

# **Adjustments to Pavement Life-Cycle Cost Analysis Procedures**

A Project for

**The Alabama Department of Transportation**

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<b>16. Abstract</b> <p>Life-cycle cost analysis (LCCA) uses economic principles to compare competing investment alternatives. It is used by the Alabama Department of Transportation (ALDOT) to help select between asphalt and concrete alternatives for large paving projects. The purpose of this University Transportation Center for Alabama (UTCA) research project was to evaluate changes which may be incorporated in ALDOT's LCCA procedures and to establish a schedule to implement the potential changes. This project was meant to be the scoping phase of a potential multi-phase project to update the LCCA process. The researchers investigated the following areas:</p> <ul style="list-style-type: none"> <li>• Developing background information for an ALDOT policy statement to address factors that identify situations when selecting the lowest cost alternative may not be the best choice.</li> <li>• Incorporating reliability into LCCA calculations.</li> <li>• Assembling data for use in anticipated new LCCA software.</li> <li>• Evaluating the effect of user costs on typical ALDOT LCCAs.</li> <li>• Using salvage value in LCCA.</li> <li>• Including routine maintenance values in LCCA.</li> <li>• Using deterministic rather than probabilistic LCCA procedures.</li> </ul>			
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## Contents

Contents.....	iii
Tables .....	v
Figures .....	v
Executive Summary.....	vi
1.0 Introduction .....	1
2.0 Background .....	3
LCCA Basics .....	3
Performance Period .....	4
Agency Costs and User Costs .....	5
Deterministic vs. Probabilistic.....	6
LCCA Peer Review.....	6
FHWA Software.....	7
3.0 Southeastern States Concrete Data.....	8
Tennessee .....	8
Louisiana .....	9
Georgia.....	10
Mississippi .....	11
Ohio .....	12
4.0 Southeastern States LCCA Practices.....	13
Survey 1 Results.....	13
Survey 2 Results.....	14
5.0 Routine Maintenance.....	17
Additional PCC Maintenance.....	18
6.0 Pavement Performance Periods.....	19
Current Values.....	19
Re-evaluation.....	19
Values for New Paving Materials.....	19
7.0 Probabilistic LCCA.....	21
Risk Analysis.....	21
Deterministic vs. Probabilistic LCCA.....	21
Monte Carlo Simulation Technique.....	22
8.0 User Costs and Queues.....	24
Origins of User Costs.....	24

Calculating User Costs.....	26
Calculating Queue Lengths.....	27
9.0 FHWA Software.....	28
Probabilistic LCCA 1.0 Inputs.....	29
Deterministic Results.....	35
Simulation.....	38
Probabilistic Results.....	38
Queue Length Determination.....	41
10.0 LCCA Procedure Comparisons.....	43
Software Results Comparisons.....	43
Montgomery LCCA.....	44
Adjusted Montgomery LCCA.....	47
Talladega LCCA.....	48
11.0 Summary and Conclusions.....	51
FHWA Software Package.....	52
HYDRA.....	53
Schedule.....	53
Further Work.....	54
12.0 References.....	55
Appendix 1: Montgomery Project.....	57
Appendix 2: Talladega Project.....	67

## List of Tables

Number		Page
3-1	Tennessee bid prices.....	9
3-2	Louisiana bid prices.....	10
3-3	2001 Georgia bid prices.....	11
3-4	2001 Mississippi bid prices.....	11
3-5	Ohio bid prices.....	12
4-1	Survey data.....	14
5-1	Yearly routine maintenance costs.....	17
10-1	NPV agency cost comparisons.....	44
10-2	Deterministic results of the Montgomery project.....	45
10-3	Deterministic results of adjusted Montgomery project.....	48
10-4	Deterministic results of Talladega project.....	49
10-5	Probabilistic results of Talladega project.....	49

## List of Figures

Number		Page
2-1	Pavement service life.....	4
2-2	Expenditure stream diagram.....	5
7-1	NPV distribution generation.....	22
7-2	Monte Carlo simulation.....	23
8-1	Free flow conditions.....	25
8-2	Forced flow conditions.....	26
9-1	LCCA switchboard.....	29
9-2	Input spreadsheet.....	30
9-3	Analysis options.....	32
9-4	Alternative 1 input form.....	34
9-5	Deterministic results.....	35
9-6	Expenditure stream.....	36
9-7	Agency cost comparison.....	36
9-8	Probabilistic results.....	38
9-9	Probabilistic results worksheet.....	38
9-10	Correlation coefficients.....	39
9-11(a)	User cost table.....	41
9-11(b)	User cost table.....	42
10-1	Probabilistic results of Montgomery LCCA.....	47
10-2	Tornado plot and output distributions.....	50

## Executive Summary

The Alabama Department of Transportation (ALDOT) uses life-cycle cost analysis (LCCA) to help choose between asphalt and concrete pavement for large projects. ALDOT funded this University Transportation Center for Alabama research project after it received the results of a “Life-Cycle Analysis Peer Review” from the Federal Highway Administration (FHWA) in 2002. The FHWA identified several good practices during the review and also listed several areas where ALDOT could consider refining its practices. The purpose of this UTCA research project was to evaluate which FHWA suggestions may be incorporated in ALDOT’s LCCA procedures and to identify a schedule to implement the changes. This project was meant to be the scoping phase of a potential multi-phase project to update the LCCA process.

UTCA researchers drew the following major conclusions during the study:

- ALDOT does not include user costs in its current analysis and does not currently possess adequate concrete work zone duration and configuration data required to calculate user costs.
- Example calculations indicate that user costs can exceed agency costs and can change the higher cost alternative to the lower cost alternative.
- ALDOT currently uses deterministic LCCA procedures; however, it could produce probabilistic output by changing only two or three input parameters.
- ALDOT does not include routine maintenance costs in its current analysis, but those values are quite small in comparison to construction cost inputs.
- Other states list items to consider when costs for asphalt and concrete alternatives are extremely close. ALDOT could use those lists as a resource to produce its own “tie-break” procedure.
- ALDOT does not include salvage value in its current analysis, but several other states in the region do not use salvage value.
- ALDOT has the data to utilize the new FHWA computer program *Probabilistic LCCA 1.0* to provide deterministic and probabilistic LCCA output that does not include user costs and queue lengths. It must develop more detailed concrete work zone duration and configuration data to calculate those values.

UTCA researchers made the following observations concerning schedule:

- ALDOT can use FHWA’s *Probabilistic LCCA 1.0* in the near future to produce basic deterministic and probabilistic LCCA output. Two more years of data are probably needed to add user costs and queue lengths to LCCA calculations, if ALDOT so desires.
- ALDOT can prepare a policy statement in the near future that addresses factors for not selecting the lowest life-cycle alternative based on policies of other states described in this report.

## **Section 1 Introduction**

Life-cycle cost analysis (LCCA) is a technique that utilizes economic principles to evaluate and compare competing investment alternatives (Smith & Walls, 1998). An LCCA incorporates initial and discounted future costs over the useful lives of competing alternative investments. A life-cycle cost analysis is conducted to identify the best value, i.e., the lowest long term cost. It may be used as a tool to help select the most appropriate design for the particular project. For example, an LCCA may be conducted to help decide whether a rigid pavement design or a flexible pavement design should be used for a particular project. An LCCA is typically performed during the design stage of a project.

The Alabama Department of Transportation (ALDOT) performs life-cycle cost analyses to compare alternative pavement designs and reconstruction strategies for the following situations:

- New construction projects, flexible pavement reconstruction projects, and projects involving the addition of a separate roadway to an existing roadway when the pavement design structural number equals or exceeds 6.00.
- Any project involving the reconstruction of concrete pavement.

ALDOT funded this University Transportation Center for Alabama (UTCA) research project after it received the results of a “Life-Cycle Analysis Peer Review” (FHWA, 2002, Primer) it had requested from the Federal Highway Administration (FHWA). The FHWA identified several good practices during the review and also listed the following areas where ALDOT could consider further refining its practices:

1. Use pavement management system information to evaluate the cost effectiveness of new paving materials/procedures such as Superpave, stone matrix asphalt (SMA), modified asphalts, and tied concrete shoulders.
2. Develop a formal policy statement that addresses factors for not selecting the lowest life-cycle alternative such as excessive queues and user delays during rehabilitation.
3. Incorporate reliability into pavement life estimates.
4. Begin to assemble data on the variability of LCCA inputs to be prepared for the implementation of the anticipated new edition of AASHTO’s Guide for Design of Pavement Structures (AASHTO, 1993).
5. Evaluate the effect of proposed out-year rehabilitations on users of the facility such as the analysis of queue lengths and user delays.

The purpose of this UTCA research project was to evaluate which FHWA suggestions may be incorporated in ALDOT’s LCCA procedures and to identify data sources, personnel, and the schedule to implement the changes. This project was meant to be the scoping phase of a potential multi-phase project to update the LCCA process. Other

issues were identified during the project work, so the report also contains results of two surveys, supplemental data on prices for concrete reconstruction activities, as well as routine maintenance costs for both asphalt and concrete pavements.

The remainder of this report is divided into topic areas with the following major headings:

- Background information
- Southeastern states concrete data
- Southeastern states LCCA procedures
- Routine maintenance
- Pavement service life
- Probabilistic analysis
- User costs and queues
- New FHWA software
- LCCA procedure comparison
- Summary and conclusions



## **Section 2**

### **Background**

The following discussion provides background information concerning effective pavement life-cycle cost procedures and current ALDOT practices with respect to pavement LCCA.

#### **LCCA Basics**

Various methods are used for performing a life-cycle cost analysis. These methods include net present value (NPV), equivalent uniform annual costs (EUAC), rate of return (ROR), break even analysis, and benefit-cost (B/C) ratios. The FHWA recommends the net present value (NPV) method for performing a LCCA. ALDOT currently utilizes the NPV method for conducting a life-cycle cost analysis.

The designer must choose between using nominal dollars or real dollars when performing a life-cycle cost analysis via the NPV method. Real dollars reflect a constant purchasing power, while nominal dollars reflect fluctuations in purchasing power as a function of time. For example, the price for a ton of hot-mix asphalt may be \$35 today, and is also represented as \$35 in twenty years using real dollars. If nominal dollars are used for this same example, the designer might consider inflation and represent a ton of hot mix asphalt as \$65 in twenty years. Real dollars are more widely used in an LCCA. Real dollars and nominal dollars should not be mixed in the same analysis (FHWA, 2002, Primer). ALDOT currently uses real dollars in its life-cycle cost analyses.

The discount rate, or interest rate, is one of the variables necessary to complete an LCCA utilizing the NPV method. FHWA suggests using a discount rate between 3 and 5 percent (Smith & Walls, 1998). ALDOT currently uses a 4 percent discount rate on its life-cycle cost analyses.

The analysis period is the length of time selected for the life-cycle cost analysis. The analysis period for two competing alternatives should be the same. FHWA recommends an analysis period of at least 35 years. However, 20 to 30 year analysis periods are frequently used. In general, the analysis period should be longer than the pavement performance period and long enough to incorporate at least one rehabilitation activity (FHWA, 2002, Primer). The Alabama Department of Transportation currently uses a 28-year analysis period.

## Performance Period

The designer conducting an LCCA must define a performance period for the initial pavement design and subsequent rehabilitation activities. These performance periods have a major impact on LCCA results. It is easy to see the importance of construction activity timing or performance periods by examining the basic formula for computing the NPV:

$$\text{NPV} = \text{Initial Cost} + \sum \text{Rehab Cost} [1/(1+i)^n] \quad (1-1)$$

Where,  $i$  = discount rate;

$n$  = year the cost occurs

Figure 2-1 below shows a diagram of performance period (service life) vs. pavement condition. This figure illustrates that the pavement condition deteriorates during the service life of a pavement. The pavement deteriorates faster as the pavement condition worsens. This is evident by an increasing slope of the curve during one service life. The pavement condition is then rehabilitated, and the pavement deterioration cycle begins again.

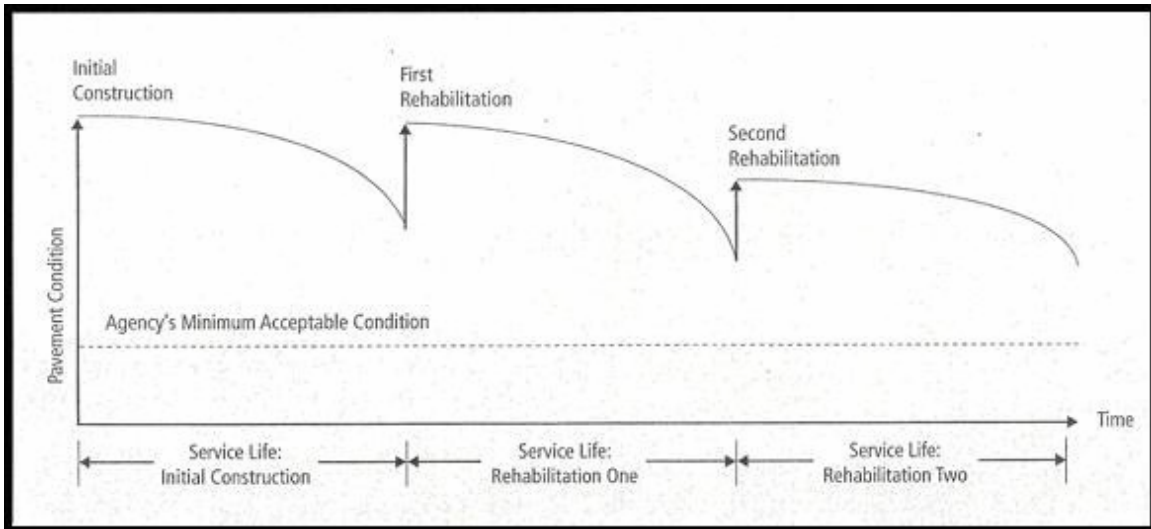


Figure 2-1. Pavement service life

A state highway agency must determine specific performance information for various pavement strategies through an analysis of pavement management historical data. ALDOT currently uses a 12-year initial performance period for flexible pavements, a 20-year initial performance period for rigid pavements, and an 8-year performance period for all subsequent rehabilitation activities for both flexible and rigid pavements.

### Agency Costs and User Costs

An LCCA does not require that all costs associated with each alternative be included, but only the costs that demonstrate differences between alternatives. Agency costs refer to costs directly incurred by the highway agency. These include initial construction costs, periodic maintenance costs, and major rehabilitation activities. User costs are the costs incurred by the traveling public such as vehicle operating costs, travel time costs, and crash costs. User costs arise from the timing, duration, and scope of construction work zones, because work zones usually restrict the normal capacity of the facility (FHWA, 2002, Primer). ALDOT currently performs life-cycle cost analyses utilizing only agency costs. This report will suggest a way to capture work zone related user costs in an LCCA, if ALDOT chooses to employ that option.

The highway designer may develop an expenditure stream diagram to help visualize the timing and quantity of expenditures to assist in the net present value calculation. The diagram can be created by carefully selecting the performance periods and assigning each activity its appropriate cost. An example of an expenditure stream diagram is shown in Figure 2-2 (FHWA, 2002, Primer).

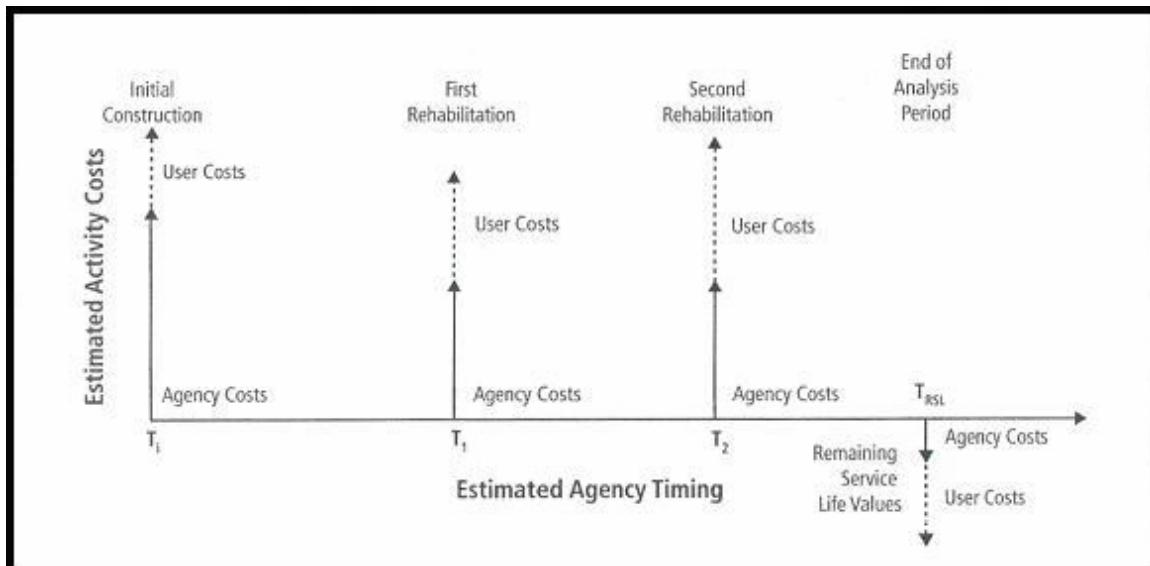


Figure 2-2. Expenditure stream diagram

## **Deterministic vs. Probabilistic**

There are two approaches to performing a life-cycle cost analysis: deterministic and probabilistic. These methods differ in the way they deal with uncertainty associated with input parameters such as activity costs and timing. The deterministic approach assigns each input variable a distinct fixed cost (discrete value). This discrete value is usually the average of historical data. Assigning discrete values to input variables yields a discrete value for the LCCA estimate. A deterministic approach does not recognize the uncertainty associated with the various inputs (FHWA, 2002, Primer). ALDOT currently conducts life-cycle cost analyses using the deterministic approach.

The probabilistic approach to conducting an LCCA allows the designer to define the values of individual inputs by a probability distribution (frequency distribution). One or more uncertain input parameters must be identified for each project alternative. The designer identifies project parameters for which a frequency distribution can be identified, and then develops a distribution for each parameter. A simulation technique, known as Monte Carlo simulation, draws values from the probability distributions for each uncertain input variable, and uses these values to compute a single NPV output value. This sampling process is repeated thousands of times to generate a probability distribution for the net present value (NPV). The resulting NPV distribution can be compared to other alternative's NPV distributions to determine the most economical option for any given risk level (FHWA, 2002, Primer). A more detailed description of this process is provided later in this report.

