A Review of the Alabama Department of Transportation's Policies and Procedures for Life-Cycle Cost Analysis for Pavement Type Selection

by

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Abstract

This thesis examines the process of life-cycle cost analysis for pavement type selection and gives specific consideration to the policies and procedures used by the Alabama Department of Transportation as of June 2013. Life-cycle cost analysis is a structured approach to determine the economic benefit of an investment alternative over a lengthy time horizon. Life-cycle cost analysis is a common tool used to determine which pavement surface type, asphalt or concrete, should be used to best allocate transportation agencies limited resources. In order to accurately calculate the life-cycle cost of a pavement, the costs and timing of construction, maintenance, and rehabilitation activities must be known. Data collected from federal and nearby state agencies was used to best determine these parameters for use in Alabama. Other paramount factors, such as the analysis period and discount rate, were examined and recommendations were made based upon state-of-practice policies and sensitivity analysis. Five projects recently constructed in Alabama were examined based upon these recommendations. The recommendations were originally made by the National Center for Asphalt Technology to the Alabama Department of Transportation; these include an analysis period of 35 years, a discount rate equivalent to the rolling 10-year average of the OMB's 30-year discount rates, a performance period of 19 years for new asphalt pavements and a rehabilitation period of 13.5 years for asphalt overlays.

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1. Introduction

1.1. Background

Life-cycle cost analysis (LCCA) is an economic method used to calculate the total cost of asset ownership. Commonly, this procedure is used to compare multiple investment alternatives in order to determine which investment will allow for the most economical allocation of limited resources. The structure of the LCCA depends on the entity considering investment, and indeed, public and private enterprises approach the calculation quite differently. Succinctly, private use of LCCA calculates the purchase price required based upon the return of the investment, whereas use of LCCA by public institutions seeks to determine the cheapest investment alternative based upon current and future expected costs and returns. Economic considerations of LCCA must include the initial purchase price and future costs and returns; however, the manner in which future economic activities are treated varies greatly. LCCA has become increasingly common amongst state transportation agencies, and it is a focus of this thesis to analyze the use of LCCA for pavement-type selection at the Alabama Department of Transportation (ALDOT).

ALDOT has used LCCA as a tool for determining whether to construct an asphalt or concrete pavement since 1990 (Wilkerson, 2003). A bill introduced to the Alabama State House of Representatives in April of 2012 called for significant changes to be made to the manner in which ALDOT conducts LCCA (McCuctheon, 2012). The bill, HB 730, was subsequently postponed indefinitely. This prompted ALDOT to organize a review of their LCCA policies and procedures. Part of this review was ALDOT's request of the National Center for Asphalt Technology (NCAT) to issue recommendations on when and how an LCCA should be performed. These recommendations and their justifications are included in this thesis. ALDOT also contracted the University of Alabama (UA) to make concurrent recommendations on the structure of ALDOT's LCCA. The UA recommendations are largely based on the viewpoint of the concrete pavement industry, whereas NCAT's recommendations are largely based on the viewpoint of the asphalt paving industry.

1.2 Objectives

The objectives of this thesis are to:

- Justify NCAT's recommendations to ALDOT regarding the analysis period, discount rate, performance and rehabilitation periods, and the use of user costs.
- Analyze the sensitivity of the life-cycle cost (LCC) of a project to changes in LCCA inputs.
- Examine commonly used software platforms.

1.3 Scope

This report examines all factors considered before and during an LCCA. Recommendations to ALDOT made by NCAT and UA are considered. The effects of including user costs, probabilistic distributions, and various software platforms were not a significant portion of either NCAT's or UA's recommendations; their use and validity are expanded upon in this thesis. The parameters investigated are applicable to all roadway surfaces and construction methods. ALDOT provided data from five LCCAs on recent projects. These projects were used to analyze the impact of utilizing NCAT's and UA's recommendations in lieu of ALDOT's current procedures.

1.4 Report Organization

This report is organized into nine chapters. Chapter 1 is this brief introduction. Chapter 2 is a brief primer on LCCA calculations. Common LCCA inputs are discussed in Chapter 3. The inclusion of user costs is discussed in Chapter 4. Probabilistic approaches are considered in Chapter 5. Chapter 6 explores the use of various software platforms. A sensitivity analysis is performed in Chapter 7. NCAT and UA inputs are further examined with ALDOT data in Chapter 8. A summary of conclusions is presented in Chapter 9.

2 Primer on Life-Cycle Cost Analysis

2.1 LCCA in Practice

The concept of LCCA for pavement type selection has been used, in some form, since the 1950s (Walls III, 1998). The original approach was the consideration of benefit-cost ratios. Over time, the preferred method has been to calculate the net present value (NPV) of an alternative by discounting future costs and benefits to account for the time-value growth of money. State highway agencies' practices varied widely until a 1993 request by AASHTO for federal guidance. In 1994, President Clinton signed Executive Order 12893, *Principles for Federal Infrastructure Investments*, which called for infrastructure investment decisions to be based upon a systematic analysis of benefits and costs over the life cycle of the investment. The National Highway System (NHS) Designation Act of 1995 specifically required states to conduct life-cycle cost analysis on NHS projects costing $25 million or more. The Transportation Equity Act for the 21st Century (TEA-21) (1998) expanded the knowledge of implementing LCCA by establishing appropriate analysis periods, discount rates, and a procedure for evaluating user costs. TEA-21 also removed the requirement for LCCA on high-cost NHS projects.

The Federal Highway Administration (FHWA) published an Interim Technical Bulletin entitled *Life-Cycle Cost Analysis in Pavement Design* in September 1998 that recommended "good practice" standards for LCCAs. This bulletin is widely cited as the primary reference for using LCCA in pavement type selection.

The Moving Ahead for Progress in the 21st Century Act (MAP-21) required the Government Accountability Office (GAO) to examine the guidance given from the FHWA on LCCA. At the time of the passage of MAP-21, the FHWA had provided the following guidance summarized in Table 2.1 (Government Accountability Office, 2013).

