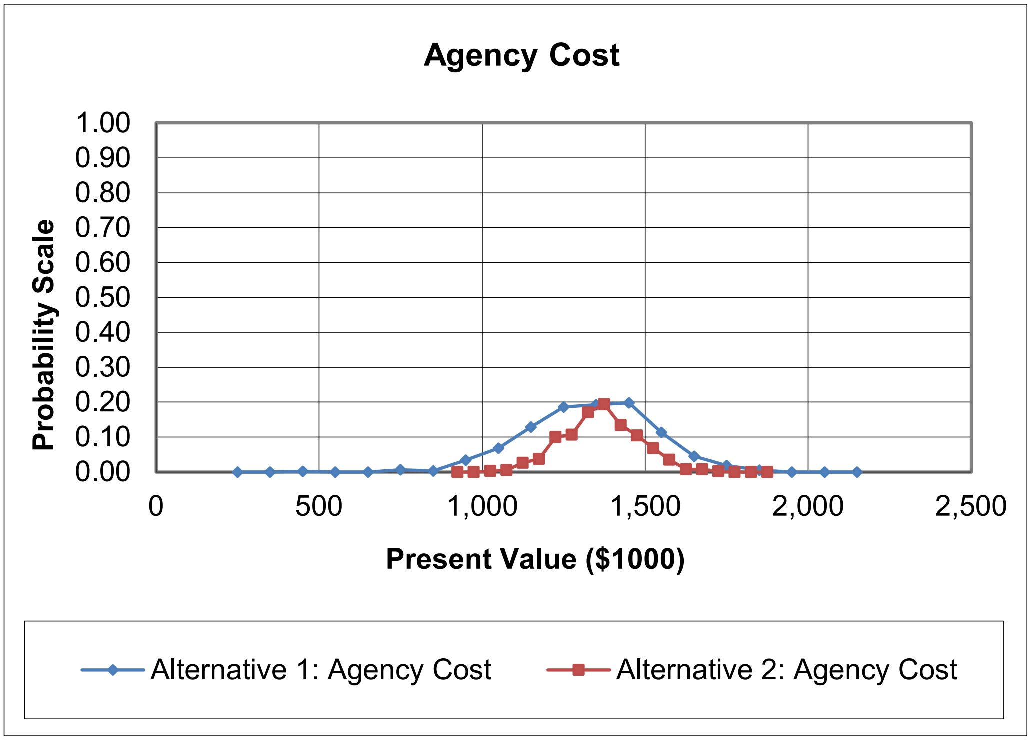
Table 38. Probabilistic results—rural reconstruction/widening.

Total Cost (Present Value)	Alternative 1: HMA Pavement Cost ($1,000)	Alternative 1: HMA Pavement User Cost ($1,000)	Alternative 2: PCC Pavement Agency Cost ($1,000)	Alternative 2: PCC Pavement User Cost ($1,000)
Mean	1,328.74	616.63	1,363.57	841.13
Standard deviation	190.86	70.68	114.42	79.85
Minimum	484.00	436.38	1,029.30	665.60
Maximum	1,825.83	847.57	1,700.83	1,061.68

Frequency and cumulative probability distribution curves are shown in figure 57 through figure 60. In these figures, the mean present value of both the agency cost and the user cost is lower for the HMA alternative than the PCC alternative. However, because of the higher

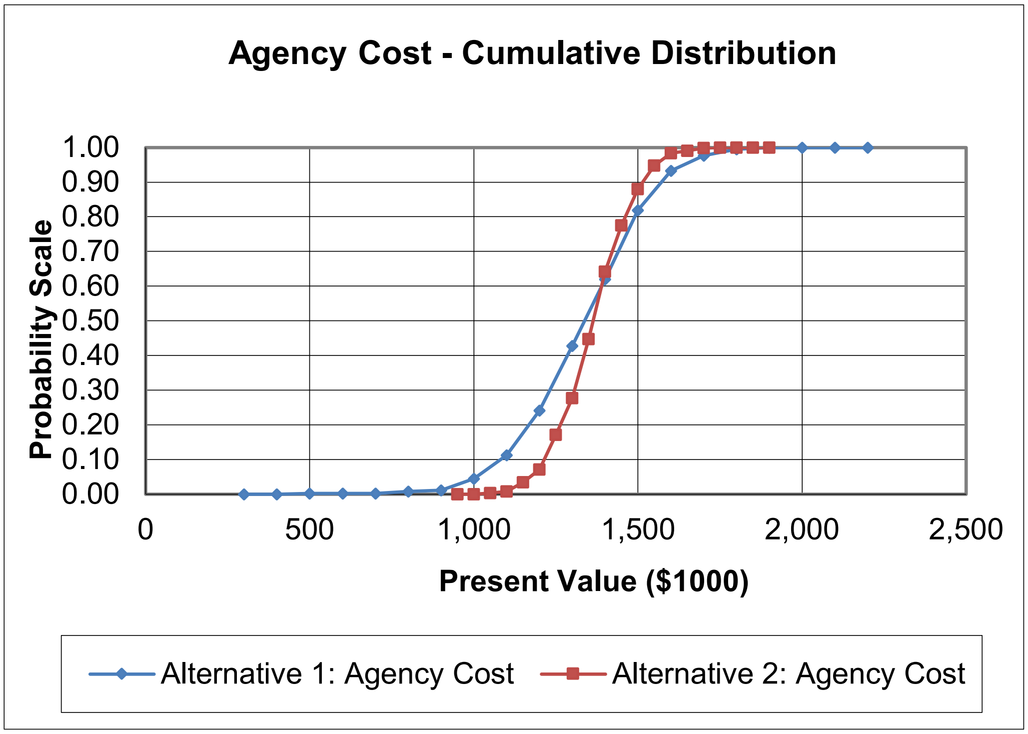
[3]The computation time may vary, depending on users' computer hardware and software.

variability of the agency cost of the HMA alternative, the PCC alternative has a lower agency cost than the HMA alternative at the 90 to 100 percent probability level (figure 58). Concerning lifecycle user costs, those of the HMA alternative are considerably lower than the PCC alternative at all probability levels.



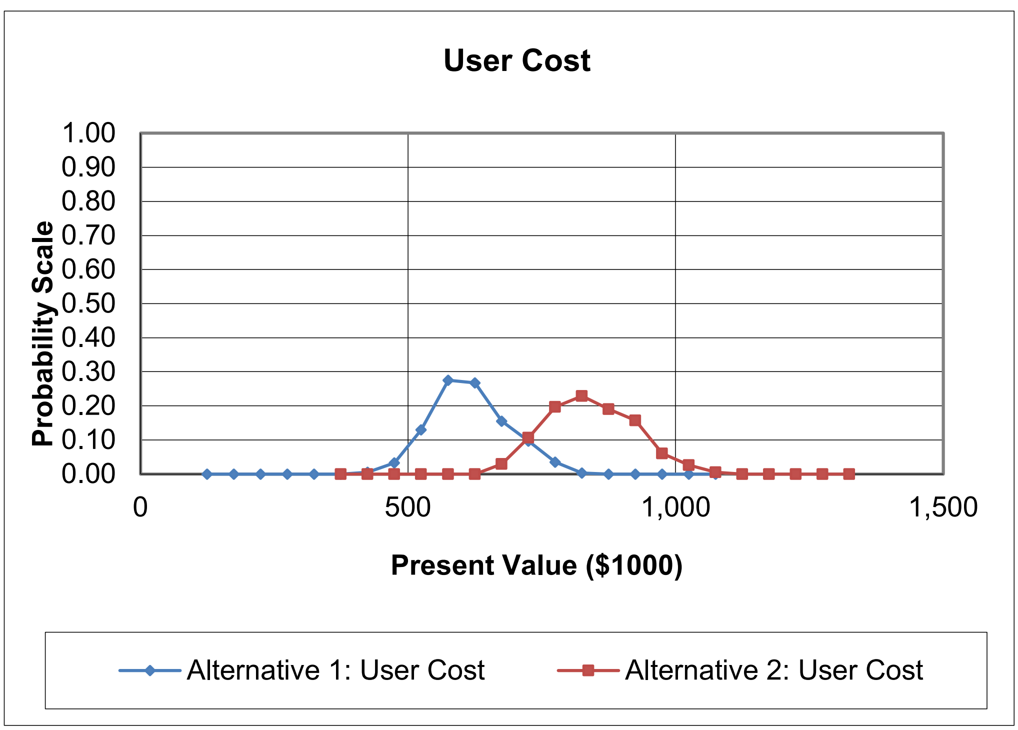
Source: FHWA.

Figure 57. Graph. Probability distribution of agency costs—rural reconstruction/widening.



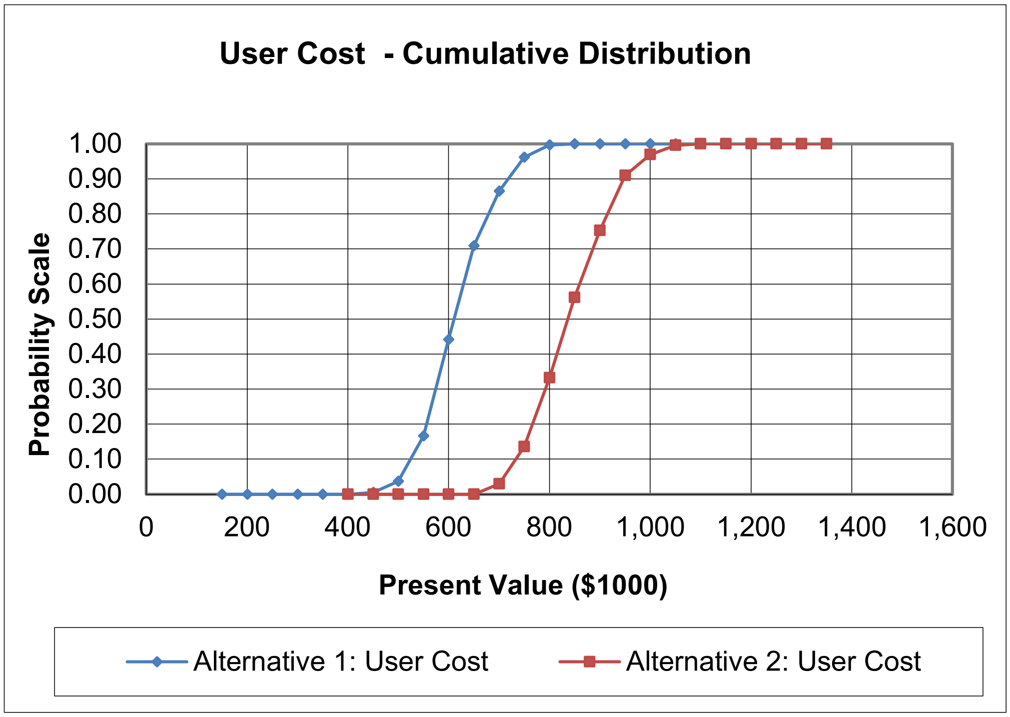
Source: FHWA.

Figure 58. Graph. Cumulative probability distribution of agency costs—rural reconstruction/widening.



Source: FHWA.

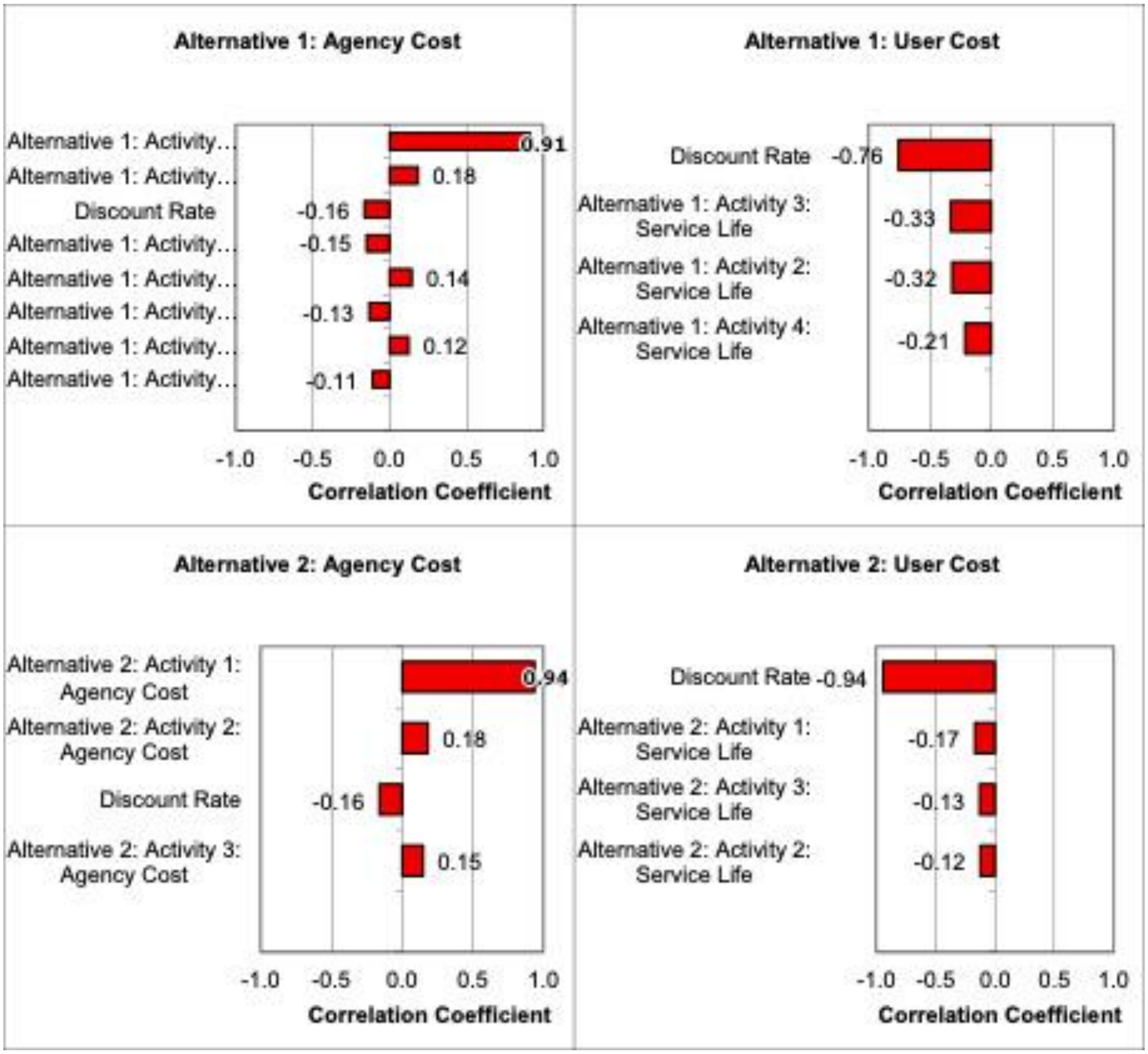
Figure 59. Graph. Probability distribution of user costs—rural reconstruction/widening.



Source: FHWA.

Figure 60. Graph. Cumulative probability distribution of user costs—rural reconstruction/widening.

The results of the tornado analyses are summarized in figure 61. As seen in this figure, the most dominant input for the present value of agency costs is the initial construction cost, which has a correlation of 0.91 and 0.94 for alternatives 1 and 2. Concerning user costs, the main driver is the discount rate, which has a correlation of -0.76 and −0.94 for alternatives 1 and 2.



Source: FHWA.