## **LCCA Peer Review**

The FHWA conducted an LCCA peer review in January 2002 to identify positive ALDOT life-cycle cost analysis practices (ALDOT, 2002). The review team also identified some areas for improvement. ALDOT provided the FHWA with its procedures on conducting an LCCA and also provided an example of a past LCCA. The FHWA peer review team confirmed that ALDOT's stated procedures were used in its analyses and found the following good LCCA practices:

- ALDOT LCCA procedures use the following current national FHWA recommended procedures:
  - Use of a 4% discount rate
  - Use of an analysis period that includes at least one rehabilitation
  - Use of the NPV method to compare discounted costs
- A well documented history of the evolution of LCCA procedures
- A good working relationship between the FHWA Division and the state DOT
- Good use of available cost data

The FHWA peer review team noted some areas in which ALDOT's LCCA procedures could be refined:

1. Use pavement management system information to evaluate the cost effectiveness of new paving materials/procedures such as Superpave, stone matrix asphalt (SMA), modified asphalts, and tied concrete shoulders.

2. Develop a formal policy statement that addresses factors for not selecting the lowest life-cycle alternative such as excessive queues and user delays during rehabilitation.
3. Incorporate reliability into pavement life estimates.
4. Begin to assemble data on the variability of LCCA inputs in preparation for the implementation of the anticipated new edition of AASHTO's Guide for Design of Pavement Structures (AASHTO, 1993).
5. Evaluate the effect of proposed out-year rehabilitations on users of the facility such as the analysis of queue lengths and user delays.

### **FHWA Software**

The FHWA recently released its newest *Probabilistic LCCA version 1.0* software. This software is able to perform an LCCA utilizing either the probabilistic approach or the basic deterministic approach. The FHWA software can also calculate user costs, if the designer chooses. This software is modeled after the method presented in the FHWA publication "Life-Cycle Cost Analysis in Pavement Design – In Search of Better Investment Decisions" (Smith & Walls, 1998). FHWA currently provides workshops that provide assistance to the analyst when using the FHWA software and booklet. This workshop is known as FHWA Demonstration Project No. 115. Information on this workshop can be obtained from the FHWA website by searching for "DP 115." A more thorough description of the FHWA software is provided later in this report.

ALDOT currently performs LCCAs utilizing *DARWin™* software. *DARWin™* is only capable of performing a deterministic analysis. The designer is not able to factor in the variability of inputs. *DARWin™* is only used to calculate agency costs in an LCCA; it does not calculate user costs or queue length.

### **Section 3**

## **Southeastern States Concrete Data**

This section briefly summarizes average costs for various rigid pavement construction and rehabilitation activities for several states. ALDOT requested that this data be identified for its use in future LCCA calculations because little concrete roadway work is performed in Alabama and little domestic data is available. Alabama performs so much asphalt construction and rehabilitation that it will use its own historical data in future asphalt LCCA's. The UTCA project team researched construction company bid prices between 1999 and 2002 for various Southeastern and Midwestern states. This section presents data acquired from the Tennessee, Louisiana, Georgia, Mississippi, and Ohio Departments of Transportation (DOTs). The state by state summaries shown in Tables 3-1 through 3-5 contain the following data:

- Rigid pavement construction item
- Rigid pavement rehabilitation item
- Item code (state specific)
- Construction units of measure
- Average unit prices
- Standard deviation of the unit price (where applicable)

#### **Tennessee**

The Tennessee DOT publishes an annual report containing the average amount the department paid for each construction activity over the year. This report can be viewed at the Tennessee DOT's website (Tennessee DOT, 2002). Table 3-1 presents the average prices for construction and rehabilitation activities between 1999 and 2001 involving Portland cement concrete (PCC) pavement. It should be noted that the unit prices for various thicknesses of "PCC PVMT" include the installation of dowell bars and tie bars.

**Table 3-1: Tennessee bid prices**

Item Code	Description	Unit of Measure	1999 Average Unit Price (\$)	2000 Average Unit Price (\$)	2001 Average Unit Price (\$)
501-01	PCC PVMT (REPLACEMENT)	SY	98.93	141.45	161.17
501-01.02	PCC PVMT (PLAIN) 9"	SY	19.56	30.29	27.41
501-01.03	PCC PVMT (PLAIN) 10"	SY	38.05	29.86	----
501-01.04	PCC PVMT (PLAIN) 11"	SY	----	44.00	----
501-01.05	PCC PVMT (PLAIN) 12"	SY	----	78.00	----
501-01.07	PCC PVMT (PLAIN) 13"	SY	----	33.00	----
501-01.15	ROLLER COMPACTED CONC PVMT	CY	----	----	63.61
501-01.20	PCC PVMT (PLAIN) 3" ULTRATHIN	CY	----	50.53	----
501-01.40	FASTRACT	SY	----	----	24.50
501-04.01	SAWING CONCRETE PVMT (FULL DEPTH)	LF	3.60	2.93	17.82
501-04.02	LOAD TRANSFER DOWELS	EACH	4.20	3.78	17.00
501-04.03	TRANSVERSE TIE BARS	EACH	3.12	3.69	15.78
501-07.11	CONCRETE PAVEMENT REMOVAL	SY	----	17.50	8.00
501-08.01	RESEALING JOINTS (HOT POUR ELSTC)	LF	0.64	1.94	1.24
501-08.03	SEALING SHOULDER JOINTS	LF	1.53	1.70	4.79
501-08.04	SEALING RANDOM CRACKS (HOT POUR ELSTC)	LF	0.54	4.25	----
501-08.05	WPRFNG CONC PVMT JOINTS -12" WIDTH	LF	3.76	----	----
501-08.07	SEALING RANDOM CRACKS (SILICONE)	LF	2.07	4.50	9.00
501-08.23	CLEAN AND RESEAL JOINTS & CRACKS	LF	----	3.06	----
502-01	CLEANING AND SEALING JOINTS	LF	----	3.06	1.97
502-03	CEMENT	BAG	----	10.00	10.00
502-03.01	CEMENT GROUTING	CF	----	----	15.00
502-03.10	FULL DEPTH PCC PAVEMENT REPAIR	SY	123.00	112.12	108.44
502-03.11	PARTIAL DEPTH PCC PVMT REPAIR	SY	----	----	30.00
502-07	SPALL REPAIR	SY	197.45	254.50	91.34
503-01	GRINDING CONCRETE PAVEMENT	SY	3.30	5.43	----
503-30	PROOF ROLLING JOINTS	EACH	31.50	----	----
503-40	STABILIZING CONCRETE SLABS	EACH	89.50	----	----
503-50	MILL MAINTENANCE OVERLAY	SY	1.10	----	----
503-60	RETROFIT DOWEL BARS	EACH	35.00	----	----
504M01	CRACKING AND SEATING CONC PVMT	m <sup>2</sup>	0.40	----	----
505M01	RUBBLIZATION CONC PVMT (250mm-300mm)	m <sup>2</sup>	1.00	2.50	3.00

**Louisiana**

Price data for the state of Louisiana was retrieved from the Louisiana DOT’s tabulated construction bid prices (LADOT, 2002). Data was collected from all construction projects related to rigid pavements from 2001 to 2002. Average unit prices over that time period as well as their corresponding standard deviations were computed and recorded in Table 3-2.

**Table 3-2. Louisiana bid prices**

Item Code	Description	Unit	Average Unit Price (\$)	Standard Deviation (\$)
601-01	PCC PVMT 9" THICK	SY	48.20	18.64
602-02A	CLEANING & RESEALING EXISTING LONGITUDINAL JOINTS	LF	1.30	0.61
602-02B	CLEAN & RESEAL EXIST TRANSVERSE JOINTS	LF	1.48	0.62
602-03	CLEAN & SEAL RANDOM CRACKS	LF	2.50	0.89
602-05-I-01	FULL DEPTH PATCHING OF JOINTED CONC (9" THICK) (<=16 yd <sup>2</sup> )	SY	156.25	40.49
602-05-I-02	FULL DEPTH PATCHING OF JOINTED CONC (9" THICK) (between 16.1 & 48 yd <sup>2</sup> )	SY	140	53.07
602-05-I-03	FULL DEPTH PATCHING OF JOINTED CONC (9" THICK) (>= 48 yd <sup>2</sup> )	SY	118.60	44.60
601-01-G	PCC PAVEMENT (8" THICK)	SY	63.33	15.28
602-16	CROSS-STITCHING RANDOM LONG. JOINTS	LF	19.67	5.03
S-004	FULL DEPTH PATCHING OF JOINTED CONC (8" THICK) (<=9 yd <sup>2</sup> )	SY	150.00	N/A
S-005	FULL DEPTH PATCHING OF JOINTED CONC (8" THICK) (between 9.1 & 16 yd <sup>2</sup> )	SY	130.00	N/A
S-006	FULL DEPTH PATCHING OF JOINTED CONC (8" THICK) (between 16.1 & 24 yd <sup>2</sup> )	SY	120.00	N/A
S-007	FULL DEPTH PATCHING OF JOINTED CONC (8" THICK) (between 24.1 & 40 yd <sup>2</sup> )	SY	110.00	N/A
S-008	FULL DEPTH PATCHING OF JOINTED CONC (8" THICK) (between 40.1 & 100yd <sup>2</sup> )	SY	100.00	N/A
S-009	FULL DEPTH PATCHING OF JOINTED CONC (8" THICK) (greater than 100 yd <sup>2</sup> )	SY	90.00	N/A
702(04)(A)	ADJUSTING MANHOLE	EACH	500.00	N/A
202(02)(C)	REMOVAL OF PCC PAVEMENT	SY	14.14	5.22

## Georgia

Data for construction pricing in the state of Georgia was retrieved from the Georgia DOT's tabulated item mean summary sheet (Georgia DOT, 2002), which summarizes bid prices from the state's construction bid tabulations. The item mean summary data for 2001 was located with the help of Mr. J.T. Rabun of the Georgia Department of Transportation. All concrete construction and rehabilitation projects in 2001 were included in the data. Table 3-3 shows each construction item's code, description, total quantity, unit of measure, and calculated average unit price.



**Table 3-3. 2001 Georgia bid prices**

Item Code	Description	Quantity	Unit	Average Unit Price (\$)
301-5000	PORTLAND CEMENT	340	TN	110.00
407-0010	ASPHALT-RUBBER JOINT & CRACK SEAL, TP M	8525	LF	2.60
407-0020	ASPHALT-RUBBER JOINT & CRACK SEAL, TP S	1006820	LF	1.02
431-1000	GRIND CONCRETE PAVEMENT	1687762	SY	5.07
439-0024	PLAIN PC CONC PVMT, CL 3 CONC, 11" THICK	29800	SY	62.65
439-0026	PLAIN PC CONC PVMT, CL 3 CONC, 12" THICK	87107	SY	50.15
439-0048	PLAIN PC CONC PVMT, CL HES CONC, 8" THICK	300	SY	65.65
439-0050	PLAIN PC CONC PVMT, CL HES CONC, 9" THICK	376150	SY	40.88
439-0052	PLAIN PC CONC PVMT, CL HES CONC, 10" THICK	81500	SY	59.30
439-0056	PLAIN PC CONC PVMT, CL HES CONC, 12" THICK	820	SY	117.00
439-0108	CRCP, CL HES CONC, 8" THICK	75000	SY	52.46
440-0001	PLAIN PC CONC SHOULDER	600	SY	57.22
444-1000	SAWED JOINTS IN EXIST PAVEMENT- PCC	4331	LF	6.36
445-0500	WATERPROOFING PVMT JOINTS & CRACKS	449010	LF	0.82
451-1100	PATCHING PCC PAVEMENT	5400	SF	76.91
452-1000	FULL DEPTH SLAB REPLACEMENT	21301	CY	373.05
461-1000	RESEALING ROADWAY JOINTS & CRACKS	569585	LF	2.10

## Mississippi

Cost data for concrete pavement construction activities in Mississippi for 2001 was acquired from Mr. Harry Rankin of the Mississippi Department of Transportation (Mississippi DOT, 2002). Table 3-4 lists the rigid pavement construction and rehabilitation items' description, unit of measure, and corresponding average unit prices. There are a limited number of items listed in Table 3-4 because the state of Mississippi only let two rigid pavement construction jobs during the year 2001. The apparent discrepancies in some of the data such as the unit prices for 9" and 10" plain PCC patching are due to the large differences in total quantity.

**Table 3-4. 2001 Mississippi bid prices**

Item Description	Unit	Average Unit Price (\$)
10" REINFORCED PCC PVMT	SY	26.45
11" REINFORCED PCC PVMT	SY	23.00
4" FIBER REINFORCED PCC PATCHING	SY	42.00
9" REINFORCED PCC PATCHING	SY	42.00
9" PLAIN PCC PATCHING	SY	80.00
10" PLAIN PCC PATCHING	SY	43.00
11" PLAIN PCC PATCHING	SY	43.00
12" PLAIN PCC PATCHING	SY	67.00
SILICONE JOINT SEALING	LF	4.75

## Ohio

Construction and rehabilitation price data for rigid pavements in the state of Ohio was acquired from the Ohio DOT. The average unit prices were obtained from a single, January 1999 LCCA limited to two rigid pavement and two flexible pavement alternatives (Ohio DOT, 2002). The Ohio DOT conducted the LCCA in January 1999. Table 3-5 lists various rigid pavement construction and rehabilitation activities and their corresponding average unit prices included in that LCCA.

**Table 3-5. Ohio bid prices**

<b>Item #</b>	<b>Description</b>	<b>Unit</b>	<b>Average Unit Price (\$)</b>
452	PLAIN CONC PAVEMENT	SY	19.67
202	REMOVE CONC PAVEMENT	SY	4.74
255	RIGID REPAIRS	SY	52.00
255	PAVEMENT SAWING	LF	1.80
801	LONG JOINT SEALING	LF	1.00
801	TRANSVERSE JOINT SEALING	LF	1.25
special	DIAMOND GRINDING	SY	2.20
256	BONDED PATCHING	SF	30.00

## **Section 4**

### **Southeastern States LCCA Practices**

This section summarizes the findings of two LCCA surveys. Mr. Michael Smith of the FHWA, Southern Resources Center, conducted the first survey and the UTCA completed the second survey. The first survey was conducted in January 2003. Personnel from the New Mexico, Florida, Texas, Alabama, Louisiana, Arkansas, North Carolina, Mississippi, Oklahoma, and Kentucky Departments of Transportation participated. Each state was asked the following questions regarding its LCCA procedures:

1. Does your state DOT currently conduct life-cycle cost analysis as part of its pavement type selection?
2. Does the DOT consider user costs as part of the LCCA?
3. How does the DOT consider user costs?
4. Does the DOT utilize a probabilistic approach to address uncertainty in the life-cycle inputs?
5. Does the DOT plan to eventually adopt the probabilistic approach?

The UTCA conducted the second survey in the spring of 2003. Personnel from the state DOT and/or FHWA representatives of North Carolina, Kentucky, Florida, Tennessee, and Georgia participated. Each state was asked the following questions regarding its LCCA procedures:

1. What are the DOT's decision criteria when pavement LCCA values for Asphalt and Concrete are very close?
2. Does your DOT use a salvage value in its LCCA calculations?

The state of Wisconsin was also included in the second survey even though it did not actively participate in the survey. The data requested from the second survey was available for Wisconsin from Alabama's "Life-Cycle Cost Analysis Peer Review" (ALDOT, 2002). The results of the both surveys are presented below.

#### **Survey 1 Results**

The DOTs' responses to questions 1, 2, 4, and 5 are listed in Table 4-1. The table shows that nine of ten states responding perform LCCAs as part of their pavement type selection. Only four of nine states consider user costs in any method. Eight of nine respondents use deterministic LCCA procedures, and only two of those eight plan to adopt probabilistic methods, while two more may adopt them.

A description of how the state currently considers user cost (question 3) is provided below for four states. The other six states do not consider user costs in their analysis.

Question 3: How does the Department of Transportation consider user costs?

**New Mexico:** New Mexico takes into account motorists' time value and vehicle operating costs in their LCCA. A spreadsheet is utilized to determine user costs.

**Florida:** Florida tries to keep traffic disruptions to a minimum without any queue developing. There are many night construction activities.

**Texas:** Texas uses several methods for calculating user costs. These include FHWA Demonstration Project-115 method, University of Texas software, and quick and dirty lump sums.

**Louisiana:** Louisiana follows FHWA's procedures for calculating user costs from the 9/97 FHWA Technical Bulletin: Life-Cycle Cost Analysis in Pavement Design (Smith & Walls, 1998).

**Table 4-1. Survey data**

State	LCCA?	Consider User Cost?	Deterministic or Probabilistic?	Plan to adopt Probabilistic?
New Mexico	Yes (large projects)	Yes	Deterministic	No
Florida	Yes	Yes	Deterministic	Maybe
Texas	Yes	Yes	Deterministic	No
Alabama	Yes	No	Deterministic	Maybe
Louisiana	Yes (large projects)	Yes	Deterministic	Yes
Arkansas	Yes (large projects)	No	Deterministic	No
North Carolina	Yes (major projects, SN >6)	No	Deterministic	Maybe
Mississippi	Yes	No	Deterministic	No
Oklahoma	No	A+B Bidding	-----	No
Kentucky	Yes	No	Probabilistic	-----

## Survey 2 Results

The results of the survey conducted by the University of Alabama are presented below. The results show that three of six respondents use a salvage value in their LCCA calculations. Three of six states rely on long lists of decision criteria if the asphalt and concrete alternatives are close, while two of the other three rely on less complicated judgments.

### *North Carolina*

The North Carolina DOT currently allows the Division responsible for the project to select its preferred pavement type if the LCCA results are very close. The DOT also considers the type of pavement on adjacent projects and usually tries to match it.

The North Carolina DOT does not currently use a salvage value in its LCCA calculations.

## ***Kentucky***

If LCCA results for asphalt and concrete options are very close in the state of Kentucky, an engineering decision is made on the type of pavement best suited for that specific project. This decision is based on many factors, such as those listed in Appendix B of the 1993 “AASHTO Guide for the Design of Pavement Structures” (AASHTO, 1993):

- Traffic
- Soils characteristics
- Weather
- Construction considerations
- Recycling
- Performance of similar pavements in the area
- Adjacent existing pavements
- Conservation of materials and energy
- Availability of local materials
- Contractor capabilities

The Kentucky DOT currently utilizes a salvage value when conducting LCCA’s. Their salvage value is based on converting the existing pavement structure to an equivalent thickness of aggregate base.