Table 2.1 FHWA Guidance and Assistance Available to States on LCCA, 1998-Present

FHWA Guidance and Assistance	Description
Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin (1998)	Describes how LCCA can be used to inform pavement-type selection and how to conduct LCCA. Currently being revised.
Life-Cycle Cost Analysis Primer (2002)	Summarizes LCCA techniques and benefits.
RealCost LCCA software (first released in 2002, most recent version 2011)	Facilitates the conduct of LCCA by providing a computational tool.
RealCost LCCA User Manual (updated in 2010)	Explains how to use RealCost software and discusses LCCA concepts and practices.
LCCA training by FHWA (2013)	Provides training on a variety of LCCA concepts and tools, including RealCost.

The GAO compared the FHWA's guidance with the principles set forth in the GAO's *Cost Guide* (2009). The *Cost Guide* provides federal guidance about processes, practices, and procedures needed to ensure credible cost estimates. The GAO evaluated the FWHA on four phases of cost estimation, and 12 best practice sub-categories described in the *Cost Guide.* These criteria are shown in Table 2.2.

Table 2.2 GAO's Cost-Estimating Process Best Practices

Phase	Best practice	Summary of tasks within best practices
Initiation	Define estimate's purpose	Determine purpose, scope, required level of detail of estimate, as well as who will receive estimate.
	Develop estimating plan	Determine cost estimating team, schedule, and outline tasks in writing.
Assessment	Define program characteristics	Identify technical characteristics of planned investment, quality of data needed, and plan for documenting and updating information.
	Determine estimating structure	Define the elements of the cost estimate, including best method for estimating costs and potential cross-checks, and standardized structure.
	Identify ground rules and assumptions	Define what the estimate will include and exclude, key assumptions (such as life cycle of investment), schedule or budget constraints, and other elements that affect estimate. Assumptions should be measurable, specific, and consistent with historical data. Assumptions should be based on expert, technical judgment and approved by management.
	Obtain data	Create data collection plan, identify sources, collect valid and useful data, analyze data for cost drivers and other factors, and assess data for reliability and accuracy.
	Develop a point estimate and compare it to an independent cost estimate	Develop cost estimation model and calculate estimate, in constant dollars for investments that occur over multiple years, and other cross checks and validation, and compare estimate to an independent estimate and previous estimates. Update as more data are available.
Analysis	Conduct sensitivity analysis	Test the sensitivity of cost elements to changes in input values, ground rules, and assumptions.
	Conduct risk and uncertainty analysis	Determine which cost elements pose technical, cost, or schedule risks; analyze those risks; and recommend a plan to track and mitigate risks. A range of potential costs, based on risks and uncertainties, should be identified around a point estimate.
	Document the estimate	Document all steps used to develop the estimate so it can be recreated, describing methodology, data, assumptions, and results of risk, uncertainty, and sensitivity analysis.
Presentation	Present estimate to management for approval	Develop briefing on results, including information on estimation methods and risks, making content clear and complete so those unfamiliar with analysis can comprehend estimate and have confidence in it.
	Update the estimate to reflect actual costs and changes	As technical aspects of project change, the complete cost estimate should be regularly updated and, as project moves forward, cost and schedule estimates should be tracked.

The GAO evaluated the degree to which FHWA LCCA guidance aligns with the *Cost Guide* best practices. Each phase and best practice was judged using the following criteria:

- Aligns—completely satisfied the best practice
- Substantially Aligns—satisfied a large portion of the best practice
- Partially Aligns—satisfied about half of the best practices
- Minimally Aligns—satisfied a small portion of the best practices
- Does Not Align—did not satisfy the best practice

The GAO examined literature provided by the FHWA, conducted interviews with 16 state agencies, and determined the degree to which FHWA guidance satisfies the best practices set forth in the *Cost Guide.* These results are shown in Table 2.3.

Table 2.3 Summary of GAO's Assessment of the FHWA LCCA Guidance

Phase	Phase Assessment	Best practice	Best Practice Assessment
Initiation	Aligns	Define estimate's purpose	Aligns
		Develop estimating plan	Substantially Aligns
Assessment	Partially Aligns	Define program characteristics	Partially Aligns
		Determine estimating structure	Substantially Aligns
		Identify ground rules and assumptions	Substantially Aligns
		Obtain data	Partially Aligns
		Develop a point estimate and compare it to an independent cost estimate	Partially Aligns
Analysis	Substantially Aligns	Conduct sensitivity analysis	Aligns
		Conduct risk and uncertainty analysis	Aligns
		Document the estimate	Partially Aligns
Presentation	Partially Aligns	Present estimate to management for approval	Minimally Aligns
		Update the estimate to reflect actual costs and changes	Partially Aligns

The GAO found the FHWA to be only partially aligned with the *Cost Guide's* best practices in two of the four phases. Since the FHWA's *Life-Cycle Cost Analysis in Pavement Design Interim Technical Bulletin* was released 11 years before the *Cost Guide*, this was not unexpected. The FHWA has been in the process of updating the *Interim Technical Bulletin* since 2009 but has not yet released an update (which was originally planned for 2011). FHWA officials have stated the delay of the update is due to waiting on guidance from others in order to incorporate new information (Government Accountability Office, 2013).

The worst aligned best practice was the "present estimate to management for approval", which was rated as Minimally Aligns. The GAO found only brief references to presenting results to management in the FHWA's guidance, and no recommendations on what should be included in such presentations. Specifically, the GAO cited assistance in presenting probabilistic results and felt that additional guidance on presentation would be useful in communicating results and benefits of LCCA to legislators considering adopting LCCA as a tool.

The GAO recommended the Secretary of Transportation direct the FHWA Administrator to issue updated LCCA guidance to fully incorporate the best practices set forth by the *Cost Guide,* which special consideration to:

- input data quality and reliability,
- use of independent cost estimates
- documentation of the analysis,
- how to present the analysis for management approval, and
- describing when the estimate should be updated.