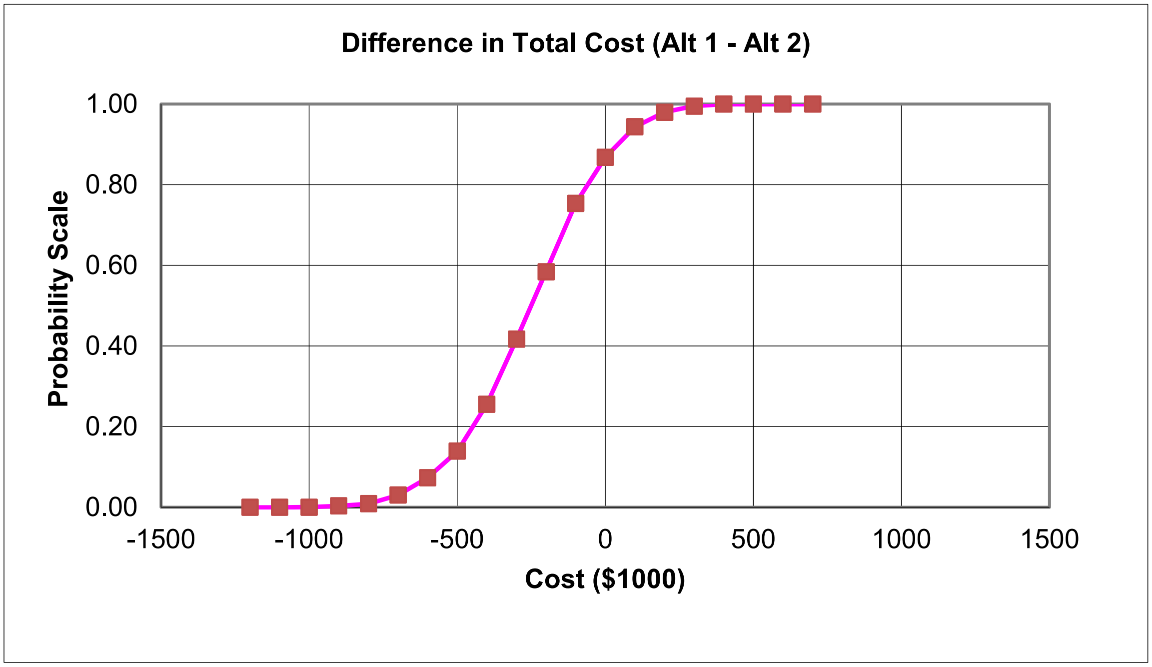
Figure 61. Screenshot. Tornado graphs—rural reconstruction/widening.

Analysis 3B

A new worksheet was inserted into the workbook to demonstrate the user-defined outputs, and three outputs were defined for the differences in the total cost, agency cost, and user cost. The simulation was formed using 2,500 iterations. The simulation converged after 1,400 iterations with the final error of 2.20 percent (computation time is 795 s[4]). Figure 62 through figure 64 show the cumulative probabilistic difference distribution for the total, agency, and user costs, respectively. As shown in figure 62, 85 percent of the simulation outcomes for alternative 1 are less than Alternative 2. Similarly, comparing agency and user costs, the simulation outcomes for

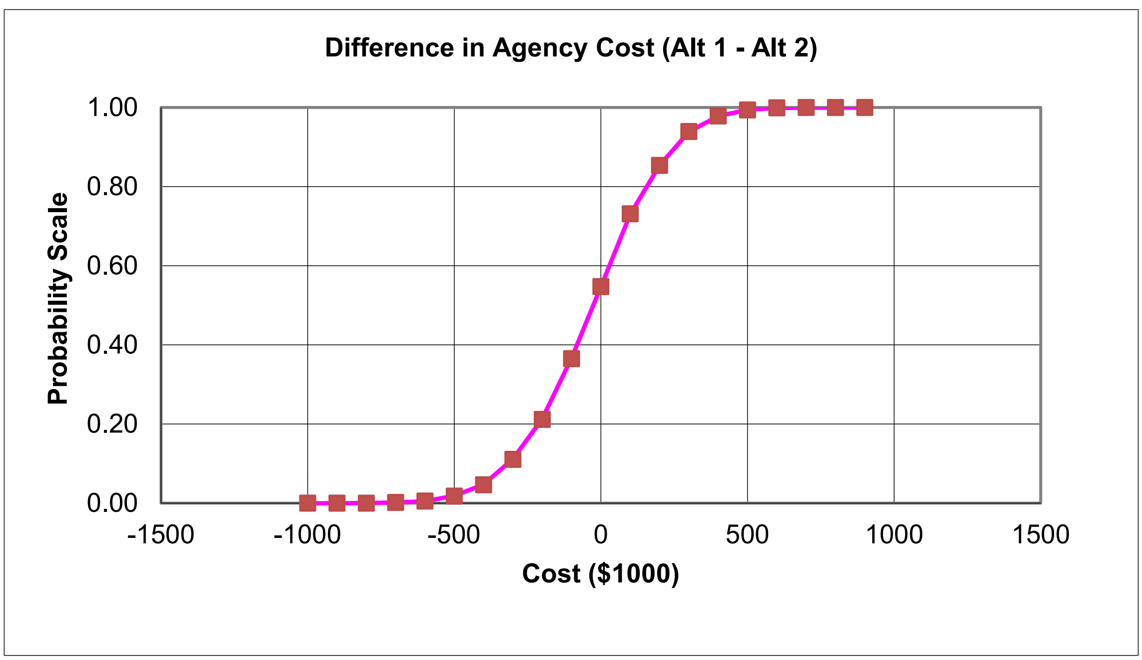
[4]The computation time may vary, depending on users' computer hardware and software.

Alternative 1 are less than Alternative 2, 55 percent for agency costs and 100 percent for user costs.



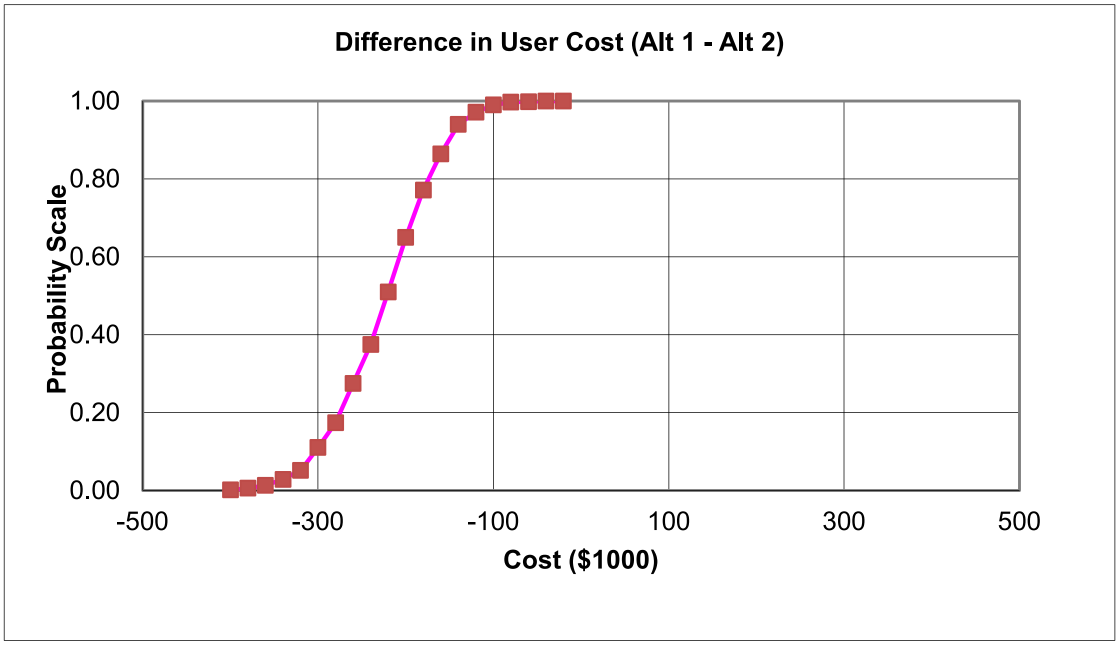
Source: FHWA.

Figure 62. Graph. Cumulative probability distribution difference—total costs.



Source: FHWA.

Figure 63. Graph. Cumulative probability distribution difference—agency costs.



Source: FHWA.

Figure 64. Graph. Cumulative probability distribution difference—user costs.

Preferred Alternative

Deterministic LCCA results clearly indicate that the HMA alternative is preferred concerning agency and user costs. Probabilistic LCCA results also favor the HMA alternative, even though for high probability levels for agency costs, the PCC alternative has the edge over the HMA alternative. The substantially higher user costs for the PCC alternative over the entire probability range greatly diminish this edge.

For the preceding examples, the total agency cost was inserted into RealCost as a single value (mean and standard deviation) for each new construction and future rehabilitation treatment. However, RealCost has the flexibility to incorporate bid item tabulations that can be used for a more detailed analysis. For example, a relational database or worksheet that includes unit bid item costs can be developed and used within RealCost. In this manner, the impact (mean and standard deviation) of single-bid items can be analyzed. For example, figure 65 shows an example of a bid-item tabulation worksheet that can be used in the calculation of agency costs for construction or rehabilitation activities. In this figure, the SHA determines the mean and standard deviation of each bid item (which can be based on the bid tabulations from statewide, regional, or local projects) and includes the applicable probabilistic equation in the unit price column. Each cell shown in the unit price column will need to be established as a RealCost Output.

ID	Bid Item	Unit	Mean	StdDev	Unit Price
1	Mobilization	Est	10%	1.0%	10%
2	Planing Bituminous Pavement	SY	$2	$0.2	$2
3	Cement Concrete Pavement Grinding	SY	$9	$0.9	$9
4	Roadway Excavation Including Haul	CY	$9	$0.9	$9
5	Crushed Surfacing Base Course	Ton	$11	$1.1	$11
6	Asphalt For Fog Seal	Ton	$400	$40.0	$400
7	Crack Sealing	FA	$2,000	$200.0	$2,000
8	Asphalt for Tack Coat	Ton	$185	$18.5	$185
9	Anti Stripping Additive	Est	$1	$0.1	$1
10	HMA CL 1/2" PG 64-22	Ton	$60	$6.0	$60
11	HMA CL 3/4" PG 64-22	Ton	$90	$6.0	$90
12	Compaction Price Adjustment	Est	2%	0.2%	2%
13	Job Mix Compliance	Est	3%	0.3%	3%
14	Cement Concrete Pavement	CY	$125	$12.5	$125
15	Stainless Steel Type Dowel Bars	Each	$17.00	$1.7	$17.00
16	Ride Smoothness Compliance Adjustment	Est	4%	0.4%	4%
17	Longitudinal Joint Seal	LF	$2.00	$0.20	$2.00
18	Clean and Sealing Random Crack	LF	$11.00	$1.10	$11.00
19	Sealing Transverse and Longitudinal Joints	LF	$1.50	$0.15	$1.50

=@LCCATNORMAL (D11,E11,D11-3*E11, D11+3*E11)

Source: FHWA.
CL = class; CY = cubic yard; Est = estimate; FA = force account; LF = linear feet; PG = performance grade; SY = square yard.

Figure 65. Screenshot. Example worksheet containing bid item cost data.

Figure 66 shows an inserted worksheet for calculating agency construction costs using the bid item cost data. Since RealCost is an Excel-based tool, an SHA can customize it to include a wide array of analyses.

With the added flexibility of including bid items, an SHA can conduct a more critical review of the associated material costs. For example, figure 67 illustrates a tornado graph for a PCC initial construction alternative, which shows that the PCC pavement and HMA costs have the highest effect on the probabilistic output. With this knowledge, an SHA would ensure that the costs for these two bid items are as accurate as possible (e.g., using local rather than statewide bid items).

Initial Construction

Year No: 0

Year: 2010

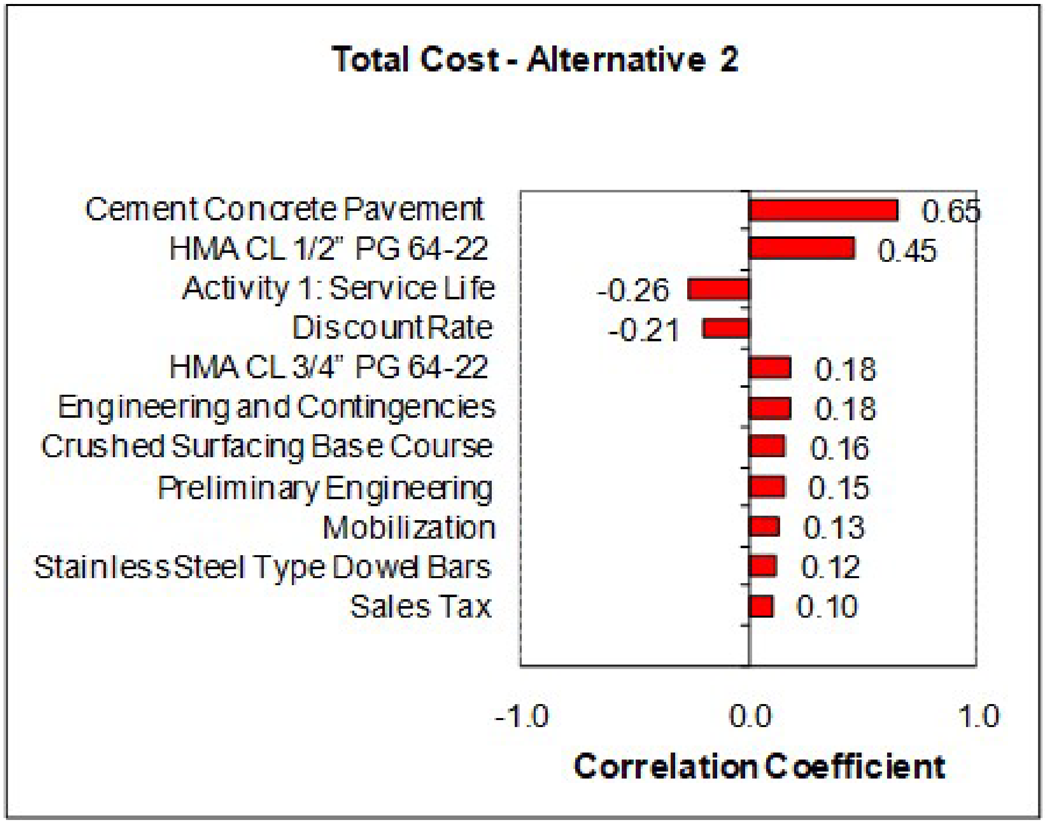
Title: HMA 8-YEAR REHAB CYCLE

Detail: New HMA Construction - Six 12' Lanes (1.10 ft HMA CL 1/2" PG 64-22, and 0.40 ft CSBC), Two 10' Right Shoulders and T

Quantity	Unit	Bid Item	Unit Price	Amount
41,170	Ton	Crushed Surfacing Base Course	$11	$452,870
39,768	Ton	HMA CL 1/2" PG 64-28	$60	$2,386,080
9	Ton	Asphalt for Tack Coat	$185	$1,665
39,768	Ton	Anti Stripping Additive	$1	$39,768
$1,724,877	2%	Compaction Price Adjustment (HMA CL 1/2" PG 64-28)	2%	$34,498
$2,386,080	3%	Job Mix Compliance (HMA CL 1/2" PG 64-28)	3%	$71,582
-	-	Traffic Control: Assume the construction time and traffic control resources ar	-	-
-	-	Construction and Traffic Control Subtotal	-	$2,986,463
-	-	Mobilization (5% of Items Subtotal)	-	$298,646
-	-	Contract Items Subtotal (Items Incl Mobilization)	-	$3,285,109
-	-	Sales Tax (8.4% of Contract Items Subtotal)	-	$275,949
-	-	Contract Subtotal (Contract Items Incl Sales Tax)	-	$3,561,058
-	-	Engineering and Contingencies (15% of Contract Subtotal)	-	$534,159
-	-	Total Construction Subtotal (Contract Incl Engineering and Contingencies)	-	$4,095,217
-	-	Preliminary Engineering (10% of Total Construction Subtotal)	-	$409,522
-	-	Total Project Cost (Total Construction Incl Preliminary Engineering)	-	$4,504,739

Source: FHWA.
-No data.
PCCP = portland cement concrete pavement.