## ***Florida***

The Florida DOT uses the contractor’s bid to help decide which project alternative to select when the LCCA’s are very close. Florida’s current bid procedure is called the “A + B + C” bidding system. The “A” represents the contractor’s bid; the “B” represents the number of contract days in which the contractor says he can complete the work; the “C” represents the cost of future rehabilitations. The contractor has to bid on either an asphalt pavement project or a PCC pavement project.

The Florida DOT currently uses a salvage value, normally based on the remaining life of an alternative at the end of the analysis period rehabilitation cost.

## ***Tennessee***

The Tennessee DOT stated that if the LCCA results for concrete and asphalt pavement are very close, it is no longer an engineering decision at that point. Salvage value is not usually addressed in its LCCA calculations unless there is a clear indication of a need for a salvage value.

## ***Georgia***

The Georgia Department of Transportation points out that an LCCA is not the determining factor for any pavement type selection decision. Georgia evaluates other factors for pavement type selection such as staging, traffic control, constructability, budget, scope of work, and type of project.

The Georgia DOT does use a salvage value in its LCCAs. GDOT is currently in the process of implementing the new FHWA software, *Probabilistic LCCA 1.0*, which was used by the UTCA team in this project.

### ***Wisconsin***

If the Wisconsin DOT performs an LCCA that reveals less than 5% difference in costs between the asphalt alternative and concrete alternative, selection is based on the following factors:

- Impact to urban areas from pavement generated noise
- Surface friction characteristics
- Delineation
- Longevity
- Maintenance minimization
- Construction duration
- Budgetary issues and initial costs
- Historical performance of pavements on or adjacent to project
- Local project factors

The Wisconsin DOT does not include a salvage value in its LCCA.

## Section 5 Routine Maintenance

This section explores the feasibility of including the costs for routine maintenance activities in ALDOT’s pavement life-cycle cost analyses. Routine maintenance refers to any maintenance that is performed on a facility between initial construction and any subsequent major rehabilitation activity. For example, crack sealing and patching may be classified as routine maintenance activities.

ALDOT currently excludes routine maintenance activities from their pavement life-cycle cost analyses. This is because maintenance costs are minimal in relation to the overall NPV for any given alternative.

UTCA investigated the costs of minor maintenance activities on both asphalt pavement (flexible pavement) and concrete pavement (rigid pavement) at ALDOT. Data on routine maintenance costs was acquired from Mr. Ed Phillips, Assistant State Maintenance Engineer. Routine maintenance activities for asphalt pavement included spot premix patching, major premix patching, skin patching, strip patching, crack sealing, and pavement planing. Concrete maintenance activities included crack sealing, cleaning joints, joint sealing, and concrete pavement repair.

The costs for performing those activities were retrieved from ALDOT’s MM-902 reports for the 2000, 2001, and 2002 fiscal years. The inventory lane miles of these pavements were retrieved from ALDOT’s MM-600 reports from the corresponding fiscal years. This data was then used to calculate average maintenance costs on a per mile basis. The results of these findings are presented in Table 5-1.

**Table 5-1. Yearly routine maintenance costs**

Year	Asphalt Pavement	Concrete Pavement
2002	\$173.30 per lane mile	\$68.09 per lane mile
2001	\$242.14 per lane mile	\$87.28 per lane mile
2000	\$196.99 per lane mile	\$64.40 per lane mile

The prices per lane mile for both asphalt and concrete pavement shown in Table 5-1 are very low in comparison to the NPV costs associated with a particular project alternative. For example, referring to the agency costs per lane mile for the I-20, Talledega County Project discussed in Section 10, “LCCA Procedure Comparisons,” the total NPV agency cost for the asphalt alternative is almost \$6 million. That particular project is about 6 miles long and 3 lanes in each direction. If routine maintenance is performed over the entire project two times, the total routine maintenance cost for the project would be only

about \$6000. This is only 0.1% of the total agency cost. Because of this extremely small percentage, routine maintenance may be omitted in ALDOT LCCAs.

It should also be noted that FHWA recommends not including user costs for work zones erected for routine maintenance when performing an LCCA. Routine maintenance work zones are typically infrequent, of short duration, and outside of peak traffic flow periods. Section 8, "User Costs and Queues," describes the basics of user cost calculations.

### **Additional PCC Maintenance**

Routine maintenance costs listed above are performed by ALDOT forces and cost data are collected by the Maintenance Bureau. Other concrete maintenance activities are contracted:

- Pressure grouting
- Cleaning, sealing, and waterproofing joints and cracks
- Grinding
- Slab removal
- Slab replacement

The costs for performing those activities for calendar years 2001 and 2002 were taken from ALDOT's published bid tabulations (ALDOT, 2002) and divided by the lane-miles of concrete pavement in the state. For 2001, the cost was \$873 per lane mile. For 2002, the cost was \$1,150 per lane mile. These costs are also extremely small compared to initial agency costs and can be eliminated from LCCA calculations without significantly affecting the results.



## **Section 6**

### **Pavement Performance Periods**

The performance period of a pavement activity is essential in determining the appropriate year that any future rehabilitation activity is performed. Given the importance of correctly identifying a pavement activity's performance period, the UA team researched the performance periods of various asphalt and concrete pavement designs.

#### **Current Values**

ALDOT currently uses a 28-year cycle in its LCCA. The cycles for asphalt pavement and concrete pavement are given below:

- Asphalt pavement is assigned a 12-year initial performance period followed by two, eight-year asphalt overlays.
- Concrete pavement is assigned an initial 20-year performance period followed by one major concrete pavement rehabilitation project that extends the pavement life another 8 years.

#### **Re-evaluation**

The UA research team attempted to re-evaluate the performance period values presented under the previous heading to determine if the values needed updating. The re-evaluation was initially attempted using the computer program "Highway Yearly Distress Rating and Analysis" (HYDRA) that is currently under development by ALDOT.

Unfortunately, the program is not yet fully operational, and the analysis could not be completed for this report. However, when HYDRA is operational, that re-evaluation should be performed to determine if current values are valid and to determine if a longer LCCA analysis period should be set; FHWA recommends a minimum analysis period of at least 35 years. However, 20 to 30 year analysis periods may be used. In general, the analysis period should be longer than the initial pavement performance period and long enough to incorporate at least one rehabilitation activity (FHWA, 2002, Primer).

#### **Values for New Paving Materials**

ALDOT has begun using several new asphalt paving materials in recent years:

- Stone Matrix Asphalt (SMA) has been used in the top four inches (under an open graded friction course) of Interstate roads in Alabama since 2000. SMA has also been used on some non-Interstate routes where rutting has been a problem.
- Superpave has been used in Alabama since 1994, when each ALDOT Division performed one project. Then, each Division performed 2 Superpave projects in 1995. Since 2000, Superpave has been used almost 100% on non-Interstate ALDOT projects.

It is appropriate to evaluate the performance periods of these new materials. However, their recent adoption preclude that evaluation at this time.

## **Section 7**

### **Probabilistic LCCA**

This section introduces a probabilistic approach to life-cycle cost analysis in pavement design. The probabilistic approach is often referred to as the risk analysis approach. This section will explain the concept of risk analysis and will also describe some of the shortcomings associated with the deterministic approach. The Monte Carlo simulation technique is introduced for treatment of uncertain LCCA input variables.

#### **Risk Analysis**

Risk comes from the uncertainty associated with future events. Risk analysis is performed to estimate what event might happen in the future, how likely that event is to happen, and the consequences of that event happening. In the case of a pavement LCCA, one event that is a prime concern is the overall net-present value (NPV) agency cost of a project. A risk analysis is an excellent way to analyze it.

Risk analysis results are usually presented in the form of a probability distribution, which shows the range of possible values and the probability of their occurrence. This allows the decision maker to weigh the probability of an outcome actually occurring (Smith & Walls, 1998).

#### **Deterministic vs. Probabilistic LCCA**

In a deterministic approach to a life-cycle cost analysis, the analyst uses a single discrete value, or mean value, for each input variable. Discrete values are typically best estimates based on historical data and engineering judgment. Using a mean value for the input variable does not account for the randomness of the process, and may result in a different outcome from that of the probabilistic approach (Tighe, 2001). Thus, the deterministic outcome can lead to debate about the validity of results. To account for the uncertainties in any life-cycle cost analysis, FHWA recommends performing an LCCA using the probabilistic or risk analysis approach, rather than the deterministic approach.

A majority of input variables in a pavement LCCA are uncertain, such as the initial cost, future cost, and performance period of the pavement. Addressing these uncertainties makes the results more relevant to the real world (Tighe, 2001). A probabilistic LCCA addresses these uncertainties by allowing ranges of inputs (probability distributions) to be entered rather than a single mean value, as is entered in the deterministic approach. The probabilistic results are in the form of a probability distribution. This allows the analyst to identify the NPV for an alternative, at a specified level of probability. For example, an analyst using the probabilistic approach to an LCCA might find that there is a 90%

probability that the NPV for alternative 1 is \$4 million or less, and there is only a 20% probability that the NPV for alternative 2 is \$4 million or less. Figure 7-1 below shows how the NPV probability distribution is generated (Smith & Walls, 1998).

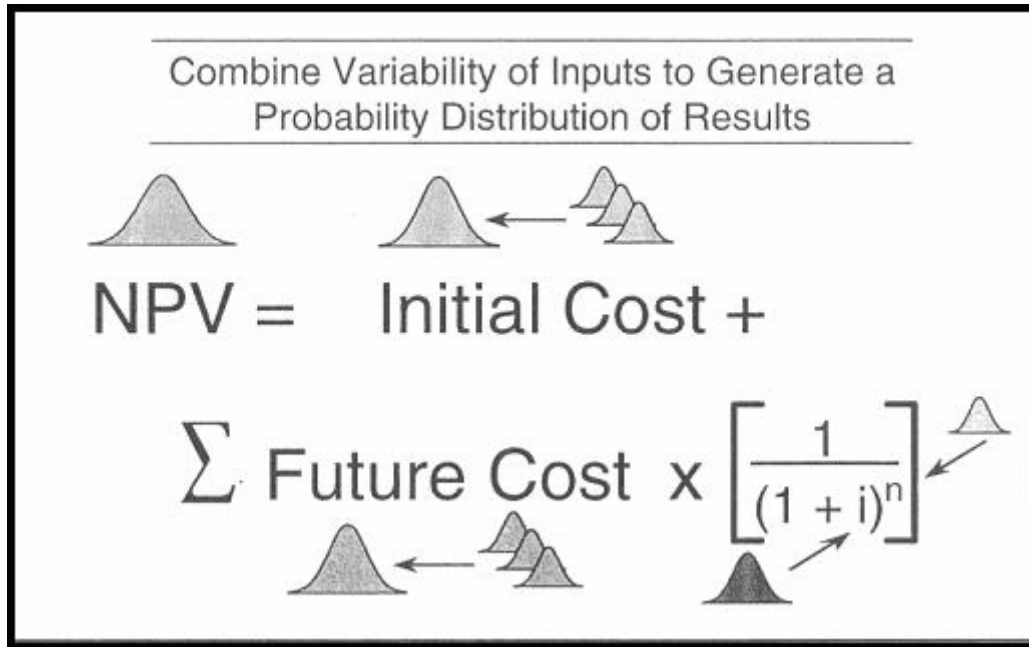


Figure 7-1. NPV distribution generation (Smith & Walls, 1998)

### Monte Carlo Simulation Technique

The Monte Carlo simulation technique is used in computerized probabilistic LCCA. Monte Carlo simulation is a process of using random numbers to sample from probability distributions. As illustrated in Figure 7-2 below, a computer generates a series of random numbers between 0 and 1 along the cumulative probability scale of the input distribution. Values corresponding to each random number are sampled along the x axis for each parameter in the LCCA. For example, when the computer generates the random number of 0.65, the corresponding value of  $X_{.65}$  is sampled. The sampled value is then combined with other distribution samples to generate a single result (Smith & Walls, 1998). In the case of a pavement LCCA, the single generated result would be the NPV cost. It is important to note that all values along the cumulative scale y-axis have equal probability of being selected.

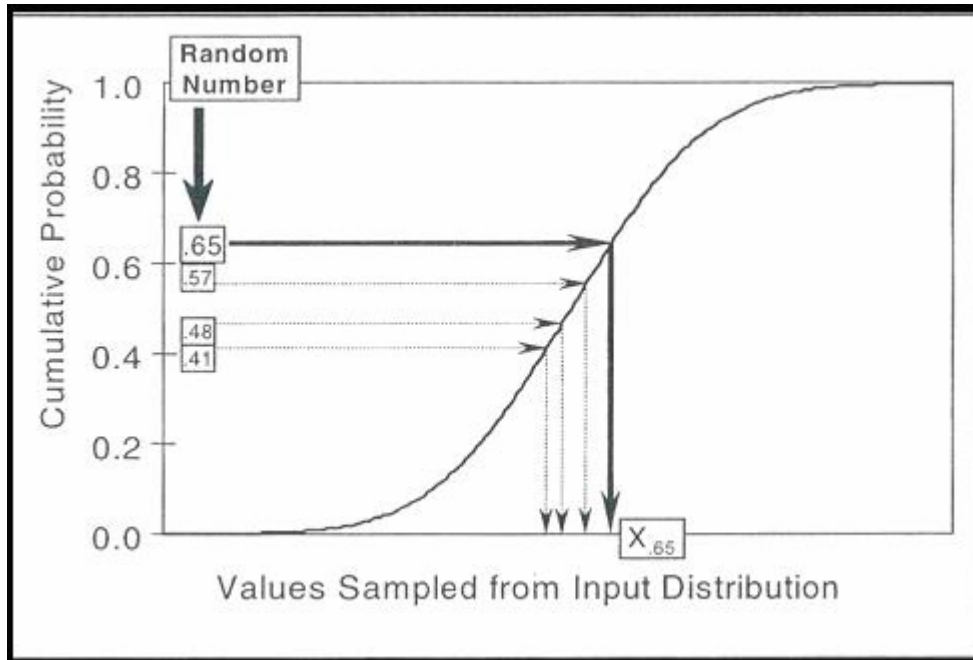


Figure 7-2. Monte Carlo simulation (Smith & Walls, 1998)

One iteration of the simulation process represents one possible scenario or outcome. The process of sampling from a probability distribution is repeated until the specified number of iterations is completed or until the simulation process converges. The simulation converges at the point where additional iterations do not significantly change the output distribution (Smith & Walls, 1998). Usually 1000 or more iterations are sufficient. A final output probability distribution is produced by the simulation.

A description of how to conduct the probabilistic analysis using the FHWA software is provided in Section 9 “FHWA Software.”

## Section 8 User Costs and Queues

This section describes the consideration of user costs in conducting a pavement life-cycle cost analysis. User costs are defined as the costs incurred by the traveling public. These costs include vehicle operating costs and travel time costs (the cost of the driver's time lost while waiting in traffic). User costs arise from the timing, duration, and scope of construction work zones, because work zones usually restrict the normal capacity of the facility (FHWA, 2002, Module 2).

Most state DOTs base their life-cycle cost analyses on costs directly incurred by the transportation agency such as construction costs, maintenance costs, and resurfacing/rehabilitation costs. However, the driving public incurs user costs. This project performed example calculations of the effect that user costs had on the final results of an LCCA. Section 10 "LCCA Procedure Comparisons" shows these results and indicates that user costs can be higher than agency costs.

The queue length of backed-up drivers that results from a work zone during the construction or rehabilitation of a roadway is also a useful value. Some states use predicted queue length as an important input during pavement type selection. This section will address the basics of how user costs are incurred, how they can be calculated, and how the length of the queue may be calculated.

### Origins of User Costs

There are seven possible user cost components that the traveling public can incur while traversing a work zone. Three of these components are associated with a free flow condition and four are associated with the forced-flow condition. The forced flow condition refers to the situation in which a queue forms upstream of the work zone, while there is no queue that forms while the work zone is in the free flow condition.

In the case of the free-flow condition, cars must slow to the posted work zone speed limit, but there is no major impediment, so no queue develops. The three user cost components that arise from vehicles traversing a work zone in free-flow conditions are 1) *speed change delay*, 2) *speed change vehicle operating costs (VOC)*, and 3) *reduced speed delay*. *Speed change delay* is the additional time required to decelerate from the upstream speed to the work zone speed, and to accelerate back to the initial upstream speed after traversing the work zone. The *speed change VOC* is the additional vehicle operating cost associated with decelerating from the upstream approach speed to the work zone speed and then accelerating back to the approach speed. The *reduced speed delay* is defined as the additional time required to traverse the work zone at the lower posted speed. *Reduced speed delay* is dependant on the upstream and work zone speed differential and the length of the work zone (Smith & Walls, 1998). *Speed change delay*

and *reduced speed delay* are travel time costs; *speed change VOC* is a vehicle operating cost. Figure 8-1 shows a work zone in free-flow condition and the user cost components associated with it (Smith & Walls, 1998).

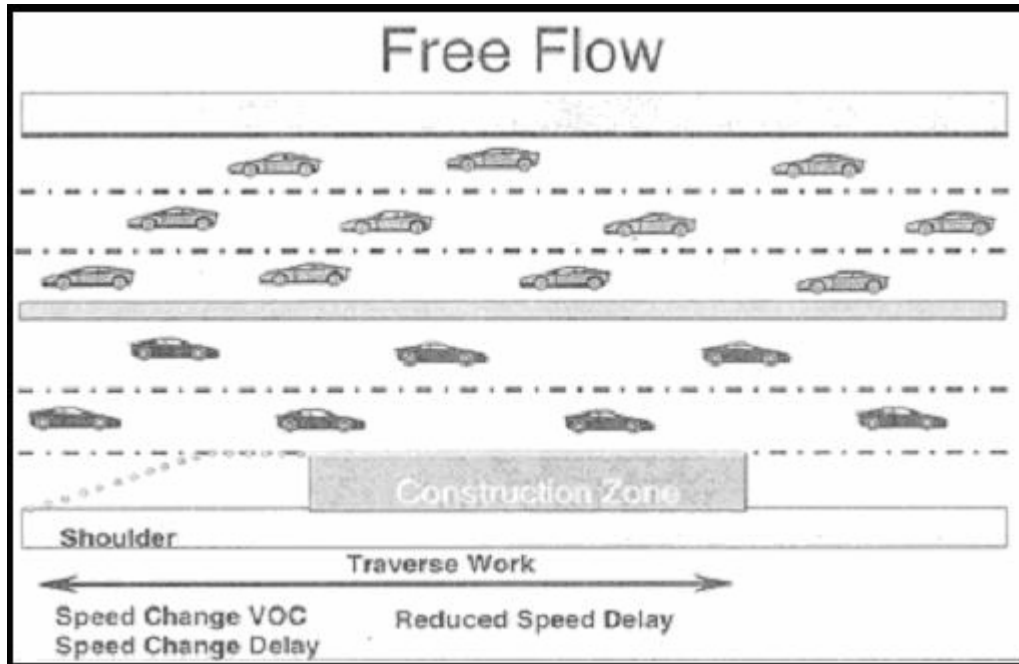


Figure 8-1. Free flow conditions (Smith & Walls, 1998)

In the case of the forced flow condition, the hourly traffic demand exceeds the work zone capacity. As a result, a queue forms upstream of the work zone. The forced flow condition imposes four user cost components: 1) *stopping delay*, 2) *Stopping VOC*, 3) *Queue Delay*, and 4) *Idling VOC*. Note: these cost components are only incurred when vehicles encounter a queue. The *stopping delay* is the additional time necessary to come to a complete stop from the upstream approach speed and the additional time necessary to accelerate back to the approach speed after leaving the work zone. The *stopping VOC* is the vehicle operating cost associated with stopping from the upstream approach speed and accelerating back up to the approach speed. The *queue delay* is defined as the time necessary to pass through the queue under forced-flow conditions. Lastly, the *Idling VOC* is the vehicle operating cost associated with stop-and-go driving while traversing the queue (Smith & Walls, 1998). Figure 8-2 shows a work zone under forced flow conditions and the user costs associated with it.