2.2 LCCA Overview

The objective of an LCCA in investment selection is to evaluate the overall long-term economic efficiency between competing alternative investment options. The net present value concept is applied to compare the costs over the life spans of the alternatives. The NPVs of competing alternatives are determined by combining initial construction costs with discounted future costs for maintenance, rehabilitation, and, if appropriate, the salvage value of the alternatives at the end of the analysis period. The LCC of alternative can be visualized using an expenditure-stream diagram in which costs and benefits are expressed as vectors over a specific time horizon. Figure 2.1 is a typical expenditure stream diagram.

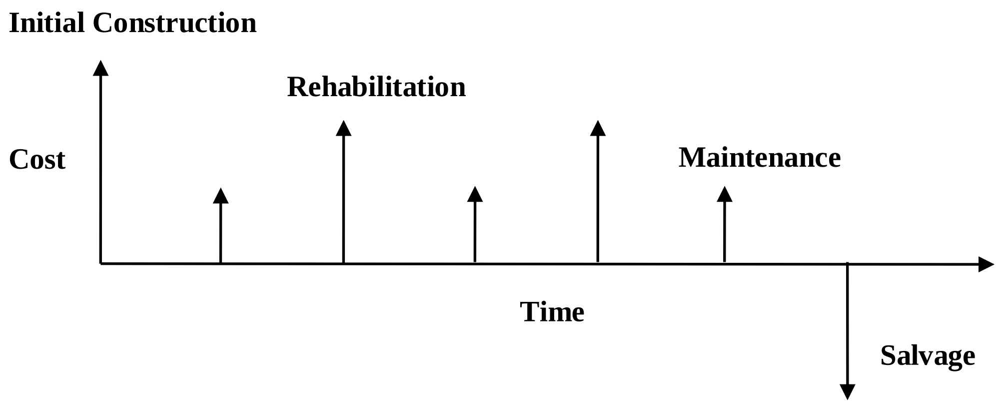

Figure 2.1 Typical Expenditure Stream Diagram (Walls III, 1998)

The NPV of a specific alternative is calculated by Equation 2.1:

$$NPV = Initial\ Const.Cost + \sum_{k=1}^{N} Future\ \ Cost_k \left[\frac{1}{(1+i)^{n_k}}\right] - Salvage\ Value\left[\frac{1}{(1+i)^{n_e}}\right] \tag{2.1}$$

Where N = number of future costs incurred over the analysis period,

i = discount rate, percent,

n_k = number of years from the initial construction to the k^{th} expenditure,

n_e = analysis period, years.

The cost components included in the NPV determination can include costs incurred by the agency (design, materials, labor, traffic control, construction management) and costs incurred by users (due to time delay and increased vehicle operation expenses). In the course of a pavement's life several maintenance operations and rehabilitation activities will be performed. Using historical data, the year and nature of the maintenance and rehabilitation activities can be predicted. In order for these predictions to be accurate, a robust pavement management system must be in place—something that many agencies (including ALDOT) currently lack. Each rehabilitation cost should be estimated from current cost data. Effects of inflation are commonly omitted from LCCA calculations, so each cost can be considered using constant dollars. These future rehabilitations costs are then discounted back to a present value using a discount rate. The discount rate accounts for the time growth of money—essentially interest. Discount rates are commonly determined by surveying interest offers from public treasuries. It is generally accepted that asphalt and concrete pavements will exhibit different condition deterioration curves and therefore the maintenance and rehabilitation schedules will also vary. Figure 2.2 shows typical rehabilitation schedules for two hypothetical pavement alternatives.

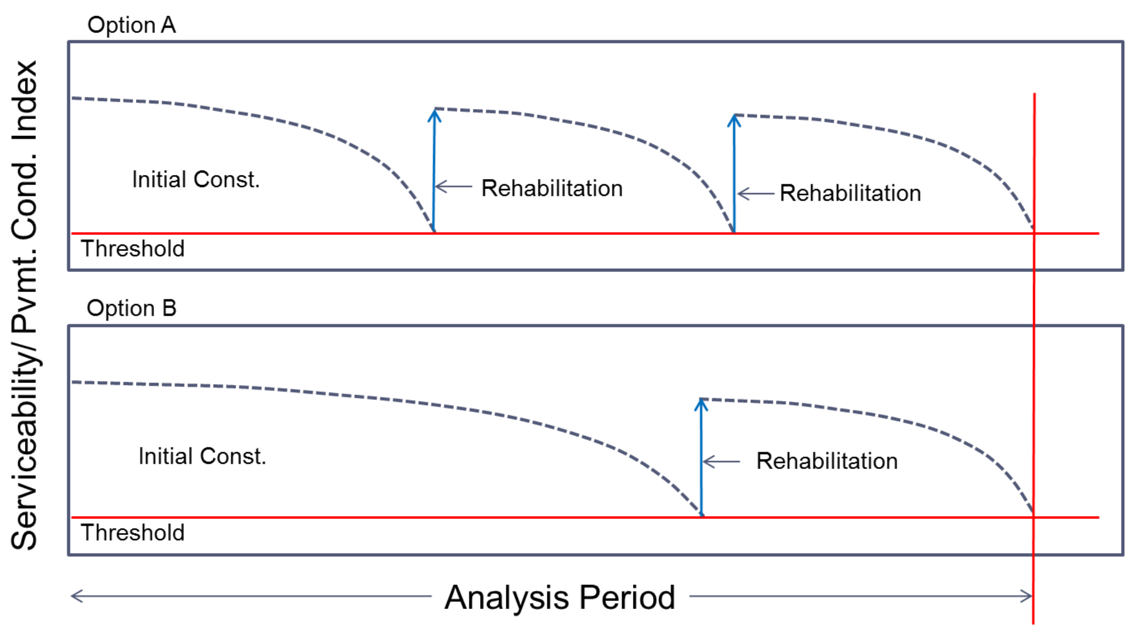

Figure 2.2 Ideal Life Cycle Diagrams of Two Pavement Alternates (West, 2012)

In the context of LCCA for pavement type selection, it is standard to consider costs as positive values, and benefits as negative. This convention is not held for all uses of LCCA, and thus it must be carefully noted. This also means that the pavement surface with the lowest NPV is the cheapest alternative.