Figure 66. Screenshot. Example worksheet for calculating activity cost from bid item costs.



Source: FHWA.

Figure 67. Chart. Example tornado chart including bid items.

EXAMPLE 4: BRIDGE LCCA EXAMPLE—REPLACEMENT OF RURAL BRIDGES

This bridge LCCA example demonstrates a case where there is a need to replace two 65-yr-old conventional concrete bridges over a stream on a four-lane divided highway in a mostly rural location. The existing bridges are 320 ft long (made up of four 80-ft spans) with decks that are 44 ft wide (two 12-ft-wide lanes with 10-ft-wide inside and outside shoulders).

For this project, engineers have developed two different 80-yr life bridge designs for the replacement bridges. Design Alternative 1 uses a conventional steel bridge superstructure with a composite pavement deck of an 8-inch reinforced PCC layer, a waterproof membrane, and a 2.5-inch dense-graded asphalt wearing surface. Design Alternative 2 consists of a prestressed concrete superstructure with a similar 8-inch reinforced PCC layer for the deck *without* the waterproof membrane and asphalt wearing surface. While the engineers have determined that the footings for the existing piers and end abutments are adequate to carry the loads associated with either of the new bridge designs, deterioration of the concrete in the existing piers and abutments requires those substructure components to be reconstructed. However, the replacement piers and abutments will be designed and reconstructed to be adequate to carry loads of either chosen superstructure design.

The two bridge designs will be evaluated on a probabilistic lifecycle cost basis using an 80-yr analysis period (a deterministic analysis will also be performed). Each alternative's lifecycle cost computations are based on the estimated agency costs for initial construction, rehabilitation, maintenance costs, and user costs computed using actual traffic conditions and an assumed 1-mi-long work zone during initial construction and rehabilitation activities. A triangular distribution is assumed for the discount rate, with the minimum, most likely, and maximum values being 0.4, 1.4, and 2.3 percent, respectively.

LCCA Inputs

The following summarizes the RealCost inputs related to traffic, bridge deck performance, agency costs, and work zone user costs.

Traffic

The following list contains the traffic data inputs to be used in the simulation. The inputs include the base year AADT, the traffic growth rate estimate, and the percent of automobiles and trucks:

- Initial AADT (both directions)—20,010 vpd.
- Traffic growth rate—1.15 percent.
- Percent automobiles—87 percent.
- Percent trucks—13 percent (9 percent single units and 4 percent combination units).

Bridge Structure Performance and Activity Timing

The service life of each proposed initial structure and projected rehabilitation was estimated using historical pavement performance data on similar bridge designs in the vicinity of the project. Historical data indicates that the HMA wearing surface on the conventional steel bridge will need to be replaced approximately every 13 yr to protect the steel superstructure adequately. The historical data indicates that the PCC surface layer on the prestressed concrete option will most likely require CPR of about 10 percent of the bridge deck area every 20 yr during its lifecycle. For probabilistic simulation, a normal distribution will be applied to the timings of these future rehabilitation treatments. A summary of the initial construction details, future rehabilitation, and future maintenance activities (and their expected service lives) associated with conventional steel structure bridge design and prestressed concrete structure bridge design alternatives are provided in table 39 and table 40, respectively.

Table 39. Summary of activities and service life—rural bridge replacement—Alternative 1: Conventional Steel Structure Bridge Design.

Activity	Pavement Structure	Service Life Years[a] (Mean)	Service Life Years[a] (Standard Deviation)
New construction	Superstructure: five conventional steel I-beam girders spaced at 9.75 ft on center. Composite bridge deck: 8.0 in PCC deck with a 2.5 dense-graded HMA wearing surface and waterproof membrane. Substructure and foundation: Replacement of existing piers and abutments.	13.0[b]	1.2
Rehabilitations 1 through 6	Mill and replace 2.5-inch HMA deck-wearing surface. (It is assumed that the HMA deck-wearing surface will be replaced up to six times during the 80-yr design life of the bridge.)	13.0	1.2
Maintenance 1	Biannual inspection of bridge components.	2.0	n/a
Maintenance 2	Painting of steel bridge superstructure every 15 yr.	15.0	n/a

[a]Normal probability distribution assumed.
[b]The initial construction service life for Alternative 1 is set to 13 yr, the most likely age at which the composite deck surface will first need to be removed and replaced.

Table 40. Summary of activities and service life—rural bridge replacement—Alternative 2: Prestressed Concrete Structure Bridge Design.

Activity	Pavement Structure	Service Life Years[a] (Mean)	Service Life Years[a] (Standard Deviation)
New construction	Superstructure: five prestressed concrete beam girders spaced at 9.67 ft on center. Composite bridge deck: 8.0 in PCC deck. Substructure and foundation: Replacement of existing piers and abutments.	20.0[b]	3.1
Rehabilitations 1 and 2	CPR—Patching of 10 percent of the PCC deck surface. (It is assumed that this PCC CPR will need to be completed approximately every 20 yr during the first half of the 80-yr bridge design life.)	20.0	3.1
Rehabilitations 3 and 4	CPR and HMA overlay—Patching of 10 percent of the PCC deck surface, followed by a 2.5-inch thick HMA overlay. (It is assumed that this CPR/overlay combination will need to be completed approximately every 20 yr during the second half of the 80-yr bridge design life.)	20.0	3.1
Maintenance 1	Biannual inspection of bridge components.	2.0	N/A

[a]Normal probability distribution assumed.
[b]The initial construction service life for Alternative 2 is set to 20 yr, the most likely age at which the PCC deck surface will require CPR.

Agency Costs

The agency costs required for the LCCA of these two different bridge design alternatives include the initial construction costs, future rehabilitation needs, and routine scheduled maintenance (inspection and painting). Using estimated quantities and historical unit cost data for these actions and all associated traffic control costs, mobilization costs, and engineering costs, the estimated costs for each action were computed and expressed in terms of means and standard deviations (normal probability distribution).

The time-series maintenance cost stream for both bridge designs include the cost of an inspection every 2 yr starting at year 2 (i.e., at years 2, 4, 6, and so on). The estimated cost of this biannual inspection of both bridges is $2,000 per inspection. For the conventional steel design, there is an additional maintenance cost associated with repainting the superstructure every 15 yr starting at year 15 (i.e., at years 15, 30, 45, and so on). Each repainting event's cost is estimated to be $134,000 (the cost of repainting both bridges). The details of the maintenance cost computations for both design alternatives are summarized in table 41 and table 42. A complete summary of the agency costs used for this bridge LCCA example is presented in table 43 and table 44.

Table 41. Summary of maintenance costs—rural bridge replacement—Alternative 1: Conventional Steel Structure Bridge Design.

Maintenance Activity	Cost Description	Costs ($[a])
Biannual inspections of bridge components (starting at year 2) and superstructure painting every 15 yr (starting at year 15). 40 inspections x $2,000 per inspection = $80,000 Painting at Year 15 = $134,000 Painting at Year 30 = $134,000 Painting at Year 45 = $134,000 Painting at Year 60 = $134,000 Painting at Year 75 = $134,000	Total of estimated time-series maintenance costs	750,000
Biannual inspections of bridge components (starting at year 2) and superstructure painting every 15 yr (starting at year 15). 40 inspections x $2,000 per inspection = $80,000 Painting at Year 15 = $134,000 Painting at Year 30 = $134,000 Painting at Year 45 = $134,000 Painting at Year 60 = $134,000 Painting at Year 75 = $134,000	Present worth of estimated time-series maintenance costs	181,918

[a]The present worth costs are computed using a 4 percent interest rate and an 80-yr analysis period.

Table 42. Summary of maintenance costs—rural bridge replacement—Alternative 2: Prestressed Concrete Structure Bridge Design.

Maintenance Activity	Cost Description	Costs ($[a])
Biannual inspections of bridge components (starting at year 2). 40 inspections x $2,000 per inspection = $80,000	Total of estimated time-series maintenance costs	40,000
Biannual inspections of bridge components (starting at year 2). 40 inspections x $2,000 per inspection = $80,000	Present worth of estimated time-series maintenance costs	23,446

[a]The present worth costs are computed using a 4 percent interest rate and an 80-yr analysis period.

Table 43. Agency unit cost input values—bridge LCCA example—Alternative 1: Conventional Steel Structure Bridge Design.

Bridge Structure/Treatment/Maintenance Activity	Activity Unit Cost Distributions ($[a]) (Mean)	Activity Unit Cost Distributions ($[a]) (Standard Deviation)
Initial Construction: Superstructure: five conventional steel I-beam girders spaced at 9.75 ft on center. Composite bridge deck: 8.0-inch PCC deck with a 2.5 dense-graded HMA wearing surface. Substructure and foundation: Replacement of existing piers and abutments.	2,749,000	274,900
Rehabilitations 1–6: mill and replace 2.5-inch HMA deck-wearing surface. (It is assumed that the deck-wearing surface will be replaced up to six times during the 80-yr design life of the bridge.)	29,990	2,999
Biannual inspections of bridge components starting at year 2.	2,000	200
Superstructure painting every 15 yr (starting at year 15).	134,000	13,400

[a]Note: The cost distributions presented in this table are unit costs of the different activities expressed in today's dollars (2020). Also, note that a normal probability distribution is assumed for each of these cost distributions.

Table 44. Agency unit cost input values—bridge LCCA example—Alternative 2: Prestressed Concrete Structure Bridge Design.

Bridge Structure/Treatment/Maintenance Activity	Activity Unit Cost Distributions ($[a]) (Mean)	Activity Unit Cost Distributions ($[a]) (Standard Deviation)
Initial Construction: Superstructure: five prestressed concrete beam girders spaced at 9.67 ft on center. Composite bridge deck: 8.0-inch PCC deck. Substructure and foundation: Replacement of existing piers, abutments.	3,044,600	304,460
Rehabilitations 1–4: CPR—patching of the PCC deck surface.	39,400	3,940
Biannual inspections of bridge components (starting at year 2).	2,000	200

[a]Note: The cost distributions presented in this table are unit costs of the different activities expressed in today's dollars (2020). Also, note that a normal probability distribution is assumed for each of these cost distributions.

Work Zone User Costs

During the initial construction of a single replacement bridge, traffic is assumed to be temporarily rerouted to the adjacent bridge via temporary pavements crossing over the median. During this temporary arrangement, traffic will be reduced to one lane in both directions. Work zone user costs will also be calculated for each future rehabilitation treatment applied. During future rehabilitation activities, each bridge's traffic will be reduced to one lane while the rehabilitation work is performed. Because the painting activities will be completed underneath the bridge, these activities will not require a work zone and will not impact traffic.

The total length of the work zone for both the initial construction project and future rehabilitation is expected to be 1 mi in length. The estimated work zone duration for both bridges' initial construction is estimated to be 360 d for the conventional steel bridge and 340 d for the prestressed concrete bridge. Both initial construction durations are assumed to have a standard deviation of 15 d. For the rehabilitation activities, the estimated work zone durations are represented by triangular distributions. For the HMA resurfacing, the distribution is defined as having a minimum of 4 d, a most-likely duration of 5 d, and a maximum of 6 d. For the CPR activities, the distribution is defined as having a minimum of 3 d, a most-likely duration of 4 d, and a maximum of 5 d. During these rehabilitation activities, the work zone is expected to be active 24 h a day (i.e., one lane of traffic in each direction will be closed during the work activity duration). Table 45 summarizes each work zone's key aspects and lists the values of time for the three-vehicle types.

Table 45. Work zone details—rural bridge replacement.

Detail	Alternative 1: Conventional Steel Bridge Design—Initial Construction	Alternative 1: Conventional Steel Bridge Design—Rehab–HMA Resurfacing	Alternative 2: Prestressed Concrete Bridge Design—Initial Construction	Alternative 2: Prestressed Concrete Bridge Design—Rehab–CPR
Work zone operation (one direction)	1 of 2 lanes open in both directions	1 of 2 lanes open in both directions	1 of 2 lanes open in both directions	1 of 2 lanes open in both directions
Approach speed (mph)	60	60	60	60
Work zone speed (mph)	40	40	40	40
Work zone hours of operation	24 h per day	24 h per day	24 h per day	24 h per day
Construction duration (d)	360	5	340	4
Value of time of passenger vehicles ($/h/vehicle)	13.96 (most likely) 12.00 (minimum) 16.00 (maximum)	13.96 (most likely) 12.00 (minimum) 16.00 (maximum)	13.96 (most likely) 12.00 (minimum) 16.00 (maximum)	13.96 (most likely) 12.00 (minimum) 16.00 (maximum)
Value of time of single-unit trucks ($/h/vehicle)	22.34 (most likely) 20.00 (minimum) 24.00 (maximum)	22.34 (most likely) 20.00 (minimum) 24.00 (maximum)	22.34 (most likely) 20.00 (minimum) 24.00 (maximum)	22.34 (most likely) 20.00 (minimum) 24.00 (maximum)
Value of time of combination trucks ($/h/vehicle)	26.89 (most likely) 25.00 (minimum) 29.00 (maximum)	26.89 (most likely) 25.00 (minimum) 29.00 (maximum)	26.89 (most likely) 25.00 (minimum) 29.00 (maximum)	26.89 (most likely) 25.00 (minimum) 29.00 (maximum)

Additional inputs established for the computation of work zone user costs are as follows:

- Free-flow capacity—2,066 vphpl (based on the 1994 *Highway Capacity Manual* (TRB 1994)).
- Queue dissipation capacity—1,818 passenger cars per lane per h (for all rehabilitation activities).
- Maximum AADT (two-way)—140,000 vpd.
- Maximum queue length—2.0 mi.
- Work zone capacity—1,340 vphpl.

Lifecycle Cost Computation

Both deterministic- and probabilistic-based LCCAs were performed, the results of which are described in the following sections.