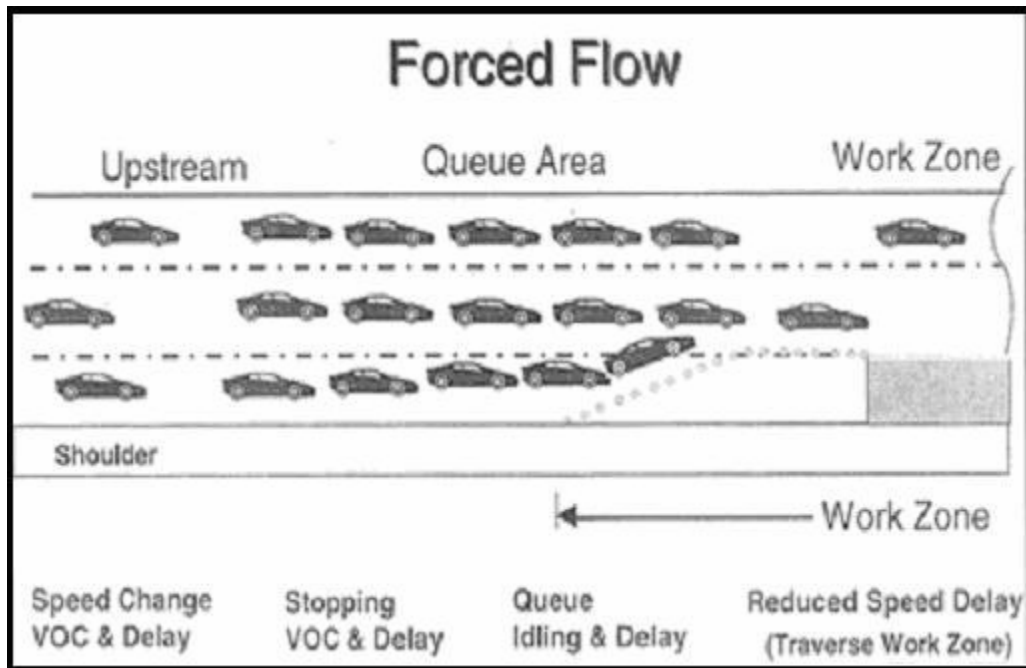


Figure 8-2. Forced flow conditions (Smith & Walls, 1998)

### Calculating User Costs

A designer must have specific knowledge of work zone characteristics and traffic characteristics to calculate the user costs that are incurred by the driving public as a result of the work zone. Each work zone established over the analysis period affects traffic flow, and thus user costs. The user costs are calculated by analyzing the hourly demand of the work zone versus the hourly capacity of the work zone. The specific characteristics of the work zone that must be acquired for each major construction or rehabilitation activity follow:

- Projected year the work zone occurs
- Number of days the work zone will be in place
- Specific hours of each day the work zone will be in place (e.g., 10 pm – 6 am)
- Work zone length
- Work zone speed limit (mph)
- Number of lanes available during construction activity (Note: if shoulder is used as a lane, it counts as a lane)

The specific traffic data that needs to be acquired to calculate work zone related user costs in the FHWA LCCA computer program follow:

- AADT (average annual daily traffic)
- Single unit trucks as percent of AADT
- Combination unit trucks as percent of AADT
- Traffic hourly distribution (hour by hour)
- Annual growth rate of traffic (percent)



- Speed limit under normal operating conditions (mph)
- Free flow capacity (vehicles per hour per lane)
- Class-by-class values of travel time (\$/vehicle-hour)

(Smith & Walls, 1998) provides a step-by-step method for calculating user costs by hand or with Microsoft Excel. This method is very labor intensive. The easiest way to calculate work zone related user costs is to use an Excel-based spreadsheet program. The new *FHWA Probabilistic LCCA Version 1.0* is capable of calculating the user costs, given the required work zone and traffic data. The FHWA program is explained more thoroughly in Section 9, “FHWA Software.” The program does an hour-by-hour comparison of roadway capacity and traffic demand. From this comparison, the program determines how many vehicles per hour traverse the work zone and how many vehicles traverse a possible queue. Class-by-class vehicle operating cost (VOC) rates and delay cost rates are then applied to calculate each of the seven possible user cost components described previously. FHWA includes recommended values for VOC rates and delay cost rates (Smith & Walls, 1998). Each of the user cost components are summed to calculate the user cost incurred by the driving public for one day’s work zone. The total user cost associated with the reconstruction or rehabilitation activity is calculated by multiplying the total number of days the work zone is in place by the user cost incurred during one day.

### **Calculating Queue Lengths**

Some state DOTs that do not directly consider user costs when performing a LCCA are still very interested in determining the queue length that might develop in the construction/rehabilitation activities modeled. The FHWA software program is also capable of calculating hour-by-hour queue lengths. The same data needed to calculate user costs is needed to calculate queue lengths, with the exception of any monetary values used. The FHWA software program calculates the length of queue during each hour by dividing the average number of queued vehicles for that hour by the change in traffic density during that hour. This method is thoroughly explained elsewhere (Smith & Walls, 1998). Instructions on how to determine the queue length as well as how to run the software are provided in Section 9, “FHWA Software.”

## **Section 9**

### **FHWA Software**

This section presents a basic overview of the FHWA's *Probabilistic LCCA Version 1.0* software. This software was released for public use in August 2002 and will probably become the standard LCCA package for state DOTs. Conducting a probabilistic LCCA considering both agency and user costs is a computationally intensive effort. However, the FHWA software allows the analyst to perform an LCCA practically at the push of a button. The analyst must have prior knowledge of the FHWA's LCCA procedures to properly operate the new software (FHWA, 2002, Draft). *Probabilistic LCCA 1.0* requires that all of the data required to perform an LCCA be acquired and input into the program. The program offers the analyst a wide range of capabilities:

- Automation of FHWA user cost method
- Option of deterministic and probabilistic modeling
- Calculation of agency and user life-cycle costs
- Calculation of queue length
- Production of text and graphic outputs
- Form and spreadsheet interface

*Probabilistic LCCA 1.0* is a Microsoft Excel 2000 spreadsheet-based program that contains a Visual Basic graphical user interface (GUI) to improve usability. It was developed over the course of a year and a half and completed in May 2002. The software has been tested by representatives from 10 state DOTs, industry group personnel, and academic institutions such as at the University of Alabama. This software was derived from FHWA Demonstration Project 115 and input from the FHWA, state DOTs, and industry groups. The outputs from this software do not completely identify which alternative is the best, but do provide means to determine the lowest net-present value (FHWA, 2002, Module 4).

The FHWA is currently developing a full set of instructions to operate this software (FHWA, 2002, Draft). This draft may be obtained from Mr. Michael Smith, FHWA, Southern Resource Center, (Michael.Smith@FHWA.dot.gov).

This section presents the inputs needed to operate the software and provides examples of the input screens. Some specific sources of input data for using *Probabilistic LCCA 1.0* in Alabama are also provided. This section also discusses the software's output and provides a description of the various output screens. Finally, this section illustrates how to retrieve queue lengths calculated by the software.

## Probabilistic LCCA 1.0 Inputs

When running *Probabilistic LCCA 1.0*, the analyst is prompted to enable or disable macros before the program is opened. The user must *enable* the macros. The analyst is then presented with the “LCCA Switchboard” when the program opens. This is the central part of the GUI. Each button on the “Switchboard” takes the analyst to a different form where data is input or functions are performed. When the analyst leaves one of these areas, the program returns to the Switchboard. Figure 9-1 shows the LCCA Switchboard.

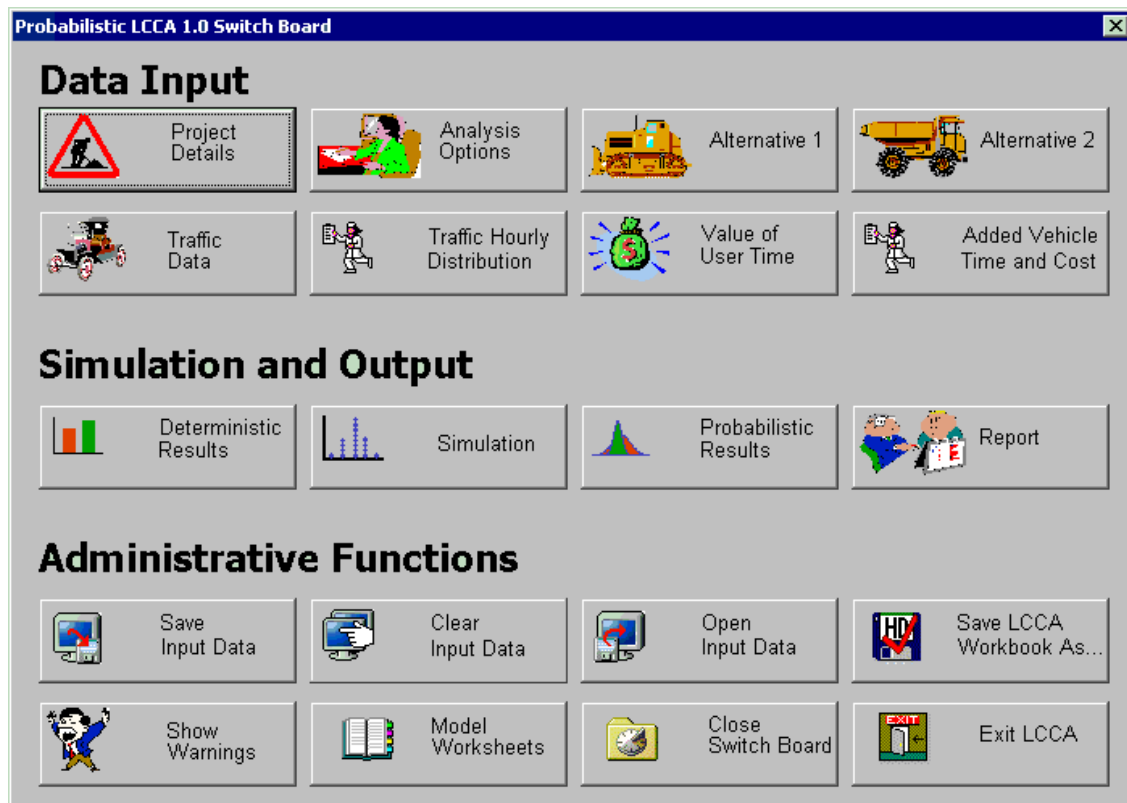


Figure 9-1. “LCCA switchboard”

The Excel-based software program contains 26 worksheets for input data, output data, supplemental data, and user cost calculations. The analyst can navigate among the worksheets by utilizing the tabs at the bottom of the screen (See Figure 9-2). Instead of using user-friendly input screens available on the Switchboard, the analyst can input data directly into the Input worksheet by closing the LCCA Switchboard and entering the correct data into the corresponding yellow boxes within the worksheet. This worksheet can be accessed by clicking on the “Input Data” tab at the bottom of the screen. Thus, the Switchboard is not required to run the program; however, it is very helpful.

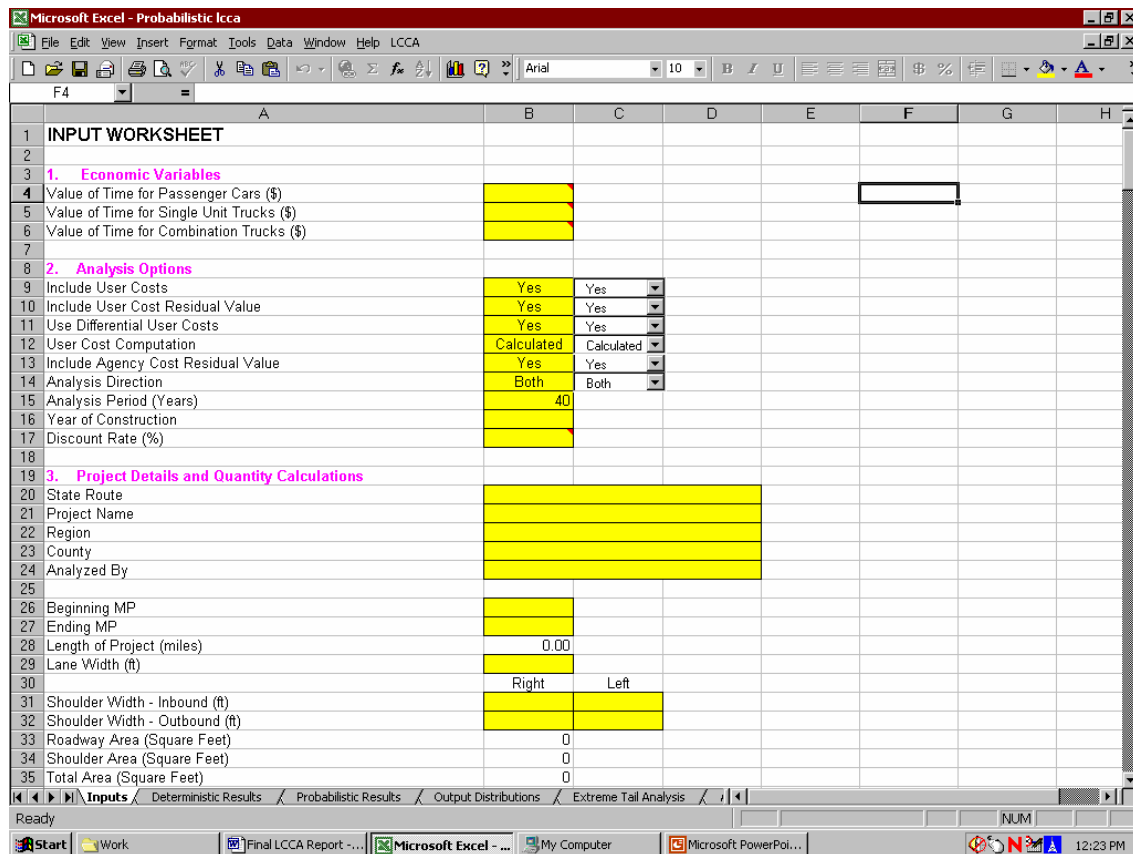


Figure 9-2. Input worksheet

There are three main areas on the LCCA Switchboard:

1. Data Input – Where information is entered about LCCA
2. Simulation and Output – Where Monte Carlo simulation is run and output is viewed
3. Administrative Functions – Contains functions such as saving and loading data, worksheet navigation, and closing the Switchboard

Each button under the “Data Input” heading of the LCCA Switchboard contains an input form. There are eight buttons or forms for entering LCCA inputs. These forms include the following:

1. Project Details – general documentation and metadata (data about the data)
2. Analysis Options – settings that are common to both LCCA alternatives
3. Alternative 1- Data specific to alternative 1 (e.g., non-discounted agency costs, work zone data, etc.)
4. Alternative 2 – Data specific to alternative 2
5. Traffic Data – Data required when user cost calculations will be performed
6. Traffic Hourly Distribution
7. Value of User Time –used to calculate user delay costs

8. Added Vehicle Time and Cost – used to calculate slowing and stopping costs and delay

A complete list of inputs is needed to successfully complete an LCCA using *Probabilistic LCCA 1.0* is given below. Sources for some of the data items are provided in brackets next to the input.

1. Project Details (route, project name, county, etc.)
2. Year of construction
3. Analysis period [ALDOT uses 28 years]
4. Discount rate [ALDOT uses 4%]
5. Construction alternative data
  - a. Description
  - b. Construction cost (\$) [Materials and Tests Bureau]
  - c. Expected life (years) (Performance Period of initial construction or rehabilitation activities)
  - d. Minor maintenance frequency (years)
  - e. Minor maintenance cost (\$)
  - f. Work zone length (miles) [ALDOT Construction Bureau]
  - g. Work zone capacity (vphpl) [(Smith & Walls, 1998) supplies a table of values]
  - h. Work zone duration (days) [ALDOT Construction Bureau]
  - i. Number of lanes open in each direction during work zone, [ALDOT Construction Bureau]
  - j. Work zone hours (periods of lane closure on 24 hr clock) [ALDOT Construction Bureau]
  - k. Work zone speed limit (mph) [ALDOT Construction Bureau]
6. AADT, [Transportation Planning Bureau, ALDOT]
7. Single Unit Trucks as % AADT, [Transportation Planning Bureau, ALDOT]
8. Combo Unit Trucks as % AADT, [Transportation Planning Bureau, ALDOT]
9. Annual growth rate of traffic (%), [Transportation Planning Bureau, ALDOT]
10. Speed limit under normal operating conditions (mph)
11. Free flow capacity (vphpl) (software is capable of performing this calculation)
12. Queue dissipation capacity (vphpl) [(Smith and Walls, 1998)]
13. Maximum AADT (used to limit AADT value for any given work zone being modeled)
14. Maximum Queue Length (miles) (used to limit queue length values for any given work zone being modeled, may prevent over-inflated user costs)
15. Rural or Urban?
16. Traffic Hourly Distribution (hr by hr) [Transportation Planning Bureau, ALDOT]
17. Added Time and Vehicle Stopping Costs (user costs due to speed changes) (software has defaults)
18. Value of Time (\$) [(Smith and Walls, 1998) provides a table of values]
  - a. Passenger cars
  - b. Single unit trucks
  - c. Combination trucks

Many variables within the FHWA software have the preset capacity to serve as probabilistic inputs if the analyst so chooses. By clicking on a button to the right of the input field, the analyst is automatically taken to the “Probability Function Form.” An example button is shown next to the Discount Rate input field in Figure 9-3 below. Once the appropriate probability distribution has been chosen, the analyst must specify values for certain parameters to define the distribution. The probability distributions available in this program, along with the corresponding parameters in parenthesis, are listed below. Note: If a probabilistic distribution has been entered for any value, the mean value will appear in red on the input form.