3 LCCA Inputs

3.1 Analysis Period

The analysis period is the time horizon over which future costs are evaluated in the LCCA. A commonly accepted notion is that the analysis period should be long enough to include at least one major rehabilitation for each design alternative. However, it is not clear as to what constitutes “major” rehabilitation. AASHTO defines pavement rehabilitation as “structural enhancements that extend the service life of an existing pavement and/or improve its load carrying capacity. Rehabilitation techniques include restoration treatments and structural overlays.” (AASHTO, 2004) It is inferred that for asphalt pavements, rehabilitation includes structural overlays with or without milling, and for concrete pavements includes a wider range of activities such as full-depth slab removal and replacement, under-sealing, dowel-bar retrofit, HMA overlays, and bonded concrete overlays. No distinction is made as to which activities are considered “major” rehabilitation.

3.1.1 ALDOT Policy

ALDOT currently uses an analysis period of 28 years.

3.1.2 FHWA Recommendation

The FHWA provided guidance on choosing the analysis period in an *Interim Policy Statement on LCCA* published in the July 11, 1994 *Federal Register* (US Government, 1994). This policy states that analysis periods “should not be … less than 35 years for pavement investments.” This minimum was cited by Walls and Smith in FHWA’s *Life-Cycle Cost Analysis* *in Pavement Design*. In its September 1996 *Final Policy Statement on Life-Cycle Cost Analysis*, the FWHA removed the recommendation of a minimum 35-year analysis period and instead insisted that "analysis periods used in LCCAs should be long enough to capture long term differences in discounted life-cycle costs among competing alternatives"—essentially recommending a policy of "good practice" (US Government, 1996). This "good practice" standard was the final recommendation made in accordance with the National Highway System Designation Act of 1995.

3.1.3 Common Practice

ALDOT currently uses an analysis period of 28 years. This value is lower than that used by most other agencies. The most recent comprehensive survey of LCCA practices amongst transportation agencies, conducted by the State Asphalt Pavement Associations in 2010, found the average analysis period to be 37.9 years (median value 40 years, 39 states responding). Other surveys in the past ten years exhibit similar findings. Figure 3.1.1 shows a box-plot diagram of three surveys. The survey conducted by the State Asphalt Pavement Associations is labeled "SAPA2010." A 2003 survey conducted by the Mississippi DOT is labeled Mississippi DOT and found the average analysis period to be 36.1 years (median value 35 years, 14 states responding). The South Carolina DOT conducted a survey in 2008 and found the mean value to be 38.5 years (median value 40 years, 22 states responding). The grey rectangles represent the central 50% of the data and the lines (referred to as whiskers) extend to the upper and lower values. The average value is represented by the crosshairs symbol.

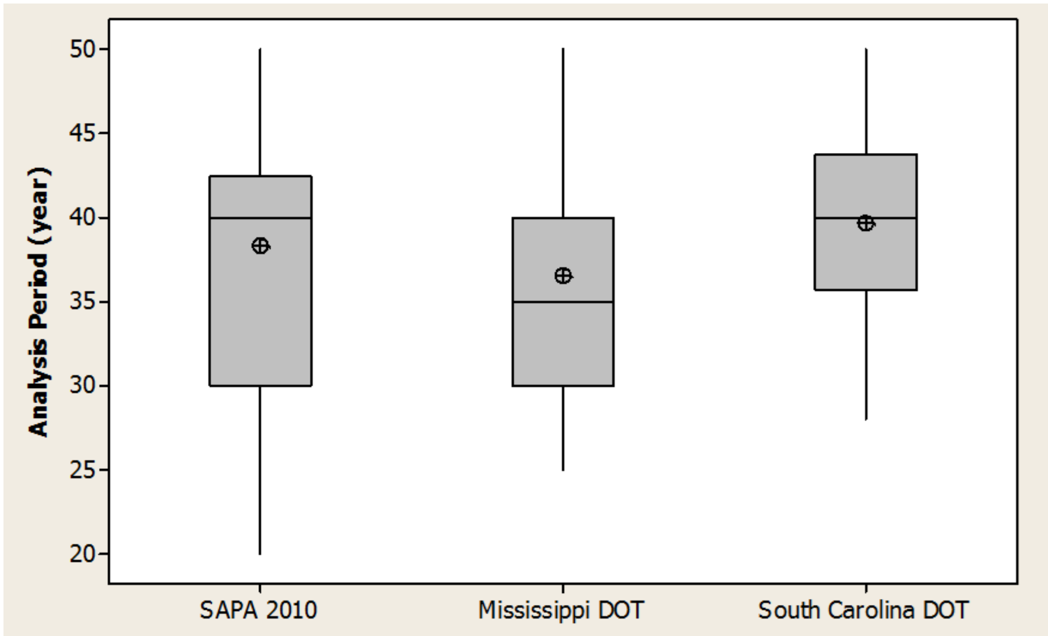

Figure 3.1.1 LCCA Analysis Periods from Recent Surveys (Monk, 2010) (Rangaraju, 2008) (Battey, 2003)

The American Concrete Pavement Association (ACPA) recommends an analysis period of "45-50+" years. The ACPA considers their recommendations suitable for airports in which Design Lives could be 45-50 years. However for pavements with a shorter design life (APCA says 30+ years for concrete pavement), the analysis period should be long enough "such that at least one major rehabilitation effort is captured for each alternative."

3.1.3 NCAT Recommendation

NCAT recommended using an analysis period of 35 years (West, 2012). This value is within FHWA's range of "good practice", albeit at the lower end. However, this value is the most appropriate because it accounts for one major rehabilitation for each surface type and minimizes uncertainty intrinsic to long prediction periods.