Deterministic Results

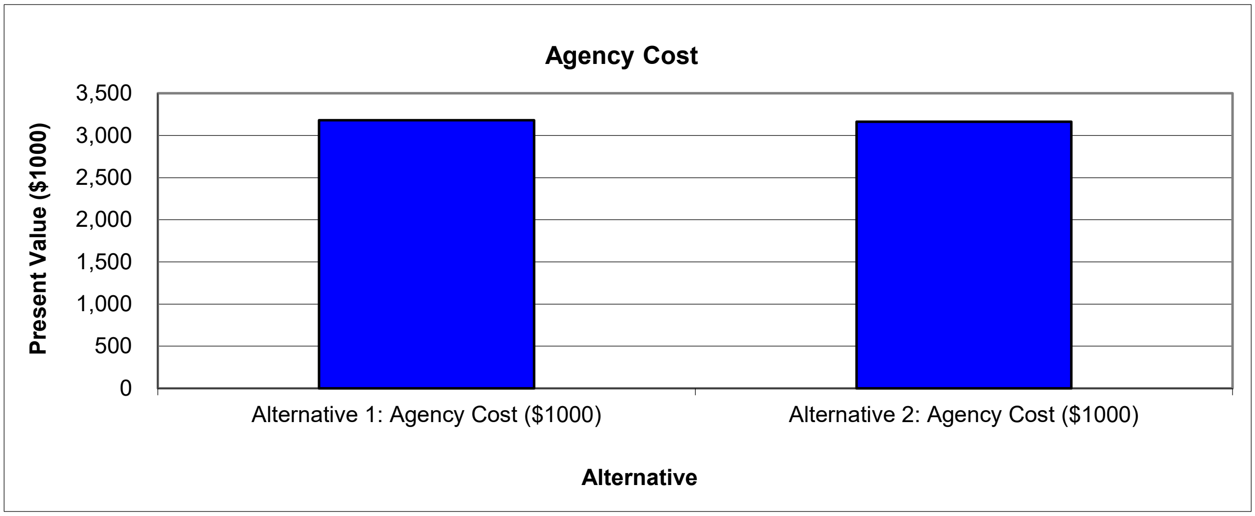
Table 46 presents the results of the deterministic analysis. Both the agency costs and user costs for each of the two alternatives are listed in NPV and EUAC. Figure 68 and figure 69 provide graphical displays of the NPV results. Based on the input values described previously, the prestressed concrete bridge design alternative resulted in the lowest agency lifecycle cost (approximately $18,000 (0.6 percent) less than the agency costs for the conventional steel bridge design alternative). Although the conventional steel design had lower initial construction costs, it had higher maintenance costs and more scheduled rehabilitation events than the prestressed concrete design alternative, resulting in a higher agency lifecycle cost. Table 47 provides a description for the alternatives considered within the deterministic analysis.

Table 46. Deterministic LCCA results—rural bridge replacement (1/2).

Total Cost	Alternative 1: Conventional Steel Bridge Design Agency Cost ($1,000)	Alternative 1: Conventional Steel Bridge Design User Cost ($1,000)	Alternative 2: Prestressed Concrete Agency Cost ($1,000)	Alternative 2: Prestressed Concrete User Cost ($1,000)
NPV	3,182.32	2,229.72	3,164.49	1,884.47
EUAC	65.66	46.00	65.29	38.88

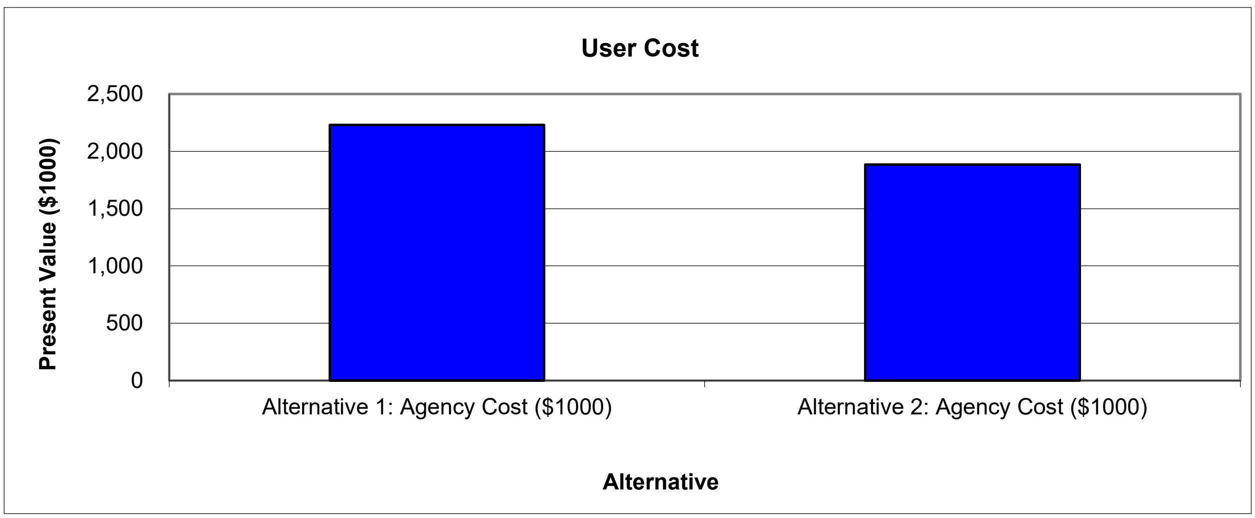
Table 47. Deterministic LCCA results—rural bridge replacement (2/2).

Description	Alternatives
Lowest NPV agency cost	Alternative 2: prestressed concrete bridge design
Lowest NPV user cost	Alternative 2: prestressed concrete bridge design



Source: FHWA.

Figure 68. Graph. Present value agency costs—rural bridge replacement.



Source: FHWA.

Figure 69. Graph. Present value user costs—rural bridge replacement.

Concerning user costs, the prestressed concrete design alternative resulted in the lowest total user lifecycle cost (approximately $345,000 (15 percent) less than the cost of the conventional steel design alternative). This result was not unexpected, as the conventional steel design had a longer initial construction duration and more scheduled rehabilitation over the 80-yr design life.

Probabilistic Results

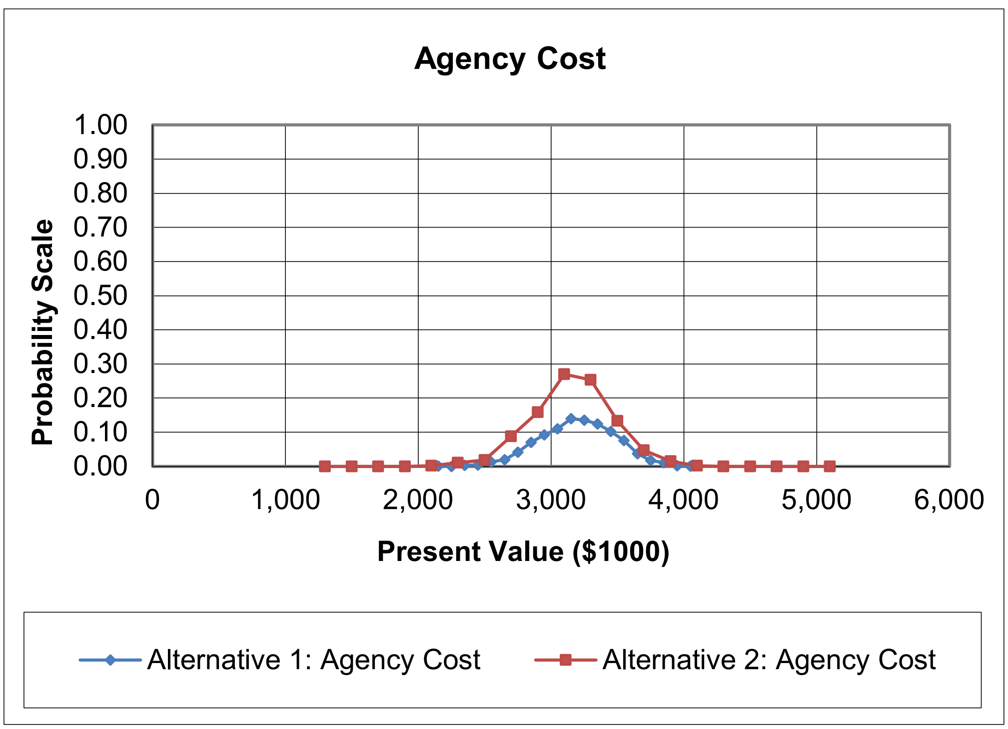
A probabilistic simulation was performed using 2,500 iterations. The simulation converges after 950 iterations with the final convergence error of 2.42 percent (computation time is 816 s[5]). The resulting agency- and user-cost NPV statistics (mean, standard deviation, minimum, maximum)

[5]The computation time may vary, depending on users' computer hardware and software.

are summarized in table 48. The frequency and cumulative distribution curves are illustrated in figure 70 through figure 73. The mean agency costs from the probabilistic analysis are very similar to the deterministic analysis values (table 48). The prestressed concrete design total agency cost mean is lower than the respective conventional steel design agency cost values. Also, the prestressed concrete design alternative has a similar lifecycle agency cost over the entire probability range.

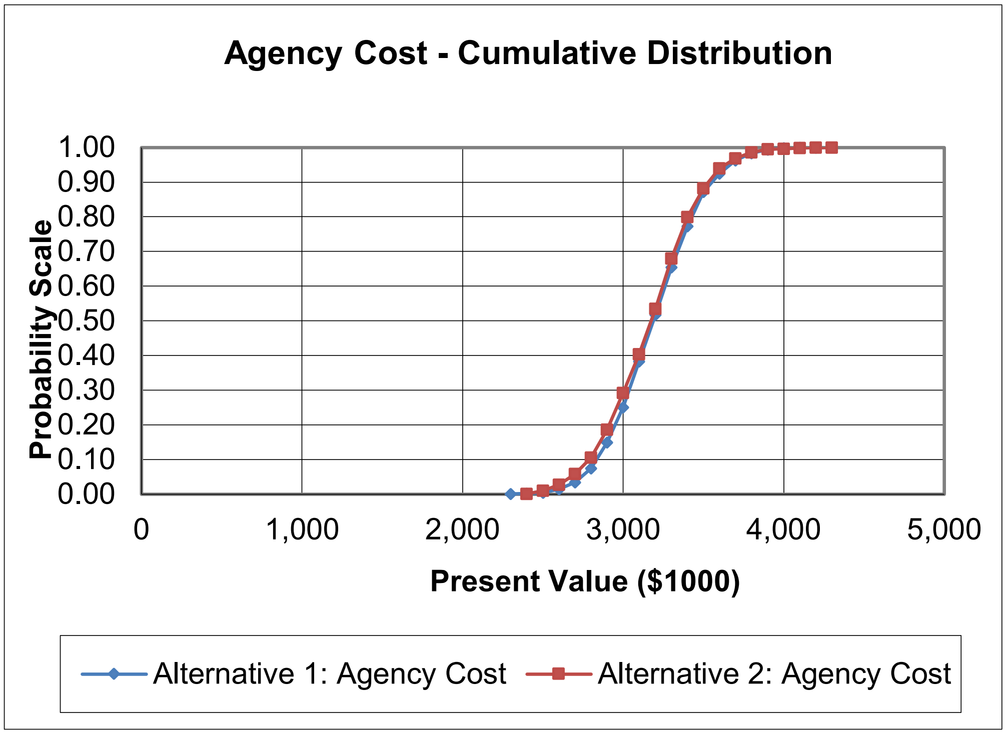
Table 48. Probabilistic LCCA results—rural bridge replacement.

Total Cost (Present Value)	Alternative 1 Conventional Steel Bridge Design Agency Cost ($1,000)	Alternative 1 Conventional Steel Bridge Design User Cost ($1,000)	Alternative 2 Prestressed Concrete Bridge Design Agency Cost ($1,000)	Alternative 2 Prestressed Concrete Bridge Design User Cost ($1,000)
Mean	3,196.38	2,238.63	3,156.19	1,906.77
Standard deviation	281.96	141.21	297.07	103.16
Minimum	2,159.45	1,887.63	2,156.61	1,649.63
Maximum	4,013.09	2,668.50	4,121.26	2,301.00



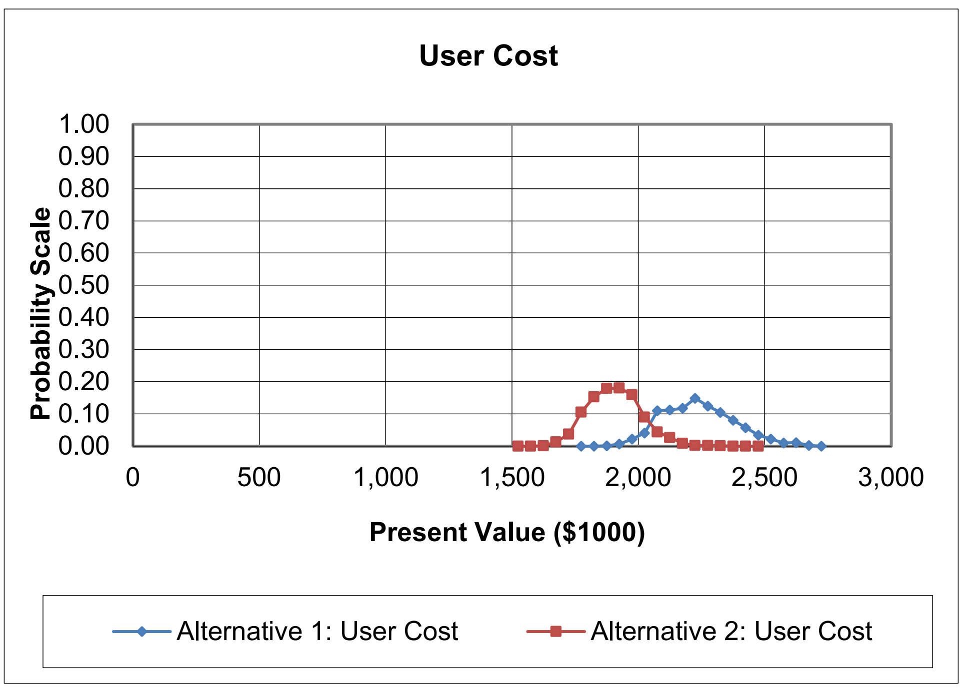
Source: FHWA.

Figure 70. Graph. Probability distribution of agency costs—rural bridge replacement.



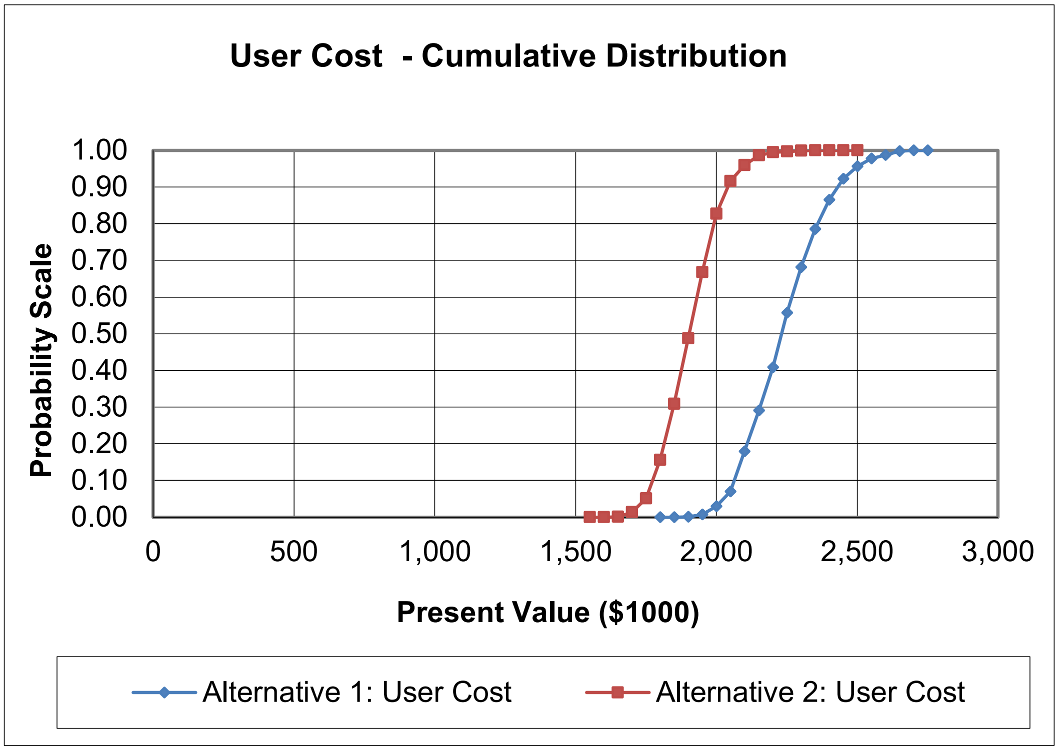
Source: FHWA.