1. Uniform (min, max)
2. Normal (mean, standard deviation)
3. Lognormal (mean, standard deviation)
4. Triangular (min, max, most likely)
5. Beta (alpha, beta)
6. Geometric (probability)
7. Truncated Normal (mean, standard deviation, min, max)
8. Truncated Lognormal (mean, standard deviation, min, max)

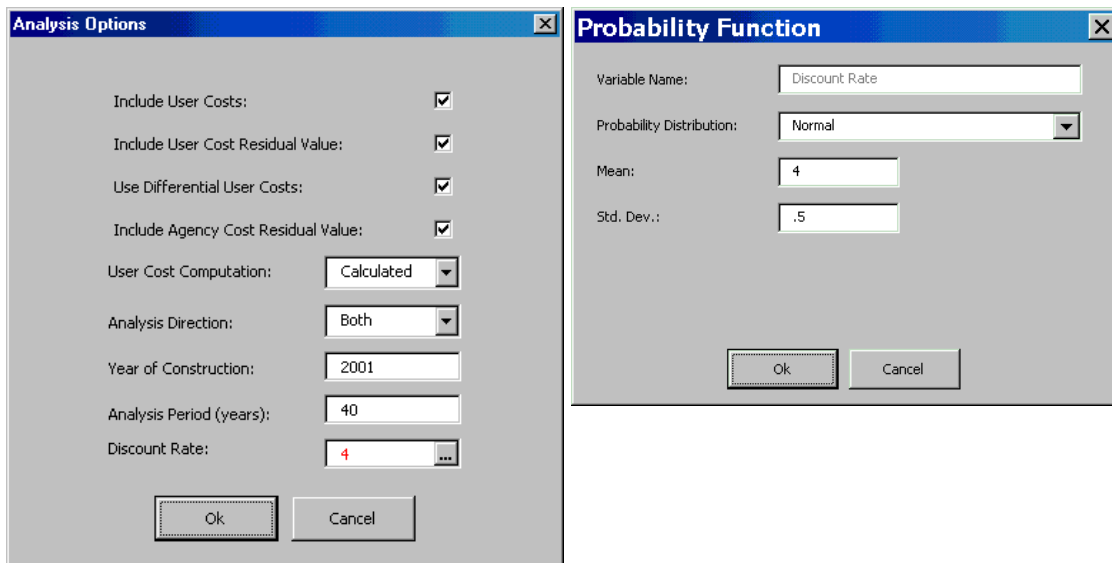


Figure 9-3. Analysis options

Probability distributions may be entered in any of the following input spaces to conduct a probabilistic LCCA:

1. Queue dissipation capacity
2. Values of user times
3. Work zone capacity
4. Work zone duration
5. Annual traffic growth rate
6. Free flow capacity
7. Discount rate
8. Construction cost
9. Expected life
10. Minor maintenance (routine maintenance) frequency (ALDOT does not use this input in the LCCA procedure)
11. Maintenance cost (routine maintenance cost) (ALDOT does not use this input in the LCCA procedure)

The program will run the Monte Carlo simulation and provide a probabilistic output if at least one input contains a distribution rather than a discrete value. Thus, the analyst does not have to use probability distributions for all eleven parameters listed above to perform a probabilistic LCCA.

Most of the input forms within this program are self-explanatory. However, the Alternative 1 and Alternative 2 forms require additional explanation. These forms define agency activities. The forms for Alternative 1 and Alternative 2 are identical. An example of an Alternative 1 input form is shown in Figure 9-4.

There are rehabilitation tabs at the top of the form in Figure 9-4. Each of the Rehabilitation tabs contains an input screen identical to that of the Initial Construction tab. Also, the User Cost space in Figure 9-4 appears “ghosted” because the analyst had previously instructed the program to calculate user cost. Note: the option to calculate user costs or specify a user cost is provided on the “Analysis Options” input form.

An analyst models at least one major rehabilitation with each alternative when performing a pavement life-cycle cost analysis. *Probabilistic LCCA 1.0* allows the user to define up to six major rehabilitation activities. It is important to note that for any of the six rehabilitation activities not modeled, the analyst must still enter three inputs for each of these input spaces for the software to run properly. The data that must be entered even if there is no scheduled rehab activity include:

1. Work zone speed limit
2. Work zone capacity
3. Number of lanes open in each direction

**Alternative 1**

Description: Flexible Pavement

Initial Construction | Rehabilitation 1 | Rehabilitation 2 | Rehabilitation 3 | Rehabilitation 4 | Rehabilitation 5 | Rehabilitation 6

Work Description: Reconstruction

Construction Cost (\$1000): 7411 ... User Cost (\$1000): 200 ...

Expected Life (years): 10 ... Maintenance Cost (\$1000): 10 ...

Maintenance Frequency (Years): 4 ... Work Zone Duration (days): 276 ...

Work Zone Length (miles): 1 ... Work Zone Speed Limit (mph): 45 ...

Work Zone Capacity (vphpl): 1470 ... No of Lanes Open in Each Direction During Work Zone: 2 ...

Work Zone Hours

	Inbound		Outbound	
	Start	End	Start	End
First Period of Lane Closure:	5	15	5	15
Second Period of Lane Closure:	0	0	0	0
Third Period of Lane Closure:	0	0	0	0

Copy

Paste

Open... Save... Ok Cancel

**Figure 9-4. Alternative 1 input form**

For example, consider a hypothetical situation where Alternative 1 consists of an initial construction and only one major rehab activity, such as an asphalt overlay. The speed limit, capacity, and number of lanes *under normal operating conditions* must be entered for 1) work zone speed limit, 2) work zone capacity, and 3) number of lanes open in each direction, respectively, for Rehabilitation Forms 2 through 6. Even though there is no construction activity and thus no work zone is being modeled, this information must still be entered.

If the analyst wishes to perform a probabilistic analysis without considering user costs, the following steps must be taken to assure that the program runs correctly:

1. Make sure the box labeled "Include User Cost" is NOT checked within the "Analysis Options" input screen.
2. The boxes labeled "Include User Cost Residual" and "Use Differential User Cost" should also be blank on the same input screen.
3. Any number greater than zero must be entered into the following spaces within the "Traffic Data" input screen:
  - A) AADT
  - B) Number of lanes



- C) Free flow capacity
  - D) Queue dissipation capacity
4. Any number greater than zero must be entered into the following spaces within the “Alternative 1” and “Alternative 2” input screens:
- A) Number of lanes open in each direction during work zone
  - B) Work zone speed limit
  - C) Work zone capacity

### Deterministic Results

As previously mentioned, this software is capable of reporting both deterministic and probabilistic results. The deterministic results of an LCCA are examined first.

The software produces the Deterministic Results worksheet even when a probabilistic analysis is performed. The deterministic results are calculated by using the most likely values of the probabilistic functions entered. The deterministic results can be viewed by clicking on the Deterministic Results button on the LCCA Switchboard. As seen in Figures 9-5, 9-6, and 9-7, the software produces tables and graphics of nominal NPV and EUAC to compare alternatives. ALDOT relies on the NPV.

**Deterministic Results**

Total Cost	Alternative 1: Flexible Pavement			Alternative 2: Rigid Pavement		
	Agency Cost (\$1000)	User Cost (\$1000)	Total Cost (\$1000)	Agency Cost (\$1000)	User Cost (\$1000)	Total Cost (\$1000)
Nominal \$	\$12,767.00	\$8,033.40	\$20,800.40	\$12,444.00	\$7,294.14	\$19,738.14
Present Value	\$9,968.73	\$4,536.00	\$14,504.73	\$11,678.05	\$5,215.76	\$16,893.81
EUAC	\$503.66	\$229.17	\$732.83	\$590.02	\$263.52	\$853.53

Lowest Present Value Agency Cost	<b>Alternative 1: Flexible Pavement</b>
Lowest Present Value User Cost	<b>Alternative 1: Flexible Pavement</b>
Lowest Present Value Total Cost	<b>Alternative 1: Flexible Pavement</b>

Go to Worksheet      Close

Figure 9-5. Deterministic results

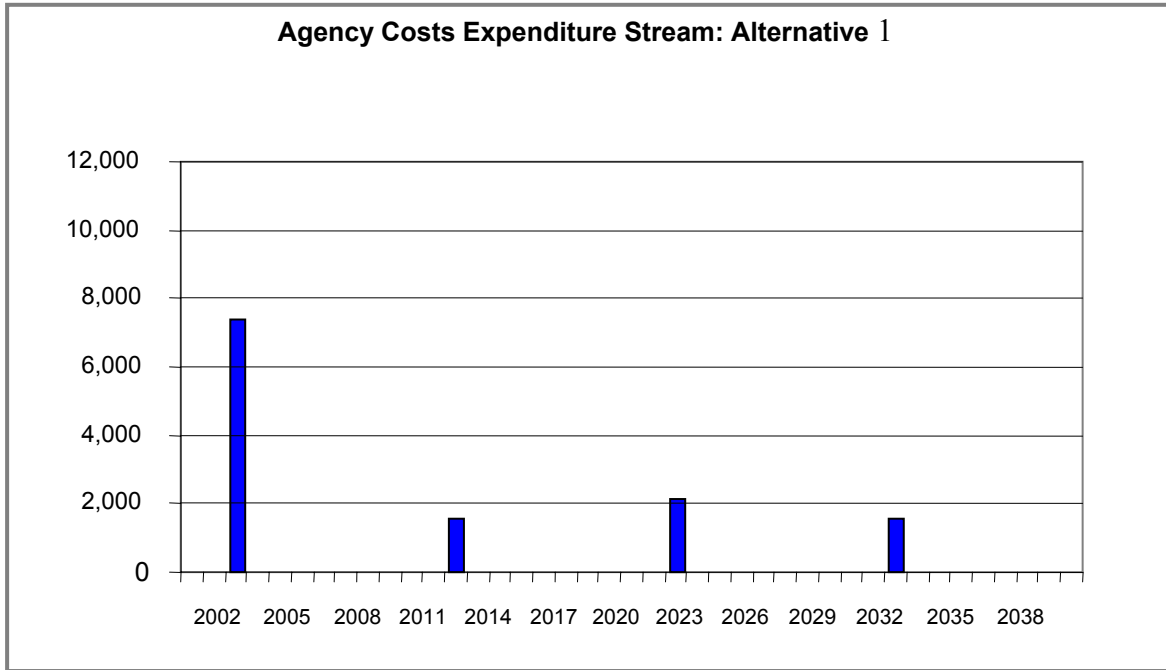


Figure 9-6. Expenditure stream

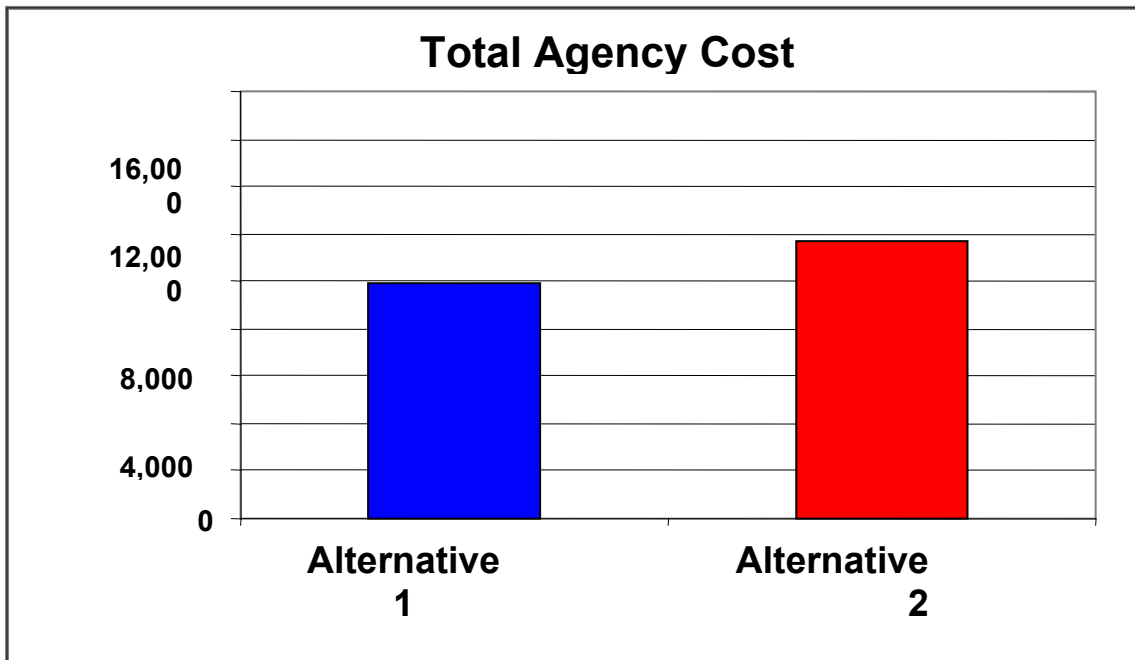


Figure 9-7. Agency cost comparison

## **Simulation**

*Probabilistic LCCA 1.0* uses Monte Carlo simulation to generate the probabilistic results. To run a simulation, the analyst must enter the number of iterations and a seed value in the corresponding spaces on the Simulation input page. The number of iterations is the number of simulation runs that the computer will perform. There are no minimum or maximum number of iterations, and many analysts run at least 1000. The seed value sets the number that the random number generator will start on. If the analyst wishes to repeat the results, the same seed value must be used for different simulation runs. If the analyst wants the computer to pick a random seed value, the “random results” bullet is selected on the Simulation input page.

The software is also able to monitor convergence if the analyst enters the convergence monitoring frequency found on the Simulation input page. The default value is 50 iterations. The simulation ends when convergence is reached. Convergence indicates that further simulation iterations will not significantly alter the probabilistic outputs (FHWA, 2002, Module 4).

## **Probabilistic Results**

Probabilistic results can be viewed by clicking the “Probabilistic Results” button on the Switchboard. The Probabilistic Results form produces a mean value, standard deviation, and minimum and maximum values for the basic LCCA outputs. The results are presented in a table, as shown in Figure 9-8. Graphs containing both the probability distribution and cumulative probability distributions for agency and user costs are produced on the Probabilistic Results worksheet shown in Figure 9-9. The leftmost line indicates alternative 1, and the line on the right indicates alternative 2.

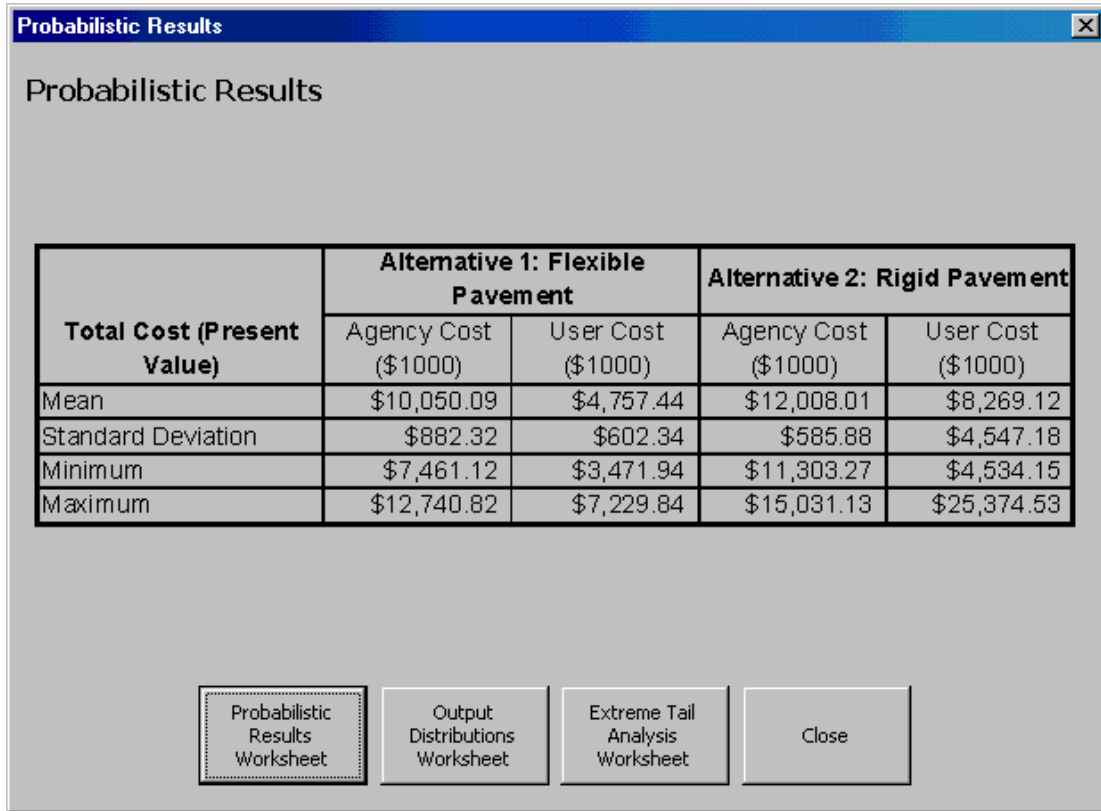


Figure 9-8. Probabilistic results

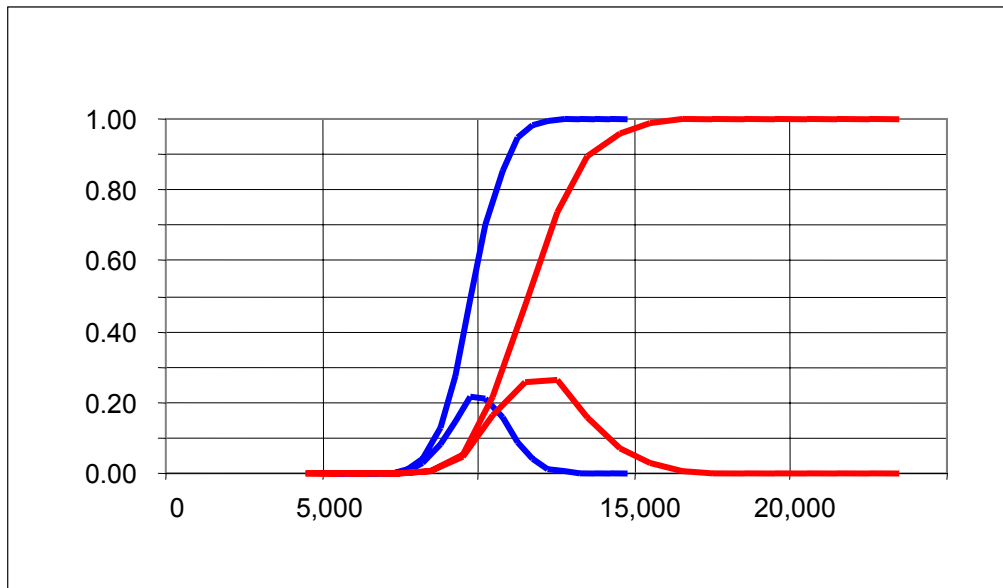


Figure 9-9. Probabilistic results worksheet

The “Probabilistic Results” worksheet also contains graphs that show the correlation coefficients of each input variable. The correlation coefficient demonstrates the sensitivity of outputs to changes in inputs. A correlation coefficient has a value between -1 and +1. A negative correlation coefficient represents an inverse relationship. As the correlation coefficient approaches +1 or -1, the relationship between the input variable and the output variable increases. A correlation coefficient of zero shows that there is no relationship between the input variable and the output variable. The Probabilistic Results worksheet presents the correlation coefficients of each input variable in both a “Tornado Plot” and a table, (see Figure 9-10). The Tornado Plot in the upper half of the screen presents a graph of the tabular data. Notice that there is a separate table/plot for the agency cost and the user cost for each alternative. For example, the Initial Construction cost for the Agency Cost of Alternative 1 has a correlation coefficient of 0.73. Because 0.73 is close to 1.0, this means that the initial construction cost for Alternative 1 has a large impact on the NPV for the Agency Cost.