NCAT determined that 35 years was sufficient to allow for one major rehabilitation was analyzing historical data provided by ALDOT and other southeastern state transportation agencies. In Alabama, the majority of concrete pavements reached their terminal serviceability at an average of 32 years (Bell, 2012). Louisiana DOT's pavement management database indicates that the average age of the concrete pavements at the time they were rubblized was 33.9 years. The Florida DOT rubblized 47 miles of concrete pavements on I-10 in the panhandle between 1999 and 2001 (Taylor, Pavement Management Section Overview, 2012). The average age of those rubblized concrete pavements in Florida was 28.2 years. The Kentucky DOT reported that the average age of concrete pavements when they were destroyed and overlayed with asphalt using the now outdated "break & seat" method was 25.5 years (Rauhut, 2000). It should also be noted that pavements are not always reconstructed at the exact moment they reach terminal serviceability. If this bias were accounted for, it is likely that the average performance lives reported by these agencies would be even lower.

It is intuitive that predicted conditions become less accurate as the time horizon is increased. To illustrate the point of increasing uncertainty with longer forecasts, NCAT examined ALDOT traffic data used in the rehabilitation design of 30 interstate pavements from 20 years ago (West, 2012). The projected traffic, quantified as annual average daily traffic (AADT), at 5, 10, 15, and 20 years was compared to measured traffic at those periods for the same roadway segments. The error was calculated as the difference between the projected AADT and measured AADT for each segment. Table 3.1.1 summarizes these results.

Table 3.1.1 Results of Traffic Projection Analysis

Analysis of Traffic Forecasting Accuracy	Forecast Years	Standard Deviation of Error (% of AADT)	Span of 90% Confidence Interval (% of AADT)
30 Alabama Interstate Projects Time span: 1986 to 2011	5	11	18.1
	10	14	23.0
	15	18	29.6
	20	24	39.5

Clearly, the standard deviation of the error increased as the traffic projection went further into the future. The results of an LCCA are dependent upon traffic volumes in several ways. The required structural design is a function of AADT. This would affect both asphalt and concrete surfaces but not necessarily equally. Furthermore, user delay costs are a function of traffic volume, and their inclusion in LCCA can often drastically affect the outcome.

Traffic volume is just one of many uncertain variables in LCCA. It is therefore advisable to choose an analysis period as short as possible (in order to mitigate uncertainty errors) that still include a major rehabilitation effort for each surface type.

3.2 Discount Rate

An agency will perform a LCCA to assess the total anticipated lifetime costs of a planned infrastructure project. Highway projects incur costs at various stages of their lifecycles, including initial construction costs, rehabilitation, maintenance, and salvage. To assess the costs of a project, an analyst must equate costs from present years and future years into like terms. Discounting transforms future costs and benefits occurring at different years to a common point in time. Discount rates have a significant impact on the determination of the NPV of alternative pavement designs.

Discounting applies a discount rate to future dollar amounts and allows for the calculation of a correct present value. In this sense, the discount rate can be considered an interest rate in reverse. A discount rate translates future values influenced by the time value of money (defined as the future value of money after the effects of inflation) to constant terms. A real discount rate reflects only the effects of the time value of money and results in a lower, current number when multiplied by a higher future value. The NPV of investments, adjusted to constant terms using a discount rate, is shown in Equation 2.1.

3.2.1 ALDOT Policy

ALDOT currently uses a real discount rate of 4.0%.

3.2.1 FHWA Recommendation

The FHWA recommends using a real discount rate that does not account for inflation. The discount rate should reflect historical trends (typically near 4%) and can be consistent with the rates provided by the Office of Management and Budget (OMB) in Appendix A Circular A-94 (Walls III, 1998).

3.2.2 Common Practice

The OMB is tasked with assisting the President with preparing the Federal budget. Since 1979, the OMB has published a recommended real discount rate. This rate represents an estimate of the average rate of return on private investment, before taxes and after inflation (Zerbe Jr., 2002). Most state highway agencies currently use either a 3.0 or 4.0 percent real discount rate. However, several states use OMB's interest rate for the current year, which is currently at an all-time low, reflecting the Great Recession and today's low inflation and interest rates. The OMB recommends that analysts use these real interest rates for discounting constant-dollar flows in cost-effectiveness analysis. Estimates of real discount rates range from 0.0 percent for the 5-year period to 2.0 percent for the 30-year period (Office of Management and Budget, 2013). The OMB notes that analyses of programs with terms different from the published terms may use a linear interpolation. For example, a four-year project uses a rate equal to the average of the three and five-year rates. Programs with durations longer than 30 years may use the 30-year interest rate. Figure 3.2.1 provides the annual 30-year interest rates published for each year from 1979 to 2012.