Figure 71. Graph. Cumulative probability distribution of agency costs—rural bridge replacement.



Source: FHWA.

Figure 72. Graph. Probability distribution of user costs—rural bridge replacement.

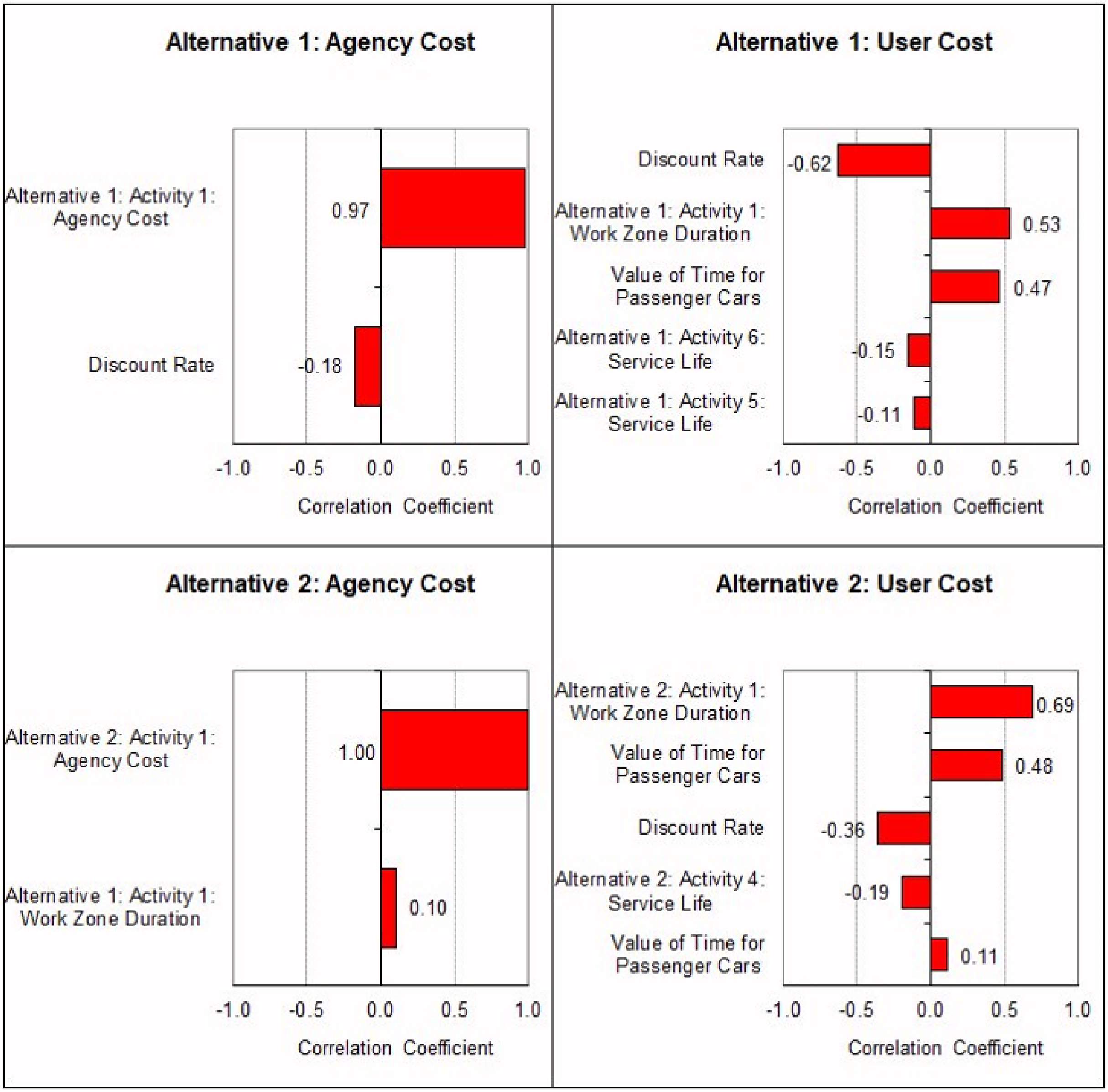


Source: FHWA.

Figure 73. Graph. Cumulative probability distribution of user costs—rural bridge replacement.

Similar to the agency cost results, a review of the user cost data shows that the prestressed concrete alternative has a lower user cost mean, while the standard deviation is also lower than the conventional steel alternative. The prestressed concrete design alternative has a lower lifecycle user cost over the entire probability range.

The results of tornado analyses are summarized in figure 74. As seen in this table, the key driver in the agency lifecycle costs is the initial construction activity cost, which has a correlation coefficient of 0.82 and 1.00 for Alternative 1 and Alternative 2. For user lifecycle costs, the discount rate, the duration of the initial construction activity, and the value of time for passenger cars are the key drivers for alternatives 1 and 2.



Source: FHWA.

Figure 74. Screenshot. Tornado graphs—rural bridge replacement.

Preferred Alternative

Although the results of both the deterministic and probabilistic analyses show that the lifecycle costs associated with the two alternatives are very close, both analyses indicate that the prestressed concrete design alternative yields the lowest total lifecycle cost. Thus, it would be considered the preferred option for the subject project on the sole basis of lifecycle costs. A final selection of an alternative would need to consider a variety of other monetary and nonmonetary factors.

APPENDIX B. CUSTOMIZATION OF REALCOST

RealCost was developed in Excel to enable the customization of the tool and meet the end users' specific requirements. The following sections showcase several relevant examples of such customization.

LINKING A COST ESTIMATION TEMPLATE

The following is an example of linking RealCost with an Excel-based cost estimation template. This example is an extension of the pavement LCCA Example 3—Rural Reconstruction and Widening in Appendix A.

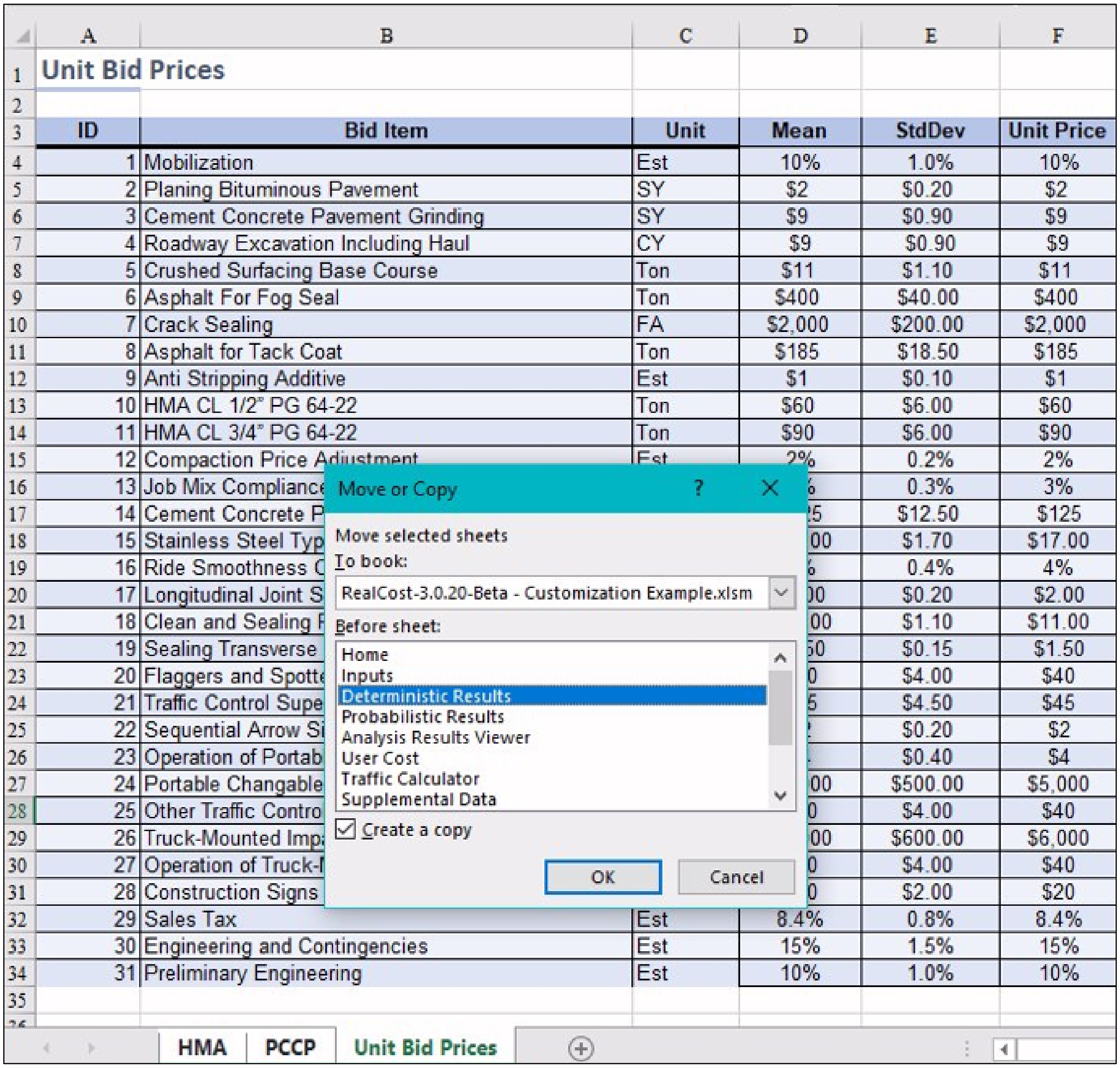
The RealCost program from the FHWA's LCCA website requires the agency cost as a deterministic or probabilistic input parameter (FHWA 2020). The procedure in the following paragraphs explains the customization procedure that will enable the user to include the bid price variability in the Agency Cost computation within the Probabilistic Analysis of the RealCost Program. This procedure uses a separate Excel workbook, Agency Cost.xlsx, consisting of three worksheets with the agency costs calculation to illustrate the steps. Users should walk through this process to learn the steps before using the cost estimation worksheet.

Except for the agency construction cost in each activity/alternative, all other RealCost software inputs can be entered following the earlier guidelines. The following steps will aid in incorporating the agency cost with the RealCost tool:

1. Open the RealCost workbook. Close the RealCost Switchboard and keep the workbook open.

2. Open the Agency Cost.xlsx workbook. Group all three agency cost computation worksheets by holding the control key and selecting all three worksheets (or right-clicking on the worksheet name tab and Select All Sheets).

3. Right-click on the worksheet group and select the Move or Copy… option. Move the sheets before the Deterministic Results worksheet in the RealCost.xlsm workbook (figure 75).



Source: FHWA.

Figure 75. Screenshot. Move the Agency Cost Computation Worksheet to the RealCost Program.

The contents of the new worksheets are explained in the following sections.

Unit Bid Prices

The Unit Bid Prices screen contains a list of bid items (figure 76) used in the computation of the Agency Cost for each activity/alternative. Each bid item is represented by its unit of measurement and mean and standard deviation observed in the past. The last column contains a formula to simulate the bid item based on the probabilistic distribution considered.

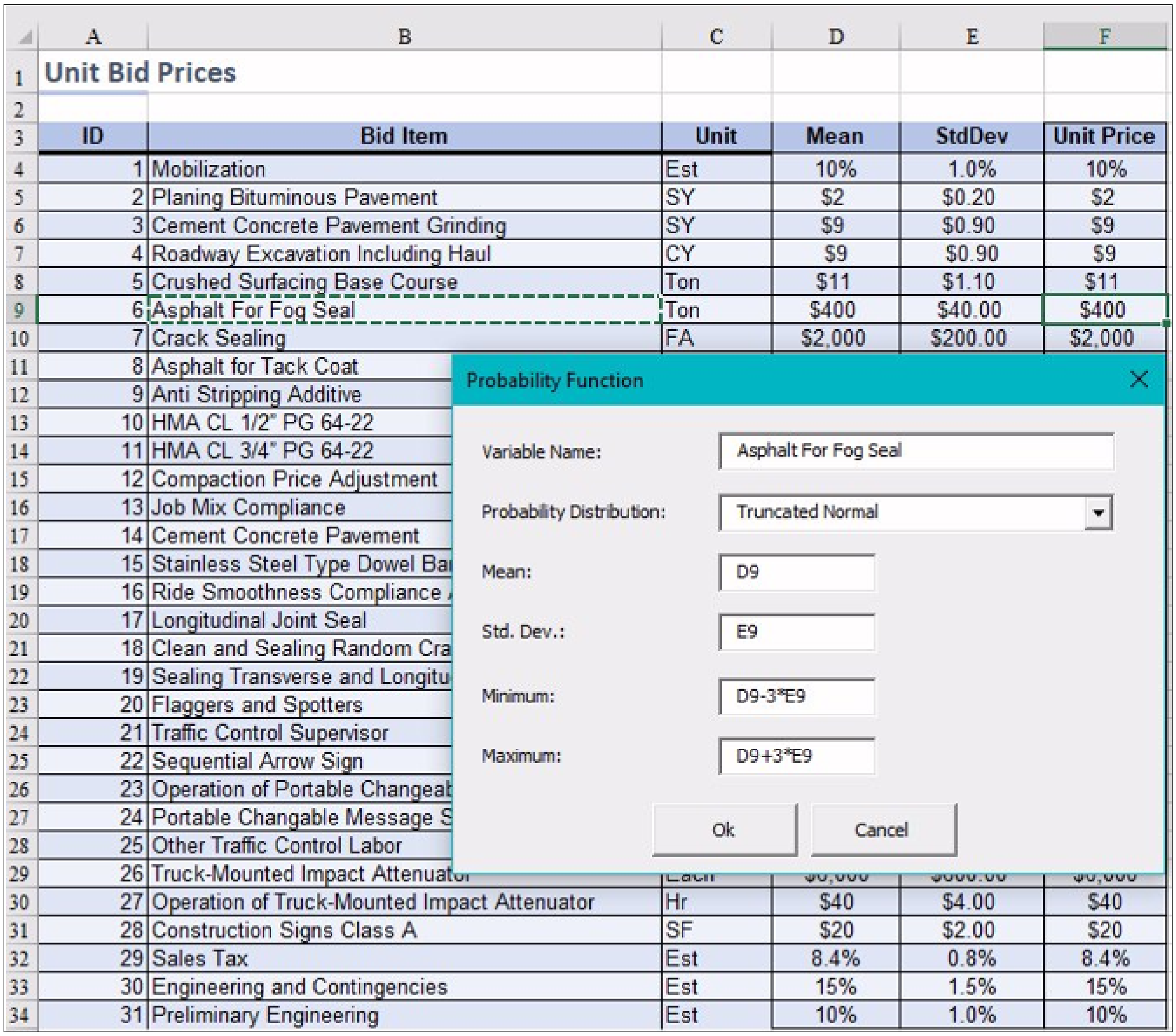
Unit Bid Prices

ID	Bid Item	Unit	Mean	StdDev	Unit Price
1	Mobilization	Est	10%	1.0%	10%
2	Planing Bituminous Pavement	SY	$2	$0.20	$2
3	Cement Concrete Pavement Grinding	SY	$9	$0.90	$9
4	Roadway Excavation Including Haul	CY	$9	$0.90	$9
5	Crushed Surfacing Base Course	Ton	$11	$1.10	$11
6	Asphalt For Fog Seal	Ton	$400	$40.00	$400
7	Crack Sealing	FA	$2,000	$200.00	$2,000
8	Asphalt for Tack Coat	Ton	$185	$18.50	$185
9	Anti Stripping Additive	Est	$1	$0.10	$1
10	HMA CL 1/2" PG 64-22	Ton	$60	$6.00	$60
11	HMA CL 3/4" PG 64-22	Ton	$90	$6.00	$90
12	Compaction Price Adjustment	Est	2%	0.2%	2%
13	Job Mix Compliance	Est	3%	0.3%	3%
14	Cement Concrete Pavement	CY	$125	$12.50	$125
15	Stainless Steel Type Dowel Bars	Each	$17.00	$1.70	$17.00
16	Ride Smoothness Compliance Adjustment	Est	4%	0.4%	4%
17	Longitudinal Joint Seal	LF	$2.00	$0.20	$2.00
18	Clean and Sealing Random Crack	LF	$11.00	$1.10	$11.00
19	Sealing Transverse and Longitudinal Joints	LF	$1.50	$0.15	$1.50
20	Flaggers and Spotters	Hr	$40	$4.00	$40
21	Traffic Control Supervisor	Hr	$45	$4.50	$45
22	Sequential Arrow Sign	Hr	$2	$0.20	$2

Source: FHWA.