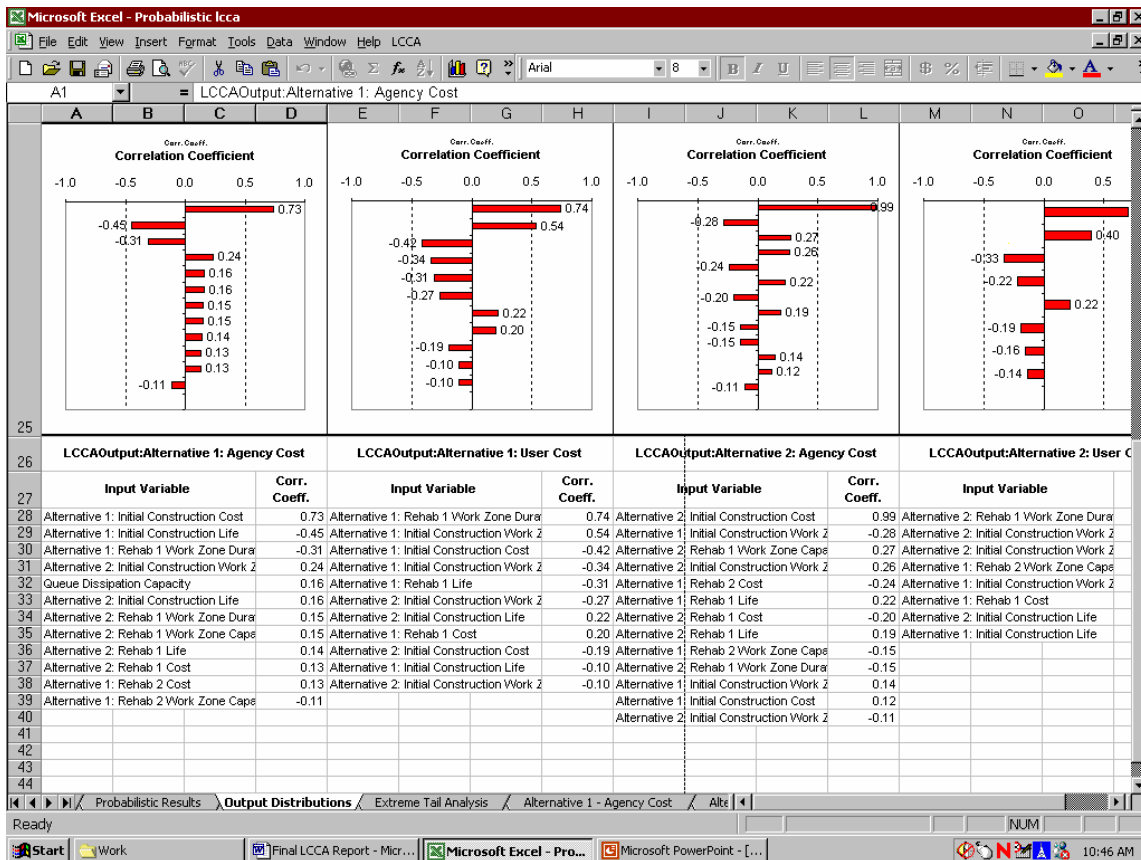


Figure 9-10. Correlation coefficients

## Queue Length Determination

Some state DOTs consider the length of the queue (that develops under forced-flow conditions of a work zone) as part of their decision criteria when conducting a life-cycle cost analysis. To calculate the length of queue that may develop as a result of the work zone for major reconstruction or rehabilitation activities, the analyst must determine all of the inputs that are needed to calculate user costs. The specific data required is listed in Section 8. FHWA's *Probabilistic LCCA 1.0* calculates the length of queue at each hour for each construction activity modeled. The length of queue is presented in a table embedded in the various "User Cost" worksheets in the program. Note: these worksheets can only be accessed when the "LCCA Switchboard" is closed. Once the Switchboard is closed, the analyst can click on the appropriate tab at the bottom of the screen. There are a total of 14 User Cost worksheets, all with identical format. The worksheet names follow:

1. Alternative 1 – User Cost 0
2. Alternative 1 – User Cost 1
3. Alternative 1 – User Cost 2
4. Alternative 1 – User Cost 3
5. Alternative 1 – User Cost 4
6. Alternative 1 – User Cost 5
7. Alternative 1 – User Cost 6
8. Alternative 2 – User Cost 0
9. Alternative 2 – User Cost 1
10. Alternative 2 – User Cost 2
11. Alternative 2 – User Cost 3
12. Alternative 2 – User Cost 4
13. Alternative 2 – User Cost 5
14. Alternative 2 – User Cost 6

There is one User Cost worksheet devoted to calculating and tabulating the user costs for each major construction activity modeled in the LCCA. For example, the worksheet named "Alternative 1 – User Cost 0" corresponds to the user cost calculations for the work zone being modeled during the initial construction of Alternative 1. "Alternative 1 – User Cost 1" corresponds to the user costs for the first major rehabilitation modeled for Alternative 1. Each of these worksheets contains seven tables that are used to determine the user costs. The tables that contain queue data are named "Work Zone User Cost: Inbound Traffic," and "Work Zone User Cost: Outbound Traffic," depending on which direction the analyst previously specified. The length of queue is tabulated under the column heading "Queue Hourly Parameters," within the sub-heading "Length". This can be located by scrolling to the right within the correct "Work Zone User Cost" table. An illustration of the table is presented in Figures 9-11(a) and (b) below. The column containing the queue length is highlighted in Figure 9-11 (b).

Microsoft Excel - Probabilistic lcca

File Edit View Insert Format Tools Data Window Help LCCA

Times New Roman 12

Work Zone User Cost: Inbound Traffic

Work Zone User Cost: Inbound Traffic												
Step 2. Build hourly demand and capacity matrix							Step 3. Quantify vehicles affected					Step 4. I zone op
Hour	Work Zone	% AADT	Demand	Capacity	Queue Rate	Number of Queued Vehicles	Change Speed	Traverse WZ	Traverse Queue	Stop for the Queue	Slow Down for the WZ	
0 - 1	Yes	0.6%	677	2926.666748	(2250)	0	677	677	0	0	677	Work Zone,
1 - 2	Yes	0.3%	413	2926.666748	(2514)	0	413	413	0	0	413	Work Zone,
2 - 3	Yes	0.3%	386	2926.666748	(2540)	0	386	386	0	0	386	Work Zone,
3 - 4	Yes	0.2%	288	2926.666748	(2639)	0	288	288	0	0	288	Work Zone,
4 - 5	Yes	0.4%	479	2926.666748	(2446)	0	479	479	0	0	479	Work Zone,
5 - 6	No	1.0%	1183	6600	(5417)	0	0	0	0	0	0	No Work Zo
6 - 7	No	3.2%	3856	6600	(2744)	0	0	0	0	0	0	No Work Zo
7 - 8	No	4.7%	5616	6600	(984)	0	0	0	0	0	0	No Work Zo
8 - 9	No	3.7%	4460	6600	(2140)	0	0	0	0	0	0	No Work Zo
9 - 10	Yes	2.9%	3432	2926.666748	505	505	3432	2927	2927	3432	0	Work Zone,
10 - 11	Yes	2.2%	2594	2926.666748	(332)	173	2594	2927	2927	2594	0	Work Zone,
11 - 12	Yes	2.6%	3116	2926.666748	190	363	3116	2927	2927	3116	0	Work Zone,
12 - 13	Yes	2.8%	3360	2926.666748	433	796	3360	2927	2927	3360	0	Work Zone,
13 - 14	Yes	2.9%	3420	2926.666748	493	1289	3420	2927	2927	3420	0	Work Zone,
14 - 15	Yes	2.9%	3469	2926.666748	543	1832	3469	2927	2927	3469	0	Work Zone,
15 - 16	No	3.0%	3588	5454	(1866)	0	3523	0	5355	3523	0	No Work Zo
16 - 17	No	3.6%	4266	6600	(2334)	0	0	0	0	0	0	No Work Zo
17 - 18	No	3.4%	4080	6600	(2520)	0	0	0	0	0	0	No Work Zo
18 - 19	No	2.7%	3257	6600	(3343)	0	0	0	0	0	0	No Work Zo
19 - 20	No	1.9%	2246	6600	(4354)	0	0	0	0	0	0	No Work Zo
20 - 21	Yes	1.6%	1861	2926.666748	(1065)	0	1861	1861	0	0	1861	Work Zone,
21 - 22	Yes	1.3%	1579	2926.666748	(1347)	0	1579	1579	0	0	1579	Work Zone,
22 - 23	Yes	1.1%	1325	2926.666748	(1602)	0	1325	1325	0	0	1325	Work Zone,
23 - 24	Yes	0.8%	918	2926.666748	(2009)	0	918	918	0	0	918	Work Zone,
Daily Totals		49.9%	59670	102154			30841	25486	22915	22915	7926	

Alternative 1 - User Cost #0 / Alternative 1 - User Cost #1 / Alternative 1 - User Cost #2 / Alternative

Ready NUM

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Figure 9-11 (a) User cost table

Microsoft Excel - Probabilistic lcca

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AW4 = Length (miles)

	AI	AJ	AK	AL	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BN
1														
2														
3	WZ Reduced Speed Delay Costs				Queue Hourly Parameters			Queue Reduced Speed Delay Costs			Queue Idling VOC			
4	Delay Time (hr/v)	AUTO \$	SU \$	COMBO \$	Speed (MPH)	Length (miles)	Delay Time (hr/v)	AUTO \$	SU \$	COMBO \$	AUTO \$	SU \$	COMBO \$	Daily Total per Hour
5	0.02338	\$176	\$6	\$4	-	-	-	-	-	-	-	-	-	\$228
6	0.02338	\$108	\$4	\$2	-	-	-	-	-	-	-	-	-	\$139
7	0.02338	\$101	\$3	\$2	-	-	-	-	-	-	-	-	-	\$130
8	0.02338	\$75	\$2	\$2	-	-	-	-	-	-	-	-	-	\$97
9	0.02338	\$125	\$4	\$3	-	-	-	-	-	-	-	-	-	\$162
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	0.02338	\$763	\$25	\$15	8.2	0.8	0.08836	\$2,885	\$96	\$58	\$174	\$4	\$2	\$4,801
15	0.02338	\$763	\$25	\$15	8.2	1.1	0.11418	\$3,728	\$124	\$75	\$225	\$5	\$3	\$5,551
16	0.02338	\$763	\$25	\$15	8.2	0.9	0.09234	\$3,015	\$100	\$61	\$182	\$4	\$2	\$4,874
17	0.02338	\$763	\$25	\$15	8.2	1.9	0.20197	\$6,594	\$219	\$133	\$397	\$9	\$5	\$8,923
18	0.02338	\$763	\$25	\$15	8.2	3.4	0.36447	\$11,899	\$395	\$240	\$717	\$16	\$9	\$14,855
19	0.02338	\$763	\$25	\$15	8.2	4.0	0.42997	\$14,037	\$466	\$283	\$846	\$19	\$10	\$17,252
20	-	-	-	-	19.2	3.9	0.14875	\$8,885	\$295	\$179	\$535	\$12	\$7	\$10,712
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	0.02338	\$485	\$16	\$10	-	-	-	-	-	-	-	-	-	\$628
26	0.02338	\$412	\$14	\$8	-	-	-	-	-	-	-	-	-	\$533
27	0.02338	\$345	\$11	\$7	-	-	-	-	-	-	-	-	-	\$447
28	0.02338	\$239	\$8	\$5	-	-	-	-	-	-	-	-	-	\$310
29	\$0	\$6,646	\$220	\$134	-	4.0	-	\$51,042	\$1,693	\$1,030	\$3,074	\$70	\$38	\$69,642
30														

Alternative 1 - User Cost #0 / Alternative 1 - User Cost #1 / Alternative 1 - User Cost #2 / Alternative

Ready Sum=19.94122453 NUM

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Figure 9-11 (b) User cost table

This section presented a brief overview of the FHWA’s new LCCA software, *Probabilistic LCCA 1.0*. For complete instructions contact Mr. Michael Smith, FHWA Southern Resource Center, (Michael.Smith@fhwa.dot.gov) or Tom Canick, FHWA (Canick.Tom@fhwa.dot.gov).



## Section 10

### LCCA Procedure Comparisons

ALDOT uses the computer program *DARWin*<sup>TM</sup> to perform LCCA. *DARWin*<sup>TM</sup> can only compute agency costs, first calculating non-discounted agency costs for each alternative, then discounting each construction activity to produce net-present value costs.

Much of this report has described the new FHWA program *Probabilistic LCCA 1.0*. The FHWA program is likely to become the tool of choice for state DOTs for a variety of reasons:

- It performs either deterministic or probabilistic analyses
- It calculates user costs
- It calculates queue length

Thus, the research team felt it advisable to perform LCCAs with the FHWA program and to compare those results to *DARWin*<sup>TM</sup> results using the same input data to examine the impacts that switching to the FHWA program might cause.

The UA research team performed those comparisons for two recent LCCAs that had been performed by ALDOT:

- Project number IM-65-1 (264), the reconstruction of a 1.4 mile section of Interstate 65 from Fairview Avenue, Montgomery, AL to the Alabama River. This project will be referred to as the Montgomery project.
- Project number IM-NHF-020-1 (129), the rubblization, reconstruction, and lane addition to a 6-mile section of Interstate 20 in Talladega County, AL. This project will be referred to as the Talladega project.

#### Software Results Comparisons

This section compares the results of the LCCAs from the Montgomery and Talladega projects. The results obtained from the *DARWin*<sup>TM</sup> software include only deterministic agency costs both non-discounted and discounted by the net-present value (NPV) method. *Probabilistic LCCA 1.0* software calculates both agency and user costs deterministically as well as performing the Monte-Carlo simulation for probabilistic results. The only results that can be compared directly between the two software programs are the total discounted agency costs for each project. The comparison of the total NPV agency costs is presented in Table 10-1.

**Table 10-1. NPV total agency cost comparisons**

Site	DARWin™		Probabilistic LCCA 1.0	
	Alternative 1 (Asphalt)	Alternative 2 (Concrete)	Alternative 1 (Asphalt)	Alternative 2 (Concrete)
Montgomery	\$2,295,023	\$2,503,654	\$2,295,023	\$2,503,654
Talladega	\$5,841,920	\$7,728,510	\$5,841,920	\$7,728,510

The total NPV agency costs calculated by the two software programs are identical. This is no surprise, considering the same discount rate and activity timing was used for the NPV calculations.

### **Montgomery LCCA**

This section discusses the results of a probabilistic pavement life-cycle cost analysis including user costs performed by the UA research team using the FHWA software program. The LCCA was performed for ALDOT project number IM-65-1 (264), the Montgomery project, which is the reconstruction of a 1.4-mile section of Interstate 65 from Fairview Avenue to the Alabama River in Montgomery, AL. This analysis was performed for the outbound direction only.

### ***Inputs***

The data needed to calculate user costs was listed in Section 8, “User Costs and Queues,” and includes the proposed work-zone data for each construction or rehabilitation activity modeled during the life of each pavement type alternative. All work zone data for the construction activities modeled for Alternative 1, asphalt pavement, were acquired from Mr. Phil Bazinet, of ALDOT’s Design Bureau. The work zone data for the concrete pavement construction activities of Alternative 2 were considerably more difficult to acquire. Given the limited number of concrete pavement construction projects being performed in the Southeast, typical work-zone data such as project duration on a per-lane-mile basis was not readily available inside of the Southeast. The specific concrete work-zone data used for this project was acquired from Mr. Pete Deere, FHWA, and Mr. Tom McDonald, Iowa Department of Transportation.

The traffic data needed to calculate user costs was acquired from Mr. Scott George, ALDOT Assistant Materials Engineer, and Mr. Charles Turney, ALDOT Transportation Planning Bureau. A complete list of inputs used for this LCCA is provided in Appendix 1, which is the report generated by the software. It contains all of the inputs defined by the user including both the deterministic and probabilistic results (where applicable). The shaded spaces within the report indicate values input by the user. When an input space contains a probabilistic input, the particular input distribution is listed with its corresponding parameters. For example, referring to the second page of Appendix 1, Montgomery LCCA #1, Alternative 1, Initial Construction, the Work Zone duration is

listed as **LCCA TRIANG(250, 300, 350)**. This indicates that a triangular distribution has been entered with a minimum value of 250 days, maximum of 350 days, and most likely value of 300 days.

***Deterministic Results***

The computer-generated report in Appendix 1 contains the deterministic results as well as some of the probabilistic results. The deterministic results of the project are shown in Table 10-2.