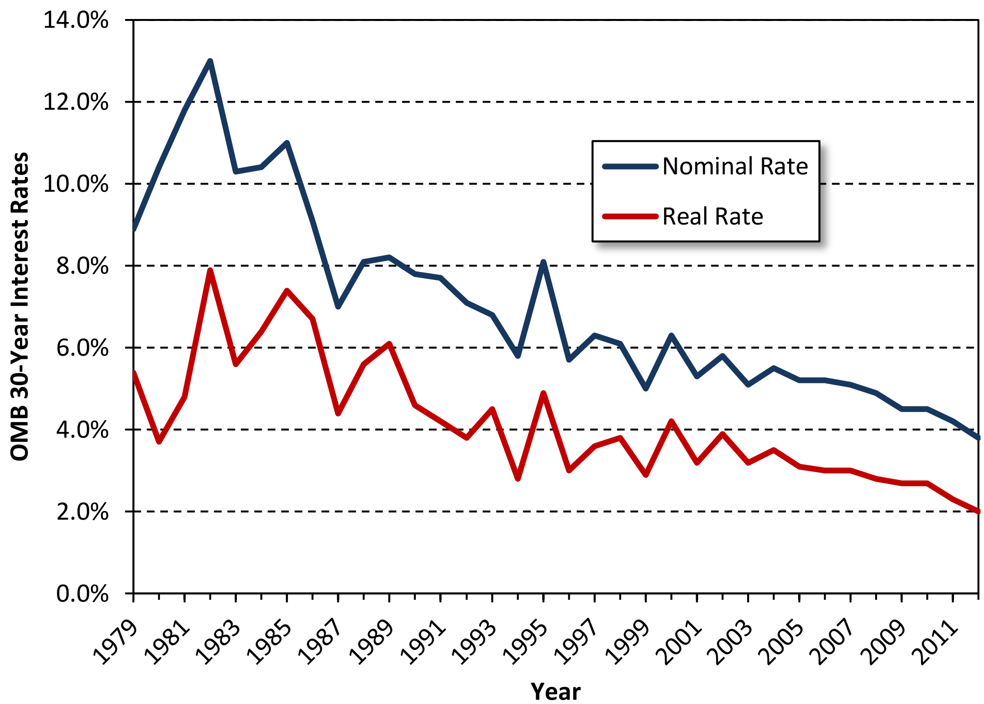

Figure 3.2.1 OMB 30-Year Interest Rates (Office of Management and Budget, 2013)

Most states have a real discount rate set in the three to four percent range. Very few states are under 3.0 percent or over 4.4 percent. There is no discernible geographic pattern to these real discount rates. Table 3.2.1 shows the results of a comprehensive 2010 survey by the State Asphalt Pavement Associations (SAPA).

Table 3.2.1 State Asphalt Pavement Associations Survey of Discount Rates Used in LCCA (Monk, 2010)

State	Discount Rate, %	State	Discount Rate, %
Alabama	4.0	Montana	4.0
Arizona	4.0	Nevada	4.0
Arkansas	3.8	New Hampshire	4.0
California	4.0	New Jersey	4.0
Colorado	3.5	New Mexico	4.0
Delaware	3.0	New York	4.0
Florida	4.0	Nebraska	2.4
Georgia	3.0	North Carolina	4.0
Hawaii	4.0	Ohio	2.8
Idaho	4.0	Oregon	4.0
Illinois	3.0	Pennsylvania	6.0
Indiana	4.0	Rhode Island	4.0
Kansas	3.0	South Dakota	7.1
Kentucky	4.0	Tennessee	4.0
Louisiana	4.0	Utah	4.0
Maine	4.0	Vermont	4.0
Maryland	4.0	Virginia	4.0
Massachusetts	3.0	Washington	4.0
Michigan	2.8	West Virginia	3.0
Minnesota	3.5	Wisconsin	5.0
Mississippi	4.0	Wyoming	4.0
Missouri	2.3		

Two states use a rolling average of OMB 30-Year Rates: Colorado uses a 10-year moving average and Minnesota uses a 6-year average.

3.2.3 NCAT Recommendation

NCAT recommended using a 10-year rolling average of the OMB 30-year discount rate (West, 2012). The use of a rolling average will protect the analysis against unpredictable short-term swings in the OMB rate. Using a single-year Circular A-94 real interest rate every year introduces inconsistency into LCCAs. In the last 34 years, the OMB value for the 30-year real interest rate has changed as much as 3.1 percent from one year to the next and as much as 4.2

percent in a two-year span. Adoption of a single year real interest rate could lead to LCCA results that vary widely from the end of one year to the beginning of the next. It is also possible for this change to occur after the LCCA has been performed yet before construction, which may present an awkward situation is which an agency is paving a road with a surface type that is not most economical by the agencies own standards. The use of a single year's rate is, by definition, nescient of historical trends and therefore not "good practice" as defined by the FHWA.

The use of the 10-year rolling average avoids these concerns. The 10-year rolling average rate is, by definition, considerate of historical trends and consistent with the practices established by the OMB. The current 10-year rolling average of the 30-year is 2.62%. Figure 3.2.2 shows the rolling average through the year 2012.

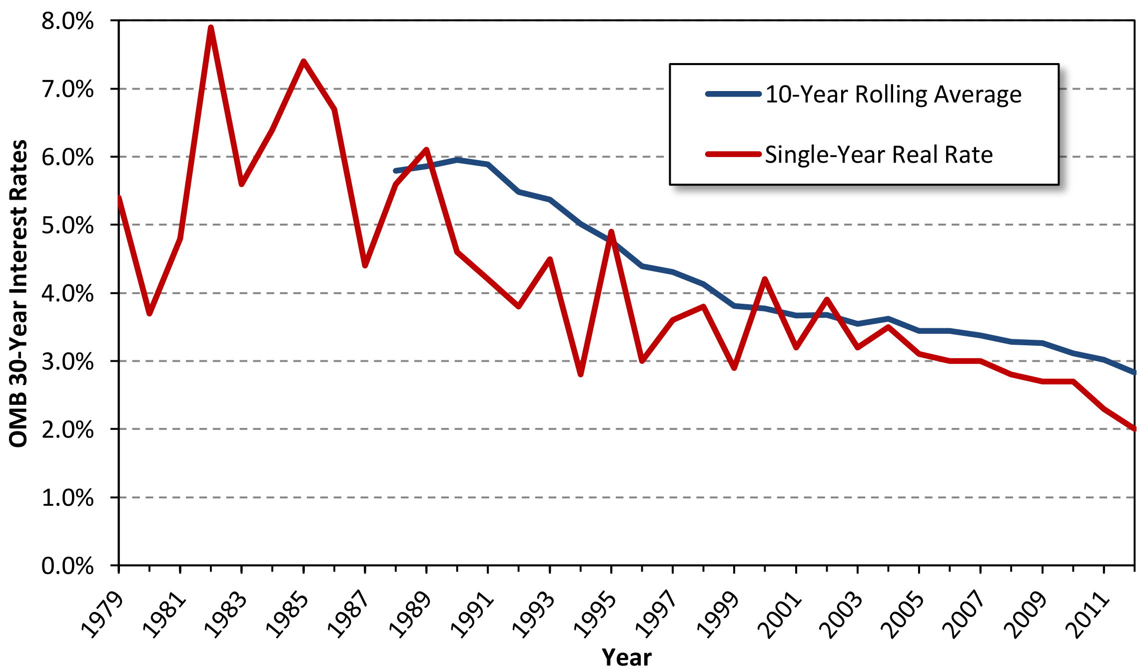

Figure 3.2.2 OMB 30-Year Real Interest Rates with 10-Year Moving Average (West, 2012)

3.3 Performance and Rehabilitation Periods

The performance and rehabilitation durations are key inputs into LCCA. In the context of LCCA, “performance period” refers to the time spanning from initial construction to the first rehabilitation of the pavement. “Rehabilitation period” refers to the time spanning between rehabilitations. Longer performance periods lead to fewer and further discounted rehabilitation efforts, thus lowering the NPV of an alternative.