Figure 76. Screenshot. Unit Bid Price Worksheet.

As in other input parameters in the RealCost program, a different probability distribution can be used to simulate the bid item. Select the Unit Price Cell of the Bid Item to be considered probabilistic. Execute the Probabilistic Input menu item from the Add-ins Excel menu. A window, as shown in figure 77, will pop up, and the required probabilistic characteristics can be entered. Instead of a probabilistic function, correlation with other bid items can be assigned in the Unit Price column. For example, 100 percent of the correlation is considered between bid item HMA Class (CL) 1/2" Performance Grade (PG) 64-22 and HMA CL 3/4" PG 64-22 in the given worksheet.



Source: FHWA.

Figure 77. Screenshot. Definition of the probabilistic distribution for the Bid Item "Asphalt for Fog Seal."

HMA (Alternative 1)

This worksheet contains the agency cost computation details for each activity of Alternative 1 (in this example, considered as HMA pavement). Each bid item (figure 78) in the activity is referred back to the corresponding unit price cell in the Unit Bid Prices worksheet.

	A	B	C	D	E	F
1	**Initial Construction**					
2	Age	0				
3	Year	2010				
4	Activity Title	HMA 8-YEAR REHAB CYCLE				
5	Activity Detail	New HMA Construction - Six 12' Lanes (1.10' HMA CL 1/2" PG 64-22, and 0.40' CSBC), Two 10' Right Shoulders and Two 10' Left Shoulders (0.50' HMA CL 1/2" PG 64-22, and 1.0' CSBC)				
6						
7	**Quantity**	**Unit**	**Bid Item**	**Unit Price**	**Amount**	**Notes**
8	-		**Construction Items**	-	-	-
9	41,170	Ton	Crushed Surfacing Base Course	$11	$452,870	-
10	39,768	Ton	HMA CL 1/2" PG 64-28	$60	$2,386,080	-
11	9	Ton	Asphalt for Tack Coat	$185	$1,665	-
12	39,768	Ton	Anti Stripping Additive	$1	$39,768	-
13	$1,724,877	2%	Compaction Price Adjustment (HMA CL 1/2" PG 64-28)	2%	$34,498	-
14	$2,386,080	3%	Job Mix Compliance (HMA CL 1/2" PG 64-28)	3%	$71,582	-
15	-	-	**Traffic Control**	-	-	-
16	-	-	Assume the construction time and traffic control resources are of equal value for both alternatives.	-	-	-
17	-	-	**Items Subtotal**	-	$2,986,463	-
18	-	-	Mobilization (5% of Items Subtotal)	-	$298,646	Use same value for PCCP Moblization
19	-	-	**Contract Items Subtotal (Items Incl Mobilization)**	-	$3,285,109	-
20	-	-	Sales Tax (8.4% of Contract Items Subtotal)	-	$275,949	Use same value for PCCP Sales Tax
21	-	-	**Contract Subtotal (Contract Items Incl Sales Tax)**	-	$3,561,058	-
22	-	-	Engineering and Contingencies (15% of Contract Subtotal)	-	$534,159	Use same value on PCCP Engineering and Contingencies
23	-	-	**Total Construction Subtotal (Contract Incl Engineering and Contingencies)**	-	$4,095,217	-
24	-	-	Preliminary Engineering (10% of Total Construction Subtotal)	-	$409,522	Use same value on PCCP Preliminary Engineering
25	-	-	**Total Project Cost (Total Construction Incl Preliminary Engineering)**	-	$4,504,739	-

Source: FHWA.

Figure 78. Screenshot. Agency Cost Computation with Simulated Variable.

The table at the end of the worksheet (figure 79) summarizes the Agency Cost for each activity. At each simulation, the unit price will be simulated based on the given probabilistic characteristics, and the table (figure 79) automatically recalculates the corresponding agency cost for the given activity.

	A	B	C	D	E
92	**Year**	**Item**		**Cost ($1000)**	**Days**
93	2010	Initial Construction		$4,504.74	-
94	2026/2034/ 2050/2058	Rehabilitations 2,3,5,6		$789.99	7
95	2018/2042	Rehabilitations 1, 4		$969.17	6

Source: FHWA.

Figure 79. Screenshot. Summary of the Agency Cost for different activities of Alternative 1.

PCC Pavement (Alternative 2)

This worksheet contains the agency cost computation details for each activity of Alternative 2 (in this example, considered as PCC pavement). Each bid item's unit price in the activity is referred back to the corresponding unit price cell in the Unit Bid Prices worksheet. The table at the end of the worksheet summarizes the Agency Cost for each activity.

Changes in the Inputs worksheet of RealCost.xlsm.

The input cell corresponding to Agency Construction Cost in each activity (figure 80) should be referred to as the corresponding cost cell in the summary table at the end of the worksheet (HMA or PCCP) for Alternative 1 or 2. An illustration is presented in Figure 80. Note that the Agency Construction Cost in the Inputs worksheet requires the cost in thousands of dollars.

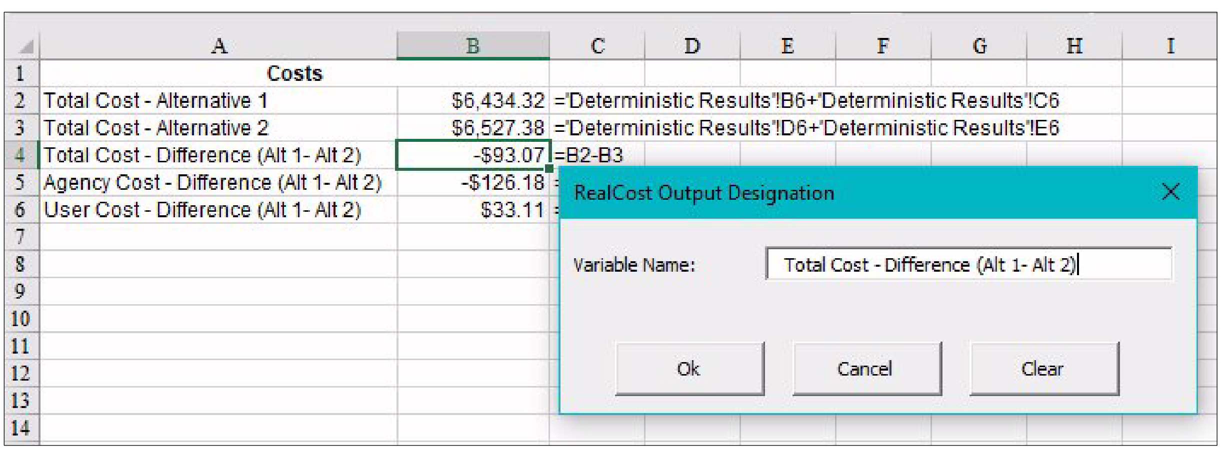
	A	B	C	D
49				
50	5. Construction			
51	Description	Value		
52	Alternative 1	HMA PAVEMENT (Night Work)		
53	*Number of Activities*	6		
54				
55	Description	Value		
56	Activity 1	2010 INITIAL CONSTRUCTION		
57	Agency Construction Cost ($1000)	=HMA!D92		
58	User Work Zone Costs ($1000)			
59	Work Zone Duration (days)			
60	No of Lanes Open in Each Direction During Work	2		
61	Activity Service Life (years)	8		
62	Activity Structural Life (years)			
63	Maintenance Frequency (years)			
64	Agency Maintenance Cost ($1000)			
65	Work Zone Length (miles)	1.0		
66	Work Zone Speed Limit (mph)	45		
67	Work Zone Capacity (vphpl)	1490		
68	Traffic Hourly Distribution	Week Day 1		
69				
70	*Inbound Time of Day of Lane Closures (use*	Start	End	
71	First period of lane closure			
72	Second period of lane closure			
73	Third period of lane closure			
74				
75	*Outbound Time of Day of Lane Closures (us*	Start	End	
76	First period of lane closure			
77	Second period of lane closure			
78	Third period of lane closure			
79				
80	Description	Value		
81	Activity 2	0.20' HMA OVERLAY; 100% ROADWAY SURFACE		
82	Agency Construction Cost ($1000)	$969.17		
83	User Work Zone Costs ($1000)			
84	Work Zone Duration (days)	6		
85	No of Lanes Open in Each Direction During Work	2		

Source: FHWA.

Figure 80. Screenshot. Input Worksheet.

An item of interest in LCCA might be to analyze the probabilistic results of the difference in agency cost between the two alternatives. By default, the RealCost program generates statistical results for agency and user cost values of each alternative. However, the user can customize the RealCost program to generate the required statistical results for other user-defined output variables. This process is explained in the following steps:

- Create a new worksheet titled "My Output" in the RealCost program.
- Include the list of user-defined output variables for which the RealCost program computes the statistical results. For example, to create a RealCost Output for the Agency LCC (NPV) difference, one would use the following formula to reference the respective cells in the Deterministic Results sheet: = 'Deterministic Results'!B6-'Deterministic Results'!D6.
- Execute the RealCost Output macro to assign each variable's value as an LCCA Output tag to enable the program to compute the required results. Select each of the user-defined output variable values and execute the RealCost Output macro present in the program's Add-ins. The macro requests a name for the user-defined variable. After executing the RealCost Output macro, a comment appears in the cell identifying the cell as the LCCA Output variable, as shown in figure 81.
- Implement the Simulation macro in the RealCost program. At each simulation, the LCCA Output variable's value is calculated with a set of simulated inputs, and the results are stored for statistical analysis. The RealCost worksheets Output Distributions, Tornado Graphs, and Extreme Tail Analysis will contain the simulation results and statistical analysis of the new user-defined RealCost Output variables in addition to the default agency and user cost values of each alternative.



Source: FHWA.

Figure 81. Screenshot. Designation of a User-Defined RealCost Output Variable.

Users can customize the report as required by their agency. Create a new worksheet titled "My Report." In the format required, add the details of the project to the RealCost worksheet. The user can move any plots from other RealCost worksheets to the new worksheet. Figure 82, figure 83, and figure 84 show a sample report regarding the cells in default RealCost worksheets.

In this example, the Project Details, Deterministic Comparison, and Probabilistic Comparison sections should use formulas to refer to the respective cells in the Inputs, Deterministic Results, and Probabilistic Comparison sheets, respectively. The Probabilistic Charts should refer to the statistics in the Output Distributions sheet, and the Tornado Charts should refer to the statistic in the Tornado Graphs sheet so that when a new probabilistic analysis is run, the information in the My Report sheet is automatically updated.

My State LCCA using RealCost

Project Details	
State Route	I-90
Project Name	Snoqualmie Pass East
Region	South Central
County	Kittitas
Analyzed By	Project Engineer
Mileposts	
Begin	57.00
End	58.00
Length of Project (miles)	1.00

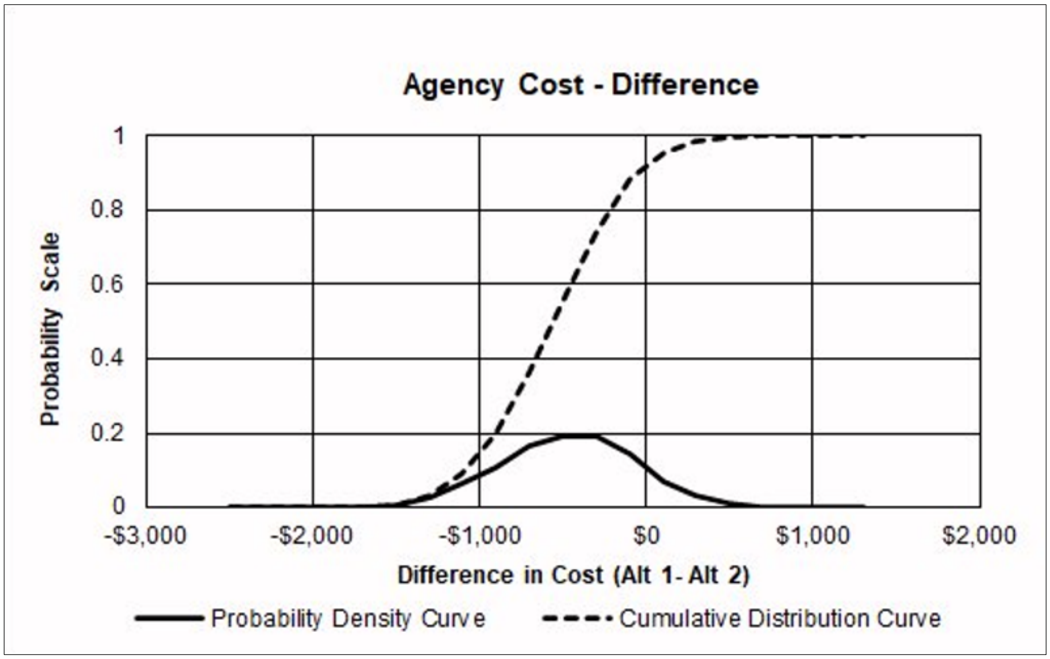
Deterministic Comparison				
	Alternative 1: HMA PAVEMENT (Night Work)		Alternative 2: PCC PAVEMENT (Night Work)	
Total Cost	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Present Value	**$6,420.55**	**$47.34**	**$6,880.47**	**$21.39**
EUAC	$298.88	$2.20	$320.29	$1.00

Lowest Present Value Agency Cost	Alternative 1: HMA PAVEMENT (Night Wor
Lowest Present Value User Cost	Alternative 2: PCC PAVEMENT (Night Worl

Probabilistic Comparison				
	Alternative 1: HMA PAVEMENT (Night Work)		Alternative 2: PCC PAVEMENT (Night Work)	
Total Cost (Present Value)	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Mean	$6,439.34	$49.02	$6,901.39	$23.41
Standard Deviation	$558.50	$11.81	$364.39	$6.95
Minimum	$4,801.79	$22.59	$5,775.61	$7.66
Maximum	$8,123.42	$98.69	$8,148.23	$54.55

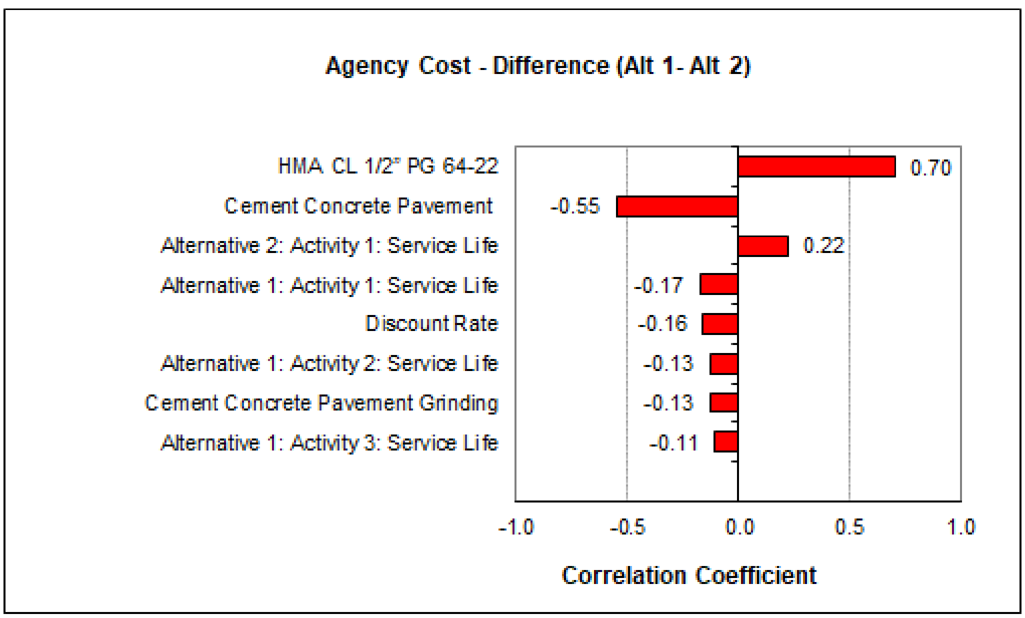
Source: FHWA.