**Table 10-2. Deterministic results of the Montgomery project**

Total Cost						
Total Cost	Alternative 1: Asphalt Reconstruction			Alternative 2: Concrete Reconstruction (Rigid Alternative)		
	Agency Cost (\$1000)	User Cost (\$1000)	Total Cost (\$1000)	Agency Cost (\$1000)	User Cost (\$1000)	Total Cost (\$1000)
Nominal \$	\$2,696.56	\$1,640.75	\$4,337.31	\$2,614.28	\$1,221.06	\$3,835.34
Present Value	\$2,295.02	\$929.92	\$3,224.94	\$2,503.65	\$679.88	\$3,183.53
EUAC	\$137.73	\$55.81	\$193.54	\$150.25	\$40.80	\$191.05
Lowest Present Value Agency Cost			Alternative 1: Asphalt Reconstruction			
Lowest Present Value User Cost			Alternative 2: Concrete Reconstruction (Rigid Alternative)			
Lowest Present Value Total Cost			Alternative 2: Concrete Reconstruction (Rigid Alternative)			

The lowest present value agency cost is Alternative 1: Asphalt Reconstruction at \$2,295,020. However, the lowest average present value user cost is Alternative 2: Concrete Reconstruction at \$679,880. The most obvious reason for the concrete construction alternative having the lowest present value user cost is because there is only one major rehabilitation activity modeled at year 20. The asphalt alternative has 2 major rehabilitation activities modeled: year 12 and year 20. It should be noted that if probabilistic inputs are entered for any of the inputs, the software uses the mean value, or most likely value to calculate the deterministic results.

Table 10-2 indicates that including user costs in LCCA calculations may affect basic results. In the Montgomery project, if only agency costs are included, Alternative 1 is lower cost. When both agency costs and user costs are included, Alternative 2 is lower total cost than Alternative 1 (\$3.183 million to \$3.225 million).

***Probabilistic Results***

During the probabilistic analysis, UA researchers used probability distributions instead of discrete values for only two input variables: the queue dissipation capacity and the work-zone duration. FHWA suggests using a normal distribution for the queue dissipation capacity with a mean of 1818 passenger cars per-hour-per-lane and a standard deviation of 144 (Smith & Walls, 1998). Triangular distributions were used for the work-zone durations because of the large uncertainty involved with predicting construction duration. FHWA suggests using a triangular distribution to model variables where an exact distribution is unknown. This allows the analyst to enter a “range” of values that closely approximates the normal distribution.

Figure 10-1 presents the probabilistic results of the Montgomery LCCA. The table in the upper left corner presents the mean, standard deviation, minimum, and maximum values of the total NPV cost distribution created by the Monte Carlo simulation technique described in Section 7, “Probabilistic LCCA.” The two graphs in the center of Figure 10-1 present the distributions of agency costs and user costs. Notice that there is no distribution generated for the agency cost, because there were no probabilistic inputs used to calculate the NPV agency cost. The analyst can easily input a range, or distribution of data for any of the agency costs to achieve a probability distribution for the total NPV agency costs.

The user cost graph from Figure 10-1 shows the NPV cost probability distributions and the cumulative probability distributions for both construction alternatives. The cumulative probability graph can be used to show that there is about a 75% chance that the total NPV user cost for Alternative 1 is less than \$1 million, and a 75% chance that the total NPV user cost for Alternative 2 is below \$0.7 million. Appendix 1 also contains the Tornado plots described from Section 7. This is helpful for determining which input variables had the greatest impact on the final results.

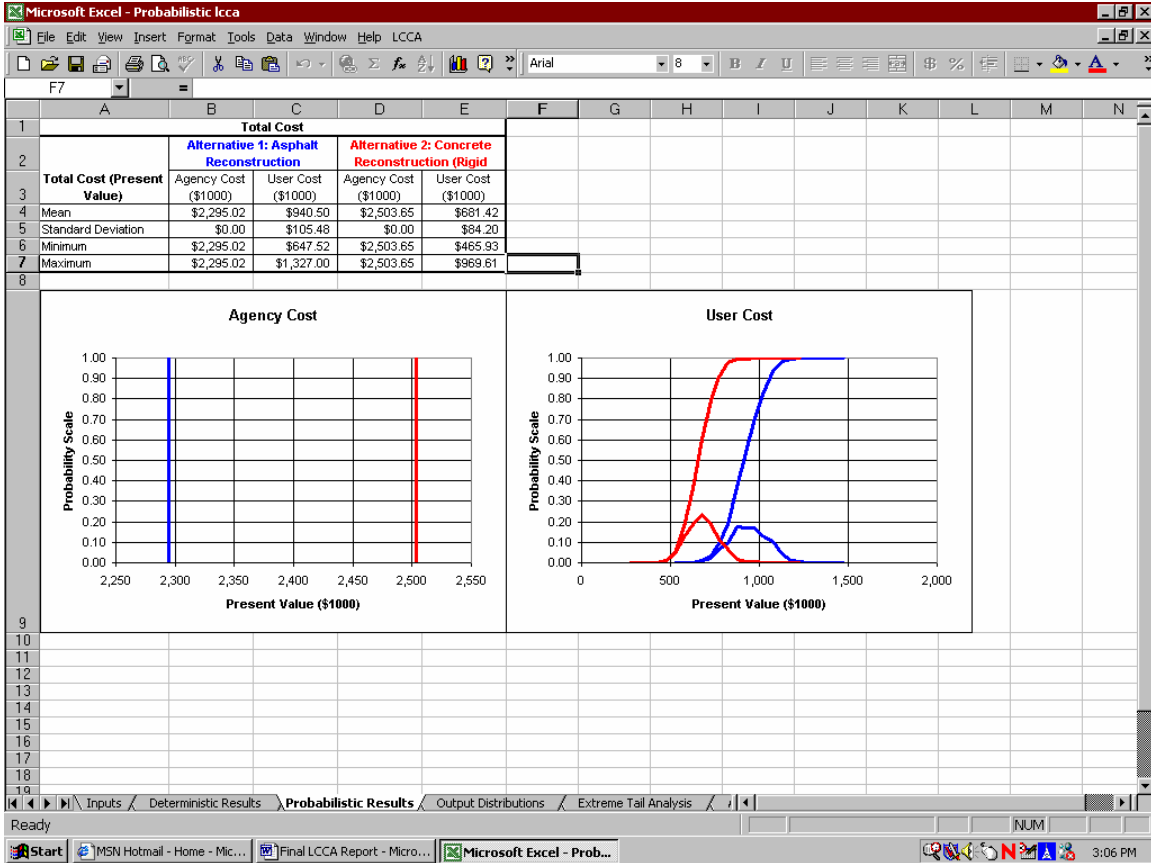


Figure 10-1. Probabilistic results of Montgomery LCCA

### Adjusted Montgomery LCCA

The Montgomery LCCA was performed a second time with slightly adjusted work-zone duration for the concrete alternative’s initial construction and major rehabilitation activities. This was done because of the lack of solid work-zone data in the Southeast concerning concrete construction activities. For the initial construction of Alternative 2, the work zone duration was changed from a triangular distribution with min = 300 days, max = 400 days, most likely = 350 days, to a min = 350 days, max = 450 days, and most likely = 450 days. The work-zone duration for the only major rehabilitation activity modeled for Alternative 2 was also adjusted. The triangular distribution with min = 4 days, max = 10 days, most likely = 7 days, was changed to a min = 7 days, max = 14 days, and most likely = 10 days. The user costs increased as a result of increasing the work zone duration. The deterministic results for the adjusted LCCA are shown in Table 10-3.

**Table 10-3. Deterministic results of adjusted Montgomery project**

Total Cost						
Total Cost	Alternative 1: Asphalt Reconstruction			Alternative 2: Concrete Reconstruction (Rigid Alternative)		
	Agency Cost (\$1000)	User Cost (\$1000)	Total Cost (\$1000)	Agency Cost (\$1000)	User Cost (\$1000)	Total Cost (\$1000)
Nominal \$	\$2,696.56	\$1,640.75	\$4,337.31	\$2,614.28	\$1,727.34	\$4,341.62
Present Value	\$2,295.02	\$929.92	\$3,224.94	\$2,503.65	\$928.45	\$3,432.11
EUAC	\$137.73	\$55.81	\$193.54	\$150.25	\$55.72	\$205.97
Lowest Present Value Agency Cost			Alternative 1: Asphalt Reconstruction			
Lowest Present Value User Cost			Alternative 2: Concrete Reconstruction (Rigid Alternative)			
Lowest Present Value Total Cost			Alternative 1: Asphalt Reconstruction			

Agency costs do not change. However, there is a difference in the present value user cost for Alternative 2 as opposed to the previous cost in Table 10-1. By increasing the work-zone durations for all of the concrete construction activities, the NPV user cost for Alternative 2 went from \$679,880 to \$928,450. This adjustment also caused the total NPV for Alternative 2 to rise above the total NPV for Alternative 1. The results of this adjustment indicate that seemingly small changes in user cost inputs can significantly affect results. It also indicates that more work is needed to obtain accurate PCC construction and rehabilitation scheduling data for Alabama and the Southeast.

### Talladega LCCA

This section describes the results of the second probabilistic LCCA performed by the University of Alabama using *Probabilistic LCCA 1.0*. This LCCA was done for project number IM-NHF-020-1 (129), which is the rubblization, reconstruction, and lane addition to a 6-mile section of Interstate 20 in Talladega County, AL. Interstate 20 currently contains 2 lanes in each direction at this location. The original deterministic LCCA performed by ALDOT was actually two LCCA's; one for the rubblization and reconstruction, the other for the lane addition. ALDOT split the project into two parts because of some limitations of *DARWin*<sup>TM</sup>. The UA team combined both LCCA's to perform its analysis of the Talladega project using the FHWA software program. This analysis was performed for the outbound direction only.

### Inputs

All of the non-discounted agency costs used in the University's analysis were acquired directly from the Alabama Department of Transportation's cost calculations using *DARWin*<sup>TM</sup>. The traffic data acquired for this project was acquired from Mr. Charles Turney, ALDOT Transportation Planning Bureau, and Mr. Scott George, ALDOT Assistant Materials Engineer. The data pertaining to the work-zones modeled for the asphalt alternative construction and rehabilitation activities was acquired from Mr. Phil Bazinet, ALDOT Design Bureau. Work-zone data for the construction and rehabilitation activities of the concrete construction alternative (Alternative 2) was acquired from Mr.

Pete Deere, FHWA, and Mr. Tom McDonald, Iowa Department of Transportation. A complete list of inputs used for this analysis is provided in Appendix 2.

### ***Deterministic Results***

The deterministic results for the Talladega LCCA are presented in Table 10-4 below.

**Table 10-4. Deterministic results of Talladega project**

Total Cost						
Total Cost	Alternative 1: Asphalt Pavement			Alternative 2: PCC Pavement Alternative		
	Agency Cost (\$1000)	User Cost (\$1000)	Total Cost (\$1000)	Agency Cost (\$1000)	User Cost (\$1000)	Total Cost (\$1000)
Nominal \$	\$7,116.15	\$9,518.93	\$16,635.08	\$8,850.52	\$10,648.99	\$19,499.50
Present Value	\$5,841.92	\$9,031.84	\$14,873.76	\$7,728.51	\$9,953.14	\$17,681.65
EUAC	\$350.59	\$542.03	\$892.62	\$463.81	\$597.32	\$1,061.13
Lowest Present Value Agency Cost			Alternative 1: Asphalt Pavement			
Lowest Present Value User Cost			Alternative 1: Asphalt Pavement			
Lowest Present Value Total Cost			Alternative 1: Asphalt Pavement			

The table shows that the total NPV for the asphalt alternative is less than the concrete alternative for both agency cost and user cost. Notice that the user costs are higher than the agency costs for both alternatives. This is because of the extended work-zone durations modeled for the reconstruction activities and also because of the queues that develop during these activities.

### ***Probabilistic Results***

Probability distributions were again entered for only the work-zone durations and queue dissipation capacities. Therefore, a total NPV distribution was generated only for the user costs. The Monte Carlo simulation performed 2000 iterations to produce the results. The probabilistic results for the Talladega LCCA are provided in Table 10-5. The Tornado plots and output distributions are shown in Figure 10-2.

**Table 10-5. Probabilistic results of Talladega project**

Total Cost				
Total Cost (Present Value)	Alternative 1: Asphalt Pavement		Alternative 2: PCC Pavement Alternative	
	Agency Cost (\$1000)	User Cost (\$1000)	Agency Cost (\$1000)	User Cost (\$1000)
Mean	\$5,841.92	\$9,034.74	\$7,728.51	\$9,946.91
Standard Deviation	\$0.00	\$153.65	\$0.00	\$481.24
Minimum	\$5,841.92	\$8,637.29	\$7,728.51	\$8,685.76
Maximum	\$5,841.92	\$9,426.29	\$7,728.51	\$11,226.28

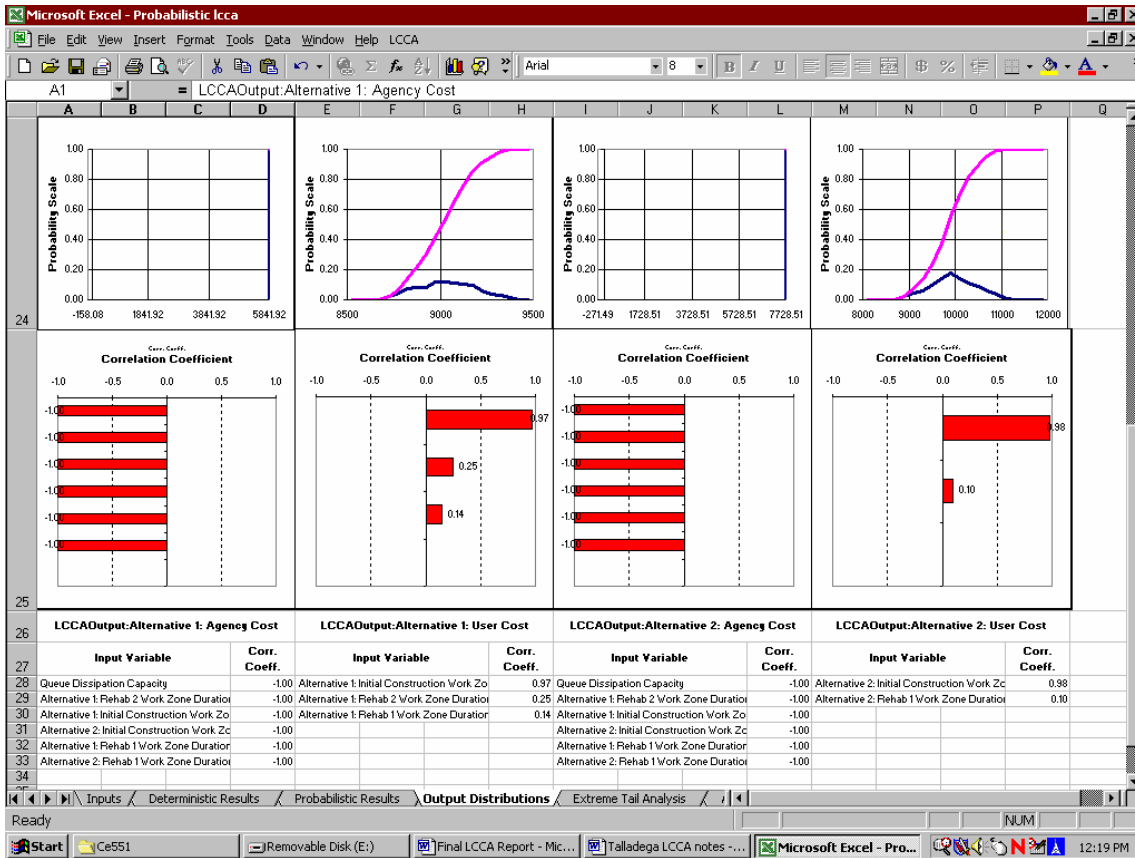


Figure 10-2. Tornado Plot and output distributions

Table 10-4 shows that the mean value for the total NPV for both agency and user cost is less for Alternative 1, asphalt pavement. It can be shown from the Tornado Plots in Figure 10-2 that initial construction work-zone durations had the greatest impact on the output distributions for the user cost, with correlation coefficients of 0.97 and 0.90 for Alternative 1 and Alternative 2, respectively. The cost distribution graphs show that there is a 90% probability that Alternative 1 will cost less than \$9.2 million versus a 90% probability that Alternative 2 will cost less than \$10.5 million. See Appendix 2 for the full computer generated report for the Talladega LCCA.



## **Section 11**

### **Summary and Conclusions**

LCCA uses economic principles to compare competing investment alternatives. An LCCA is typically used by a state DOT to help select the most appropriate design for a particular construction project, such as selecting between asphalt and concrete alternatives for a paving project. The LCCA is designed to identify the most cost effective alternative, but it may not be the only decision making tool.

ALDOT performs LCCA's to compare alternative pavement designs for the following situations:

- New construction projects, flexible pavement reconstruction projects, and projects involving the addition of a separate roadway to an existing roadway when the pavement design structural number equals or exceeds 6.00.
- Any project involving the reconstruction of concrete pavement.

ALDOT funded this UTCA research project after receiving the results of a "Life-Cycle Analysis Peer Review" (ALDOT, 2002) that it had requested the FHWA to perform in 2002. The FHWA identified several good practices during the review and also listed the following areas where ALDOT could consider refining its practices:

1. Use pavement management system information to evaluate the cost effectiveness of new paving materials/procedures such as Superpave, stone matrix asphalt, modified asphalts, and tied concrete shoulders.
2. Develop a formal policy statement that addresses factors for not selecting the lowest life-cycle alternative such as excessive queues and user delays during rehabilitation.
3. Incorporate reliability into pavement life estimates.
4. Begin to assemble data on the variability of LCCA inputs to be prepared for the implementation of the anticipated new edition of AASHTO's Guide for Design of Pavement Structures (AASHTO, 1993).
5. Evaluate the effect of proposed out-year rehabilitations on users of the facility such as the analysis of queue lengths and user delays.

The following items summarize findings regarding areas of interest to ALDOT and the FHWA concerning ALDOT LCCA procedures:

- ALDOT does not include user costs in its current analysis. Five of nine other states surveyed do not calculate user costs.
- LCCA calculations performed for this report indicate that user costs can exceed agency costs.

- LCCA calculations performed for this report indicate that the inclusion of user costs can change the lower total NPV cost from Alternative A to Alternative B.
- ALDOT does not include salvage value in its current analysis. Three of six other states surveyed do not use salvage value.
- ALDOT currently uses deterministic LCCA procedures. Eight of nine other states surveyed that conduct LCCAs conduct deterministic LCCAs, though four of the nine are investigating probabilistic procedures.
- ALDOT does not include routine maintenance in its current analysis. Section 5 of this report lists reliable values that ALDOT can use if desired, but those values are quite small in comparison to construction cost inputs.
- Five of six other states surveyed list items to consider when LCCA results for asphalt versus concrete alternatives are extremely close but pavement type selection must be made. Section 4 of this report lists those items, and ALDOT could produce its own “tie-break” procedure based on them.