3.3.1 ALDOT Policy

Current ALDOT policy is based upon data collected by the Materials and Tests Bureau in the early 1990s (Lockett, 2012). Performance periods were determined to be the average durations between initial construction and a first rehabilitation of pavements then currently in the Alabama state highway system. ALDOT currently uses an initial performance period of 12 years for asphalt. At year 12, the policy assumes that top two binder layers will be removed and replaced. At year 20, the top three layers are removed in replaced. The asphalt pavement is assumed to have zero value at year 28.ALDOT considers an initial performance period of 20 years for concrete pavements. At year 20, it is assumed that the concrete pavement will be rehabilitated by cleaning and sealing the joints. The concrete pavement is also assumed to have no value at year 28.

3.3.2 FHWA Guidance

The FHWA advises state highway agencies (SHA) to develop specific performance periods based upon pavement management data and historical experience (Walls III, 1998). The FHWA assists SHAs in this task by providing data from the Strategic Highway Resource Program (SHRP) Long-Term Pavement Performance Program (LTPP).

Furthermore, the American Association of State Highway and Transportation Officials (AASHTO) has provided guidance on the definitions of pavement preservation efforts. Ambiguous terminology can lead to confusion as to what is considered maintenance compared to rehabilitation or reconstruction. These definitions are as follows (AASHTO Highway Subcommitte on Maintenance, 2004):

- Pavement preservation: a proactive approach to maintaining existing highways. A pavement preservation program consists primarily of three components: (1) preventive maintenance, (2) minor rehabilitation (non-structural), and (3) some routine maintenance activities.
- Preventative maintenance: a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without significantly increasing the structural capacity).
- Routine maintenance: work that is planned and performed on a routine basis to maintain and preserve the condition of the highway system or to respond to specific conditions and events that restore the highway system to an adequate level of service.
- Pavement rehabilitation: structural enhancements that extend the service life of an existing pavement and/or improve its load carrying capacity. Rehabilitation techniques include restoration treatments and structural overlays.
- Pavement reconstruction: the replacement of the entire existing pavement structure by the equivalent or increased pavement structure. The existing pavement structure is either completely removed or demolished for use as an aggregate base layer. The

removed materials can be recycled as appropriate for the reconstruction of the new pavement section. Reconstruction is required when a pavement has failed structurally or has become functionally obsolete.

3.3.3 Common Practice

A 2010 SAPA survey summarized agencies performance periods for asphalt pavements. Table 3.3.1 shows these results.

Table 3.3.1 Performance Periods Surveyed by State Asphalt Pavement Associations (Monk, 2010)

State	Performance Periods (yrs.)		State	Performance Periods (yrs.)	
	Initial Const.	Rehabilitation		Initial Const.	Rehabilitation
Alabama	12	8	Missouri	20	13
Alaska	15	15	Montana	15	12
Arizona	15	5	Nevada	20	20
Arkansas	12	8	New Hampshire	20	11
California	20	5	New Jersey	15	15
Connecticut	15	15	New Mexico	12	8
Delaware	12	8	New York	12	8
Florida	14	14	Nebraska	20	15
Georgia	10	10	North Carolina	10	10
Hawaii	17	18	Ohio	12	10
Idaho	12	12	Oklahoma	30	15
Illinois	20	20	Oregon	20	20
Indiana	20	15	Pennsylvania	10	10
Iowa	20	20	Rhode Island	20	11
Kansas	12	10	South Carolina	12	10
Kentucky	10	10	South Dakota	16	16
Louisiana	15	15	Tennessee	10	10
Maine	17	9	Utah	10	10
Maryland	15	12	Vermont	18	13
Massachusetts	18	16	Virginia	12	10
Michigan	13	13	Washington	15	15
Minn < 7MESALs	20	15	West Virginia	22	4
Minn > 7MESALs	15	12	Wisconsin	18	12
Mississippi	12	10	Wyoming	20	15

The mean initial performance period in this study (excluding Minnesota low-volume roads) was 15.0 years (47 respondents, median value of 15.0 years). The mean rehabilitation period was 12.0 years (47 respondents, median value of 12.0 years).

A 2008 survey by the South Carolina DOT found different results, however (Rangaraju, 2008). These are summarized in Figure 3.3.1.

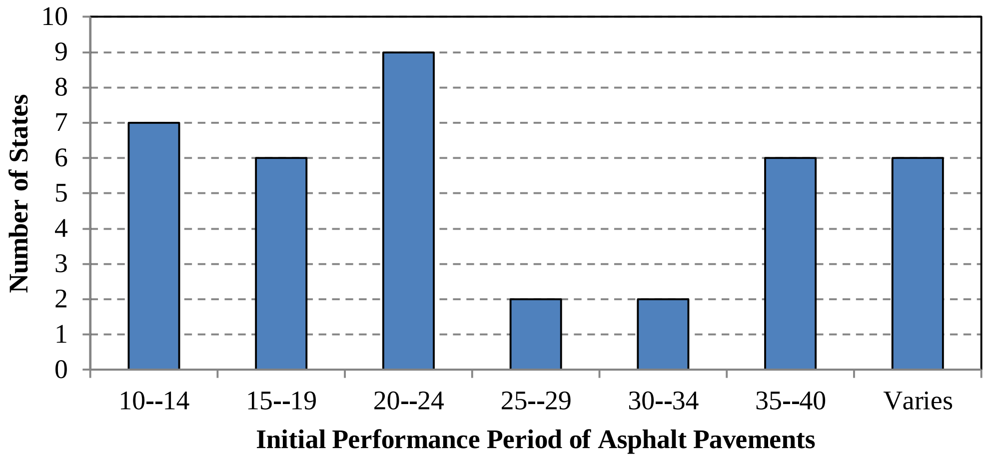

Figure 3.3.1 Initial Performance Periods of Asphalt Pavements Based on SCDOT Survey
(Rangaraju, 2008)

The mean initial performance period found in this survey was 16.1 years (28 responses considered).