Figure 82. Screenshot. Sample customized report (1).



Source: FHWA.
Alt = alternative.

Figure 83. Screenshot. Sample customized report (2).



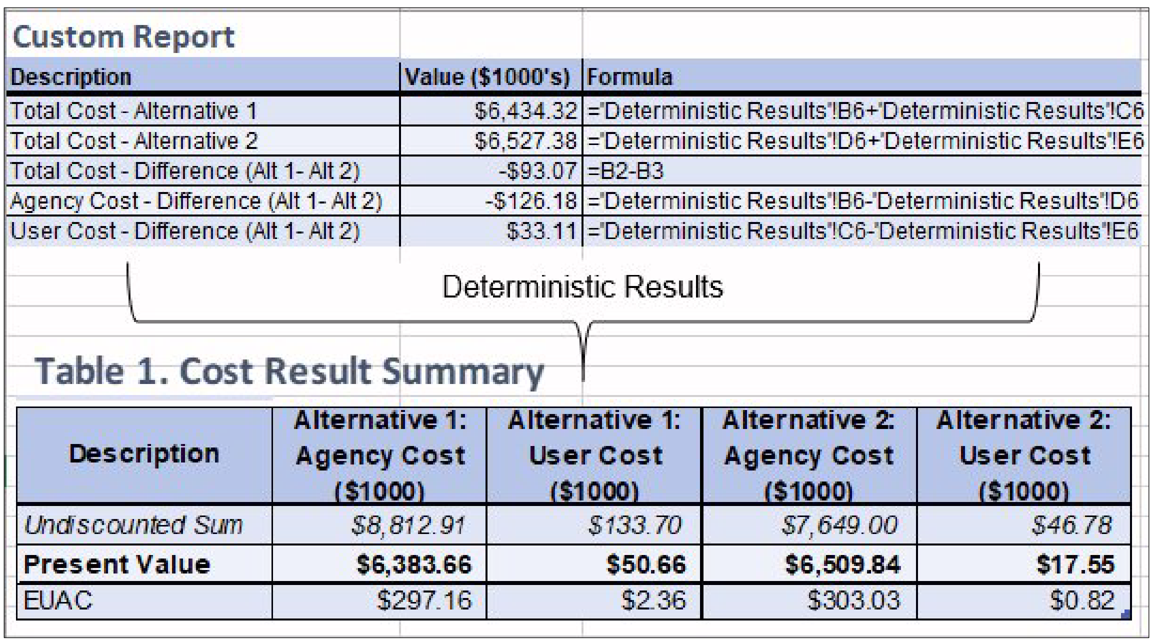
Source: FHWA.

Figure 84. Screenshot. Sample customized report (3).

CUSTOMIZED INPUT AND OUTPUT

User spreadsheets can be added to the RealCost workbook for input and postprocessing of RealCost Output to generate required statistical results for other user-defined output variables.

Further comparison of alternatives can be accomplished via the difference distribution curve. This type of analysis can be used to determine the accurate assessment of the probabilities associated with the lowest cost alternative. The difference distribution analysis can be conducted by creating a new worksheet within RealCost that includes equations for determining the cost difference between competing alternatives. For example, users can insert a new spreadsheet and name it "Custom," adding a formula to cells to calculate user-desired outputs. Figure 85 illustrates an inserted worksheet for calculating the total, agency, and user cost differences between alternatives 1 and 2. The equations used in column B are shown adjacent to the corresponding cell.



Custom Report

Description	Value ($1000's)	Formula
Total Cost - Alternative 1	$6,434.32	='Deterministic Results'!B6+'Deterministic Results'!C6
Total Cost - Alternative 2	$6,527.38	='Deterministic Results'!D6+'Deterministic Results'!E6
Total Cost - Difference (Alt 1- Alt 2)	-$93.07	=B2-B3
Agency Cost - Difference (Alt 1- Alt 2)	-$126.18	='Deterministic Results'!B6-'Deterministic Results'!D6
User Cost - Difference (Alt 1- Alt 2)	$33.11	='Deterministic Results'!C6-'Deterministic Results'!E6

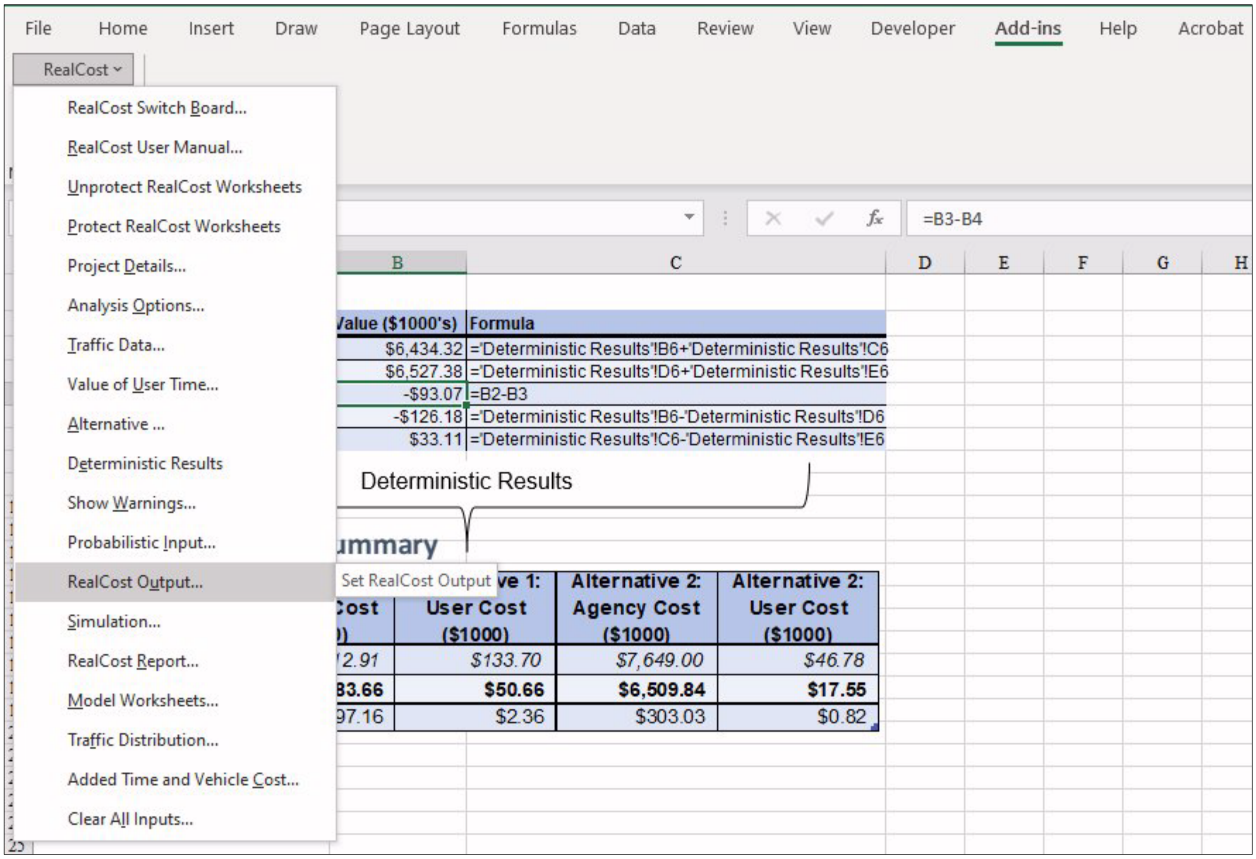
Table 1. Cost Result Summary

Description	Alternative 1: Agency Cost ($1000)	Alternative 1: User Cost ($1000)	Alternative 2: Agency Cost ($1000)	Alternative 2: User Cost ($1000)
Undiscounted Sum	*$8,812.91*	*$133.70*	*$7,649.00*	*$46.78*
Present Value	**$6,383.66**	**$50.66**	**$6,509.84**	**$17.55**
EUAC	$297.16	$2.36	$303.03	$0.82

Source: FHWA.

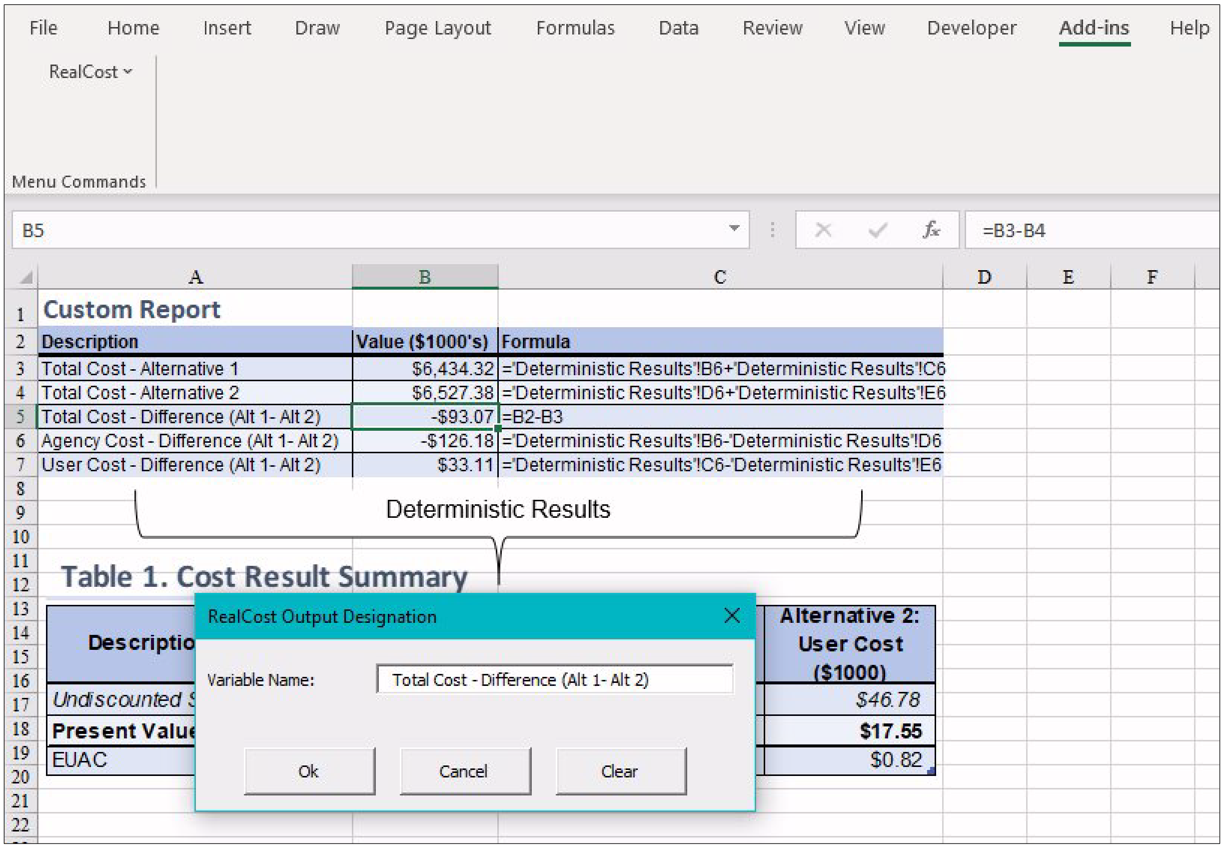
Figure 85. Screenshot. Worksheet for calculating difference distribution.

Users can define their desired outputs for further RealCost simulation and statistical analysis. Each cell of the user-defined output must also be characterized as a RealCost output to be included in the probabilistic analysis process. The user selects RealCost Output for each cell from the RealCost menu command and clicks OK to confirm adding the specific user-defined output, as shown in figure 86 and figure 87.



Source: FHWA.

Figure 86. Screenshot. Establishing a cell as a RealCost Output—Add-in menu.



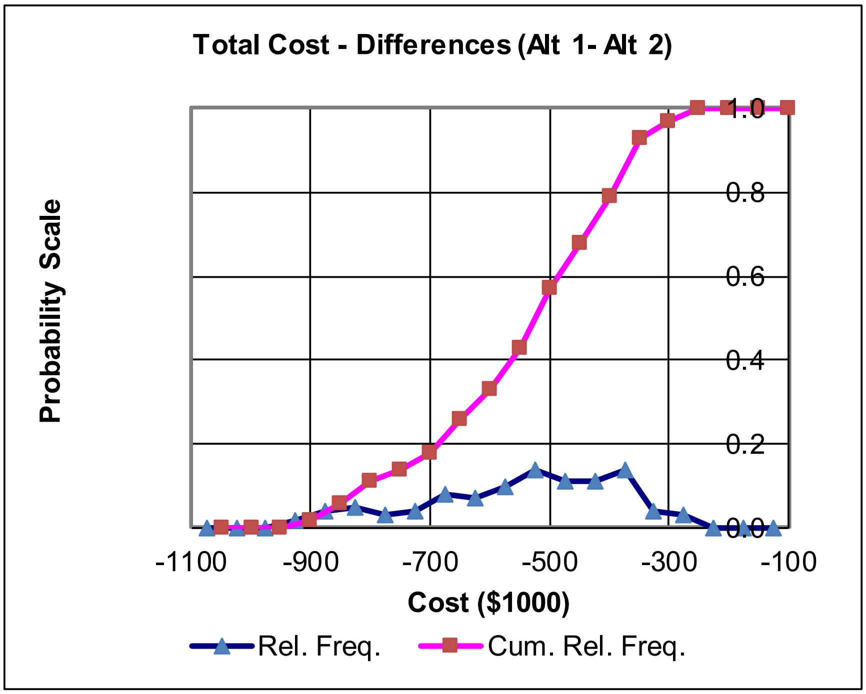
Source: FHWA.

Figure 87. Screenshot. Establishing a cell as a RealCost Output—dialog.

SIMPLIFIED ANALYSIS RESULTS

The development of analysis outputs to simplify the analysis results for interpretation can be demonstrated in the following example that uses output distribution.

Following the previous example, the resulting difference distribution curve simplifies the comparison of cumulative distribution curves by associating a level of reliability with the difference between the two alternatives. Users can simulate defining RealCost outputs for their desired cells and then examine the simulation results' user-defined output. Figure 88 shows the different distribution curves for the two alternatives compared in figure 87. The simulation outcomes favor Alternative 2. It should be noted that different distribution curves are skewed toward the negative zone of the differences between the alternatives.