### **FHWA Software Program**

ALDOT currently uses *DARWin*<sup>™</sup> software to perform LCCAs. *DARWin*<sup>™</sup> can only perform deterministic analyses and does not calculate user costs or queue lengths. The UA researchers worked extensively with the new FHWA computer program *Probabilistic LCCA 1.0*. This program can perform deterministic LCCAs, probabilistic LCCAs, and can calculate both user costs and queue lengths. The UA team came to the following conclusions concerning the FHWA program:

- ALDOT must be able to provide inputs for the parameters listed in Section 9 of this report (pages 30 – 32), to be able to use the program. ALDOT already has access to all parameters required to perform LCCA without user costs. However, historical data for parameters concerning concrete work zone lengths, configurations, and durations must be improved before reliable LCCAs containing user costs can be performed. The complete list of inputs needed to calculate user costs are found in Section 8, pages 26 and 27.
- There are 11 parameters listed in Section 9, page 33, for which probability distributions (rather than discrete values) can be input. However, as few as one parameter entered as a distribution allows the software to compute probabilistic results. Thus, probabilistic LCCAs can be performed relatively easily by changing the formats of only a few inputs. The best candidates for inputs with probability distributions (the ones ALDOT can obtain most easily) follow:
  - Queue dissipation capacity
  - Work zone duration
  - Annual growth rate of traffic
- If ALDOT desires to add queue length to its decision criteria, the FHWA program can supply queue length values. However, to perform the calculation, all the parameters required to calculate user costs in Section 8, pages 26 and 27, must be available.

## HYDRA

ALDOT is working to implement a new software package named Highway Yearly Distress Rating and Analysis (HYDRA). Once the new software is available, several values for ALDOT's LCCA may be verified or updated:

- The analysis period (currently 28 years) for asphalt pavements
- The analysis period (currently 28 years) for concrete pavements
- Performance periods for new materials and methods such as Superpave, Stone Matrix Asphalt, modified asphalts, and tied concrete shoulders. However, these items may be so new that they cannot be adequately investigated before several more years have passed.

## Schedule

In 2002, the FHWA reviewed the LCCA procedures ALDOT currently uses and found them to follow good LCCA practice. However, the study results suggest that ALDOT can improve its procedures even further by implementing an LCCA update plan employing the following schedule:

- Switch to the FHWA computer program *Probabilistic LCCA 1.0* to compute both deterministic and probabilistic LCCA without user costs. This switch can be performed almost immediately because ALDOT has all the input data available for deterministic calculations. ALDOT only has to switch two or three parameters to simple triangular distribution inputs to perform probabilistic calculations.
- Formulate a decision-making process in the event the asphalt and concrete alternatives exhibit similar costs. This work can be performed almost immediately, using the criteria of other states listed in Section 4 of this report as a basis.
- Verify analysis periods and performance periods for new materials and methods. Those analyses cannot be performed conveniently until HYDRA is operational. Additionally, some new paving materials may not be adequately investigated without several more years of service life and traffic loadings. The analysis periods and performance periods should be presented as probability distributions so that they may contribute to probabilistic LCCAs.
- Improve construction and rehabilitation historical cost data for concrete pavements. Although Section 3 of this report provides data concerning those types of costs from neighboring states, the data is scanty because several Southeastern states typically have few concrete projects let to contract each year. A more detailed search could probably be performed in less than one year, with the resulting data sorted by project size and presented as probability distributions.
- Gather better data for concrete work zone lengths, configurations, and durations. This data must be obtained before reliable user costs and queue lengths may be added to LCCA calculations. A quick survey of Southeastern states yielded little data on this topic; data used in LCCA calculations in Section 10 came from Iowa.

- A more detailed study, potentially investigating outside the Southeast, may take a year or more to accomplish.
- Finalize ALDOT's position regarding adding user costs to its LCCA procedure. The comparisons provided in Section 10 of this report should be helpful during such considerations. If ALDOT decides to add user costs, the required information cited previously must be obtained, and user costs probably could not be incorporated into ALDOT LCCAs before 2005.

### **Further Work**

Opportunities for further work were described in the previous set of bullets. They are summarized below:

- Formulate a decision-making process to select between the asphalt and concrete alternatives when they exhibit similar costs.
- Verify analysis periods for LCCA analyses and identify performance periods for new materials and methods using HYDRA.
- Improve construction and rehabilitation historical cost data for concrete pavements.
- Gather improved data for concrete work zone lengths, configurations, and durations.
- Finalize ALDOT's position regarding adding user costs to its LCCA procedures.

## Section 12

### References

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# Appendix 1 Montgomery Project

## LCCA Input Data

<b>1. Economic Variables</b>	
Value of Time for Passenger Cars (\$)	\$11.58
Value of Time for Single Unit Trucks (\$)	
Value of Time for Combination Trucks (\$)	\$22.31
<b>2. Analysis Options</b>	
	Yes
Include User Cost Residual Value	Yes
Use Differential User Costs	Yes
User Cost Computation	Calculated
Include Agency Cost Residual Value	
Analysis Direction	Outbound
	28
Year of Construction	2005
Discount Rate (%)	
<b>3. Project Details and Quantity Calculations</b>	
State Route	I-65
	I-65 Reconstruction (Fairview Ave to AL River)
Region	Alabama
County	
Analyzed By	Patrick Clark
Beginning MP	
Ending MP	
Length of Project (miles)	0.00
Lane Width (ft)	12.00
	Right
Shoulder Width - Inbound (ft)	10.00
Shoulder Width - Outbound (ft)	10.00
Roadway Area (Square Feet)	0
Shoulder Area (Square Feet)	0
Total Area (Square Feet)	0
<b>4. Traffic Data</b>	
AADT (Both Directions) - Construction Year	70,151
Cars as Percentage of AADT (%)	0.0
Single Unit Trucks as Percentage of AADT (%)	23.0
Combination Trucks as Percentage of AADT (%)	77.0
Annual Growth Rate of Traffic (%)	1.5
Speed Limit Under Normal Condition (mph)	50
No of Lanes in Each Direction During Normal Operation	3
Free Flow Capacity (vphpl)	2400
Rural/Urban	Urban
Queue Dissipation Capacity (vphpl)	1818
	<b>LCCANORMAL(1818,144)</b>
Maximum AADT (Both Directions)	200,000
Maximum Queue Length (miles)	10.0

**Alternative 1**

<b>Initial Construction</b>	<b>Asphalt Reconstruction</b>	
Construction Cost (\$1000)	\$1,820.00	
User Cost (\$1000)	\$200.00	
Work Zone Duration (days)	300	
	<b>LCCATRIANG(250,300,350)</b>	
No of Lanes Open in Each Direction During Work Zone	2	
Expected Life (years)	12.0	
Maintenance Frequency (Years)	0	
Maintenance Cost (\$1000)	0	
Work Zone Length (miles)	1.44	
Work Zone Speed Limit (mph)	45	
Work Zone Capacity (vphpl)	1490	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	22	23
Third period of lane closure	23	24

<b>Rehabilitation #1</b>	<b>Asphalt Overlay</b>	
Construction Cost (\$1000)	\$445.67	
User Cost (\$1000)	\$20.00	
Work Zone Duration (days)	7	
	<b>LCCATRIANG(4,7,10)</b>	
No of Lanes Open in Each Direction During Work Zone	2	
Expected Life (years)	8.0	
Maintenance Frequency (Years)	0	
Maintenance Cost (\$1000)	0	
Work Zone Length (miles)	1.44	
Work Zone Speed Limit (mph)	45	
Work Zone Capacity (vphpl)	1490	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure	6	12
Second period of lane closure	12	14
Third period of lane closure	14	18



<b>Rehabilitation #2</b>	<b>Asphalt Overlay</b>	
Construction Cost (\$1000)	\$430.89	
User Cost (\$1000)	\$30.00	
Work Zone Duration (days)	7	
	<b>LCCATRIANG(4,7,10)</b>	
No of Lanes Open in Each Direction During Work Zone	2	
Expected Life (years)	8.0	
Maintenance Frequency (Years)	0	
Maintenance Cost (\$1000)	0	
Work Zone Length (miles)	1.44	
Work Zone Speed Limit (mph)	45	
Work Zone Capacity (vphpl)	1490	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure	6	12
Second period of lane closure	12	14
Third period of lane closure	14	18

<b>Rehabilitation #3</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$20.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	50	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

<b>Rehabilitation #4</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$30.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	50	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

<b>Rehabilitation #5</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$20.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	50	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

<b>Rehabilitation #6</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$30.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	50	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

**Alternative 2**

<b>Initial Construction</b>	<b>PCC Reconstruction</b>	
Construction Cost (\$1000)	\$2,410.78	
User Cost (\$1000)	\$300.00	
Work Zone Duration (days)	350	
	<b>LCCATRIANG(300,350,400)</b>	
No of Lanes Open in Each Direction During Work Zone	2	
Expected Life (years)	20.0	
Maintenance Frequency (Years)	0	
Maintenance Cost (\$1000)	0	
Work Zone Length (miles)	1.44	
Work Zone Speed Limit (mph)	45	
Work Zone Capacity (vphpl)	1490	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	22	23
Third period of lane closure	23	24

<b>Rehabilitation #1</b>	<b>Concrete Repair</b>	
Construction Cost (\$1000)	\$203.50	
User Cost (\$1000)	\$50.00	
Work Zone Duration (days)	7	
	<b>LCCATRIANG(4,7,10)</b>	
No of Lanes Open in Each Direction During Work Zone	2	
Expected Life (years)	8.0	
Maintenance Frequency (Years)	0	
Maintenance Cost (\$1000)	0	
Work Zone Length (miles)	1.44	
Work Zone Speed Limit (mph)	45	
Work Zone Capacity (vphpl)	1490	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure	6	12
Second period of lane closure	12	14
Third period of lane closure	14	18

<b>Rehabilitation #2</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$300.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	50	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

<b>Rehabilitation #3</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$50.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	50	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

<b>Rehabilitation #4</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$300.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	50	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

<b>Rehabilitation #5</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$50.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	50	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

<b>Rehabilitation #6</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$300.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	50	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

**Deterministic Results**

Total Cost	Alternative 1: Asphalt Reconstruction			Alternative 2: Concrete Reconstruction (Rigid Alternative)		
	Agency Cost (\$1000)	User Cost (\$1000)	Total Cost (\$1000)	Agency Cost (\$1000)	User Cost (\$1000)	Total Cost (\$1000)
Nominal \$	\$2,696.56	\$1,640.75	\$4,337.31	\$2,614.28	\$1,221.06	\$3,835.34
Present Value	\$2,295.02	\$929.92	\$3,224.94	\$2,503.65	\$679.88	\$3,183.53
EUAC	\$137.73	\$55.81	\$193.54	\$150.25	\$40.80	\$191.05

**Probabilistic Results**

Total Cost (Present Value)	Alternative 1: Asphalt Reconstruction		Alternative 2: Concrete Reconstruction (Rigid Alternative)	
	Agency Cost (\$1000)	User Cost (\$1000)	Agency Cost (\$1000)	User Cost (\$1000)
Mean	\$2,295.02	\$939.68	\$2,503.65	\$681.74
Standard Deviation	\$0.00	\$106.24	\$0.00	\$84.43
Minimum	\$2,295.02	\$647.52	\$2,503.65	\$465.93
Maximum	\$2,295.02	\$1,327.00	\$2,503.65	\$969.61



## Appendix 2 Talladega Project

### LCCA Input Data

<b>1. Economic Variables</b>	
Value of Time for Passenger Cars (\$)	\$11.58
Value of Time for Single Unit Trucks (\$)	\$18.54
Value of Time for Combination Trucks (\$)	\$22.31
<b>2. Analysis Options</b>	
Include User Costs	Yes
Include User Cost Residual Value	Yes
Use Differential User Costs	Yes
User Cost Computation	Calculated
Include Agency Cost Residual Value	Yes
Analysis Direction	Outbound
Analysis Period (Years)	28
Year of Construction	2003
Discount Rate (%)	4.0
<b>3. Project Details and Quantity Calculations</b>	
State Route	I-20
Project Name	reconstruction and inside lane addition
Region	Talladega Co.
County	Talladega
Analyzed By	Patrick Clark
Beginning MP	173.35
Ending MP	178.17
Length of Project (miles)	4.82
Lane Width (ft)	12.00
	Right
Shoulder Width - Inbound (ft)	
Shoulder Width - Outbound (ft)	
Roadway Area (Square Feet)	916,186
Shoulder Area (Square Feet)	0
Total Area (Square Feet)	916,186
<b>4. Traffic Data</b>	
AADT (Both Directions) - Construction Year	38,360
Cars as Percentage of AADT (%)	62.0
Single Unit Trucks as Percentage of AADT (%)	3.8
Combination Trucks as Percentage of AADT (%)	34.2
Annual Growth Rate of Traffic (%)	3.5
Speed Limit Under Normal Condition (mph)	70
No of Lanes in Each Direction During Normal Operation	3
Free Flow Capacity (vphpl)	2400
Rural/Urban	Rural
Queue Dissipation Capacity (vphpl)	1818
	<b>LCCANORMAL(1818,144)</b>
Maximum AADT (Both Directions)	200,000
Maximum Queue Length (miles)	50.0

**Alternative 1**

<b>Initial Construction</b>	<b>Rubbelize and construct ashpalt with additional inside ashpalt</b>	
Construction Cost (\$1000)	\$4,327.16	
User Cost (\$1000)	\$200.00	
Work Zone Duration (days)	730	
	<b>LCCATRIANG(700,730,760)</b>	
No of Lanes Open in Each Direction During Work Zone	2	
Expected Life (years)	12.0	
Maintenance Frequency (Years)	0	
Maintenance Cost (\$1000)	0	
Work Zone Length (miles)	6.00	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1445	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	5
Second period of lane closure	5	20
Third period of lane closure	20	24

<b>Rehabilitation #1</b>	<b>Overlay #1</b>	
Construction Cost (\$1000)	\$1,438.07	
User Cost (\$1000)	\$20.00	
Work Zone Duration (days)	20	
	<b>LCCATRIANG(15,20,25)</b>	
No of Lanes Open in Each Direction During Work Zone	2	
Expected Life (years)	8.0	
Maintenance Frequency (Years)	0	
Maintenance Cost (\$1000)	0	
Work Zone Length (miles)	6.00	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1490	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure	6	10
Second period of lane closure	10	12
Third period of lane closure	12	18

<b>Rehabilitation #2</b>	<b>Overlay #2</b>	
Construction Cost (\$1000)	\$1,350.91	
User Cost (\$1000)	\$30.00	
Work Zone Duration (days)	20	
	<b>LCCATRIANG(15,20,25)</b>	
No of Lanes Open in Each Direction During Work Zone	2	
Expected Life (years)	8.0	
Maintenance Frequency (Years)	0	
Maintenance Cost (\$1000)	0	
Work Zone Length (miles)	6.00	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1490	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure	6	10
Second period of lane closure	10	12
Third period of lane closure	12	18

<b>Rehabilitation #3</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$20.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	70	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

<b>Rehabilitation #4</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$30.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	70	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

<b>Rehabilitation #5</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$20.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	70	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

<b>Rehabilitation #6</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$30.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	70	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

**Alternative 2**

<b>Initial Construction</b>	<b>Concrete overlay and inside lane addition</b>	
Construction Cost (\$1000)	\$6,786.53	
User Cost (\$1000)	\$300.00	
Work Zone Duration (days)	800	
	<b>LCCATRIANG(700,800,900)</b>	
No of Lanes Open in Each Direction During Work Zone	2	
Expected Life (years)	20.0	
Maintenance Frequency (Years)	0	
Maintenance Cost (\$1000)	0	
Work Zone Length (miles)	6.00	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1445	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	5
Second period of lane closure	5	20
Third period of lane closure	20	24
<b>Rehabilitation #1</b>	<b>PCC Repair</b>	
Construction Cost (\$1000)	\$2,063.98	
User Cost (\$1000)	\$50.00	
Work Zone Duration (days)	35	
	<b>LCCATRIANG(20,35,50)</b>	
No of Lanes Open in Each Direction During Work Zone	2	
Expected Life (years)	8.0	
Maintenance Frequency (Years)	0	
Maintenance Cost (\$1000)	0	
Work Zone Length (miles)	6.00	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1490	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure	6	12
Second period of lane closure	12	15
Third period of lane closure	15	18

<b>Rehabilitation #2</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$300.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	70	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

<b>Rehabilitation #3</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$50.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	70	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

<b>Rehabilitation #4</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$300.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	70	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

<b>Rehabilitation #5</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$50.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	70	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		



<b>Rehabilitation #6</b>		
Construction Cost (\$1000)		
User Cost (\$1000)	\$300.00	
Work Zone Duration (days)		
No of Lanes Open in Each Direction During Work Zone	3	
Expected Life (years)		
Maintenance Frequency (Years)		
Maintenance Cost (\$1000)		
Work Zone Length (miles)		
Work Zone Speed Limit (mph)	70	
Work Zone Capacity (vphpl)	2400	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

**Deterministic Results**

Total Cost	Alternative 1: Asphalt Pavement			Alternative 2: PCC Pavement Alternative		
	Agency Cost (\$1000)	User Cost (\$1000)	Total Cost (\$1000)	Agency Cost (\$1000)	User Cost (\$1000)	Total Cost (\$1000)
Nominal \$	\$7,116.15	\$9,518.93	\$16,635.08	\$8,850.52	\$10,648.99	\$19,499.50
Present Value	\$5,841.92	\$9,031.84	\$14,873.76	\$7,728.51	\$9,953.14	\$17,681.65
EUAC	\$350.59	\$542.03	\$892.62	\$463.81	\$597.32	\$1,061.13

**Probabilistic Results**

Total Cost (Present Value)	Alternative 1: Asphalt Pavement		Alternative 2: PCC Pavement Alternative	
	Agency Cost (\$1000)	User Cost (\$1000)	Agency Cost (\$1000)	User Cost (\$1000)
Mean	\$5,841.92	\$9,034.74	\$7,728.51	\$9,946.91
Standard Deviation	\$0.00	\$153.65	\$0.00	\$481.24
Minimum	\$5,841.92	\$8,637.29	\$7,728.51	\$8,685.76
Maximum	\$5,841.92	\$9,426.29	\$7,728.51	\$11,226.28