Source: FHWA.
Cum. Rel. Freq. = cumulative relative frequency; Rel. Freq. = relative frequency.

Figure 88. Graph. Difference distribution curve for two design strategy alternatives.

APPENDIX C. REAL-WORLD APPLICATIONS OF REALCOST

LCCA has become an integral component for pavement type selection in several SHAs. Based on a 2009 survey conducted under NCHRP Project 10-75 (*Guide for Pavement Type Selection*), 29 of 33 responding States reported using an LCCA procedure for new and reconstruction projects (Hallin et al. 2011). Of these 29 States, 10 States (Arizona, Colorado, Delaware, Florida, Indiana, South Carolina, Tennessee, Utah, Vermont, and Washington) reported using RealCost, and 3 States (California, Louisiana, and Maryland) reported using a customized version of RealCost as the LCCA software of choice. The remaining SHAs reported using State-developed software or spreadsheet packages (14 States) or the American Association of State Highway Transportation Officials' DARWin software (2 States) in the LCCA process (Ozbay, 2003).

As demonstrated by these 13 States, RealCost can be a handy and useful tool for assessing pavement design alternatives' economic benefits. Incorporating the LCCA early in the project development phase allows for selecting the most viable and cost-effective pavement alternative while minimizing the amount of rework and analysis during the remaining phases of the project. Also, conducting the LCCA early in the project development phase allows for sufficient time for agency review and paving industry buy-in when warranted.

Since the RealCost software allows for the incorporation of initial construction costs, future preservation and rehabilitation costs, remaining life value, and user costs, it can assist an SHA in selecting the most cost-effective pavement strategy. In this regard, allowing the highway agency to consider impacts to both itself (e.g., construction timing, material selection, treatment strategies, or total cost minimization and pavement life maximization) and the users of the facility (minimizing user delay, minimizing vehicle operating costs, and maximizing the use of dollars), the RealCost program provides for a comprehensive analysis of the economics of alternative pavement strategies. Moreover, its probabilistic simulation capability and expanded analysis scope (6 strategy alternatives and 24 activities per alternative) allow the user to project the future and predict costs accurately.

This appendix briefly describes how SHAs are using RealCost to conduct project-level pavement LCCA. It includes summaries for 5 of the 13 States that reported using RealCost in the NCHRP 10-75 survey (Hallin et al. 2011).

CALIFORNIA DEPARTMENT OF TRANSPORTATION

RealCost is used by the California Department of Transportation (Caltrans) to evaluate alternative pavement designs for new construction and reconstruction or the rehabilitation of existing roadways. Caltrans requires the use of an LCCA process for all work conducted on the State highway system, excluding major maintenance (e.g., slurry seals, chip seals, crack sealing), projects less than $750,000, engineering analysis for permit actions, maintenance pullouts, and landscape paving. LCCA is conducted twice for all projects, during the project scoping phase (project initiation document) and during the environmental approval phase (project approval and environmental document).

Currently, Caltrans only uses the deterministic approach in RealCost. Caltrans intends to implement probabilistic analysis as soon as the probabilistic distribution functions for the individual input variables have been established.

Working with the FHWA, Caltrans initiated many of the features that are currently included in RealCost v 2.5. Some of these features include the ability to incorporate weekday and weekend hourly traffic distributions and analyze more than two alternatives. Also, the Caltrans version of RealCost has incorporated predetermined values for several inputs (e.g., discount rate, the value of user time, and default hourly distribution), which are identified in the *Caltrans Life-Cycle Analysis Procedures Manual* (2013). This manual and RealCost 2.5.4CA (California Edition) can be downloaded from the Caltrans "Life Cycle Cost Analysis" web page (Caltrans 2021).

COLORADO DEPARTMENT OF TRANSPORTATION

LCCA is used by the Colorado Department of Transportation (CDOT) primarily in the comparison of asphalt and concrete pavement alternatives for projects over $2 million. Projects not requiring LCCA include crack sealing and minor rehabilitation work on concrete pavements, restoration of frictional properties or pavement ride, minor safety improvements, bridge replacement projects, and locations where the use of alternative (i.e., thicker overlay) treatments are restricted due to curb and gutter or barrier heights.

As of 2009, CDOT requires that all LCCA be performed using the probabilistic analysis (at 75 percent confidence level) component of RealCost. CDOT also specifies that the economic analysis includes the NPV. For the probabilistic analysis, a triangular distribution is used for the initial construction costs, a normal distribution is used for the discount rate, and a lognormal distribution is used for service life for both initial construction and rehabilitation strategies. Costs for the various design alternatives are to include initial design (i.e., preliminary engineering) and construction (including engineering costs and traffic control costs), future maintenance, rehabilitation, salvage value, and user (travel time and increased vehicle operating costs). User costs are calculated outside of RealCost using the WorkZone software program, which can be accessed through the CDOT "User Cost" web page (CDOT 2021). The CDOT Current Procedure for Life Cycle Cost Analysis and Discount Rate Calculations (2009) is published in (Harris 2009). In addition, Chapter 13 of the CDOT *M-E Pavement Design Manual* (CDOT 2021) provides additional RealCost inputs. It can be downloaded from the CDOT website (https://www.codot.gov/programs/research/pdfs/by-subject/by-subject-l-p/life-cycle-cost-analysis).

FLORIDA DEPARTMENT OF TRANSPORTATION

The Florida Department of Transportation (FDOT) conducts LCCA on all new construction and reconstruction projects requiring modification of the base or subbase materials. In addition, FDOT requires LCCA on all resurfacing projects with a history of poor performance (i.e., less than 10 yr for flexible pavements and less than 15 yr for rigid pavements) and when a two-lane roadway is being widened to four lanes.

FDOT conducts LCCA over an analysis period of 40 yr and includes costs for initial construction, rehabilitation, and user (delay and vehicle operating costs due to work zone activity). FDOT does not require consideration of salvage value, remaining life, or maintenance costs. Agency construction cost estimates should include the cost for traffic control, design, and construction inspection. The user cost calculation is based on the deterministic method contained within RealCost. Pavement performance life is based on the Florida pavement database and engineering considerations.

The FDOT procedures for LCCA are provided in the *Pavement Type Selection Manual* (FDOT 2019).

MARYLAND STATE HIGHWAY ADMINISTRATION

In Maryland, all projects developed through the SHA's Planning Division (as well as all projects developed outside of the Planning Division but with a construction budget greater than $15 million) are required to follow the procedures outlined in the pavement type selection process. After a project has been identified as a candidate for the pavement type selection process, the Maryland SHA completes an LCCA procedure that includes the use of FHWA's RealCost software to compute probabilistic lifecycle costs for all pavement strategy alternatives.

The typical LCCA in Maryland is a two-step process. In the first step, the user enters inputs (required for the two design alternatives being compared) into an Excel workbook tool titled LCCA-Details.xls. The types of inputs entered into this Excel workbook tool include general inputs (e.g., alternative names, project length, number of lanes, and so on), inputs required to compute material quantities (e.g., area of pavement included and thickness information), and construction line item information (e.g., unit costs and typical daily production rates). The construction line-item unit costs and daily production rates are defined in probabilistic distributions rather than single values to make the computation more realistic. After all needed inputs are entered, a first RealCost simulation run is used to determine the probabilistic distributions associated with the construction activity agency costs and construction work zone durations for each included construction event.

After agency cost and construction, duration distributions are determined from the first simulation run. These values are defined as inputs in RealCost, and a second (or final) run of the RealCost software is used to produce LCCA results for the two design alternatives that include initial agency construction costs, future agency rehabilitation costs, and user delay costs. Finally, an objective procedure is used to analyze these results and select the most cost-effective design alternative from those analyzed.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

The Washington State Department of Transportation (WSDOT) conducts LCCA for new construction and reconstruction of all mainline pavements that are 0.5 mi in length or longer or have a total construction cost of more than $0.5 million. Also, the construction or reconstruction of all high-volume ramps, collector-distributors, acceleration-deceleration lanes, and intersections with chronic rutting problems require review and consideration for LCCA.

Using RealCost, WSDOT selects the design alternative that results in the lowest NPV or EUAC. However, other non-cost-related factors, such as air pollution impacts, impacts on surrounding neighborhoods, noise variances, and so on, require consideration in selecting the most viable alternative. At a minimum, one HMA alternative is compared to one PCC alternative. Although a probabilistic analysis is preferred, WSDOT allows for a deterministic analysis but requires that a sensitivity analysis of inputs be completed.

The LCCA comparison is based on the project's total costs and includes initial construction, maintenance and rehabilitation, user costs (delay due to work zone activity only), and salvage value. For agency construction costs, mobilization (5 percent), engineering contingencies (15 percent), and preliminary engineering (10 percent) are included in the cost estimate but can be excluded for the initial construction when the costs are similar for each of the design alternatives. Washington State sales tax is included in all construction cost estimates.

A 50-yr analysis period is used for all principal arterials, interstates, and highways with more than 100,000 equivalent single-axle loads per year, and 20 yr for all other highway types. Pavement performance life for all strategies is based on performance data contained within the pavement management system.

A complete list of RealCost recommended inputs, including the probability distribution recommendations, is provided in the WSDOT *Pavement Policy* (2018).

GLOSSARY

Activity—A specific action performed by the highway agency, such as initial construction or major rehabilitation. An activity is defined by its agency costs, its service life, and its effects on highway users. An activity is a component of an alternative.

Agency cost—Money spent by a transportation agency for construction or rehabilitation activities.

Analysis period—The LCCA analysis period is the time horizon over which the various design strategy alternatives are evaluated. It should be sufficient to reflect long-term cost differences associated with reasonable design strategies.

Bridge—A structure including supports erected over a depression or an obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads, and having an opening measured along the center of the roadway of more than 20 ft between undercoating of abutments or spring lines of arches, or extreme ends of openings for multiple boxes. It may also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening under 23 CFR, Section 650.305 (U.S. Government Printing Office 2010).

Data input field—An area on an input screen where data may be entered.

Design strategy alternative—The complete set of activities over a specified analysis period that defines a strategy for achieving the performance goals of a project. In LCCA, all design strategy alternatives being considered for a project will equally meet the performance requirements of the project.

Discount rate—The discount rate represents the real value of money over time and is used in LCCA to convert future costs to present-day costs. The discount rate is nominally defined as the interest rate minus the inflation rate. Low discount rates favor those alternatives that combine large capital investments with low maintenance or user costs, whereas high discount rates favor reverse combinations.

Graphical user interface—A set of window graphics that provides an easy-to-use interface to a software program.

Inflation rate—The inflation rate is the rate of increase in the prices of goods and services that are used for the construction and upkeep of highways. The inflation rate represents past changes in the purchasing power of money. The inflation rate is derived from economic indicators like the consumer price index. It should only be used in the LCCA to bring past monetary values to present values. Forecasting future inflation rates is difficult, if not impossible, to predict. The use of nominal discount rates should be resisted without reliable forecasting methods for inflation. If an agency decides to include future inflation projections in the LCCA, care should be taken to include them in the projections of costs as well.

Input screen—A Switchboard-based pop-up window for entering and working with data in RealCost.

Interest rate—The interest rate (often referred to as the market interest rate) is associated with the cost of borrowing money. The interest rate represents the earning power of money.

LCCA menu—A special menu item that is created by RealCost and resides in the Add-ins menu of the Excel menu bar. The menu allows access to the Switchboard and various input screens.

Macro—An Excel macro is a stored set of instructions that can be triggered by a keyboard shortcut to perform a specific task or set of tasks. Macros are used to eliminate the need to repeat the steps of common tasks, such as performing computational functions or adding or removing rows and columns. In Excel, macros are written in Visual Basic for Applications.

Menu—An Excel component that allows software users to interface with the software. The menu bar is typically located at the top of the Excel window.

Pavement preservation—A program employing a network-level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety, and meet motorist expectations. A pavement preservation program consists primarily of three components: preventive maintenance, minor rehabilitation (nonstructural), and some routine maintenance activities (Geiger 2005).

Pavement preventive maintenance—Preventive maintenance is a planned strategy of cost-effective treatments to an existing roadway system that preserves the system, delays future deterioration, and maintains or improves the functional condition of the system without (significantly) improving the structural capacity (Geiger 2005). Examples of preventive maintenance include crack sealing, microsurfacing, chip seals, and thin hot-mix asphalt overlays.

Pavement reconstruction—Pavement reconstruction consists of the replacement of the entire existing pavement structure with an equivalent or increased pavement structure (Geiger 2005). Reconstruction usually requires the complete removal and replacement of the existing pavement structure and may utilize either new or recycled materials in the materials used for the reconstruction (Geiger 2005).

Pavement rehabilitation—Rehabilitation consists of structural enhancements that extend the service life of the existing pavement and/or improve its load-carrying capacity (Geiger 2005). Rehabilitation techniques include structural overlays, partial-depth recycling, and restoration treatments, such as concrete pavement restoration (i.e., patching, diamond grinding, and dowel-bar retrofit).

Project—A project involves the construction, reconstruction, rehabilitation, or preservation of an asset item, with the provision that a specific level of performance will be provided to the motoring public. In RealCost LCCA analysis, all design strategy alternatives being considered for a project must provide the same level of performance for road users.

Remaining life value—The monetary value (both agency and user costs) of potential service remaining at the end of the analysis period. It is computed as a depreciation of the costs of structural and functional activities occurring over the analysis period.

Residual value—The value of recovered or recyclable materials at the end of the analysis period (Walls and Smith 1998).

Roadway asset—For purposes of RealCost, a roadway asset typically includes major roadway infrastructure items, such as pavement, bridges, tunnels, drainage systems, and safety features.

Roadway—The strip of land or part of a bridge over which a road passes and along which various infrastructure-related items (e.g., drainage systems, traffic safety features) exist.

Salvage value—The value of an investment alternative at the end of the analysis period (Walls and Smith 1998). The two fundamental components associated with salvage value are the remaining life value and the residual value.

Service life—The period during which the product of a construction or rehabilitation activity can satisfy the performance requirements or expectations placed on it. The end of the service life in RealCost is used as a trigger for the next activity. As an example, for pavements, the service life refers to the functional life of the pavement (i.e., surface performance issues such as smoothness, friction, noise, and aesthetics). Functional pavement activities include, among other things, preventive maintenance treatments and friction restoration treatments that do not add to the structural capacity of the pavement.

Structural life—The period of time during which the product of a construction or rehabilitation activity is able to satisfy the structural, load-carrying requirements or expectations placed on it. For pavements, structural activities have both a defined structural life as well as a functional life.

Switchboard—The primary interface mechanism in RealCost. The Switchboard appears automatically when the software is started and may also be accessed through the RealCost menu.

Tab (worksheet tab)—A selection device at the bottom of a displayed Excel workbook file that allows the software user to select and move between different worksheets within the workbook.

User costs—User costs are the time delay, vehicle operating, and crash costs incurred by the users of a facility. RealCost is structured to only allow the computation of time delay and vehicle operating costs associated with work zones. However, the program's customization features can be used to compute other forms of user costs.

Visual Basic for Applications—Tool used to automate tasks ranging from adding together two inputted numbers to performing multistep, complex operations that use multiple inputs. Visual Basic code is also used to create the Switchboard interface for RealCost.

Work zone—An area of reduced roadway capacity due to agency construction or rehabilitation activities.

Workbook—An Excel file composed of one or more worksheets and additional Visual Basic for Applications code. The RealCost software is a workbook.

Worksheet—A single page of an Excel workbook; a single spreadsheet.

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