The same 2008 South Carolina DOT survey inquired about the initial performance periods for concrete pavements. Thirty-one agencies responded and the mean performance period was 25.1 years (median value of 25 years). Table 3.3.2 summarizes these results.

Table 3.3.2 Initial Performance Periods of Concrete Pavements Based on SCDOT Survey (Rangaraju, 2008)

Agency	Rigid Performance Period, yrs	Agency	Rigid Performance Period, yrs
Alabama	20	Michigan	26
Arkansas	20	Minnesota	17
California	22.5	Mississippi	16
Colorado	22	Missouri	25
Connecticut	27.5	Montana	35
Florida	20	Nebraska	35
Georgia	22.5	New York	25
Idaho	40	North Carolina	15
Illinois	40	Ohio	22
Indiana	30	South Carolina	20
Iowa	40	South Dakota	18
Kansas	20	Utah	40
Kentucky	30	Virginia	30
Louisiana	20	Washington	25
Maryland	25	Wisconsin	25
		Ontario	28

3.3.4 NCAT Recommendations

Ideally, the performance periods for asphalt and concrete pavements should be based on actual performance data from the ALDOT pavement management system. ALDOT, however, lacks a pavement management system capable of providing thorough historical data sufficient to confidently predict pavement performance (Shugart, 2012). Therefore, additional data from LTPP and southeastern transportation agencies was examined.

A 2005 study by Applied Research and Associates (ARA) analyzed LTTP data for initial performance periods. These results are presented in Table 3.3.3.

Table 3.3.3 Expected Initial Service Life of Asphalt Pavements Based on LTPP Data (Von Quintus, 2005)

Distress Type	**Average Service Life (years)**	
	Low Distress Level	**Moderate Distress Level**
Fatigue Cracking	22	25
Transverse Cracking	19	22
Longitudinal Cracking in Wheel Path	22	28
Longitudinal Cracking Outside Wheel Path	18	22
Rutting	17	22
Roughness or IRI	20	22

These results are generally longer than those found by agency surveys. It should be noted that the agency surveys asked for the duration of initial performance periods used in LCCA, not what the agencies actually believed the initial performance period to be.

The 2005 ARA study also analyzed the performance of asphalt overlays (i.e. rehabilitation performance periods). Table 3.4.4 summarizes these results.

Table 3.4.4 ARA Expected Service Life of Asphalt Overlays Based on 1997 LTPP Database (Von Quintus, 2005)

Distress Type	**Average Service Life (years)**
Fatigue Cracking	14
Transverse Cracking	9.5
Longitudinal Cracking in Wheel Path	15
Longitudinal Cracking Outside of Wheel Path	12.5
Rutting	12.5
Roughness or IRI	13

It should be noted that this study was performed using LTPP data from 1997. Several improvements to asphalt technology have been implemented since this time (specifically stone mastic asphalt mixes, polymer modified binders, Superpave specifications, and improved construction technologies). The FDOT has found a decrease in their deficient pavements since this time. Figure 3.3.2 shows the decline in miles deemed deficient in the Florida highway system from 1995 to 2011.

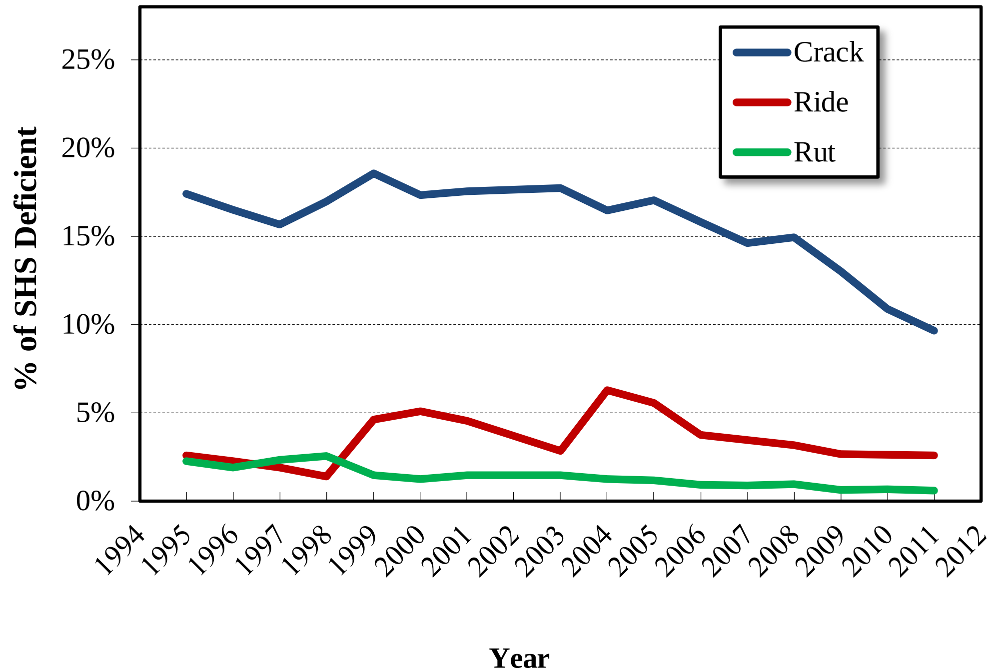

Figure 3.3.2 Declining Percentages of Deficient Lane Miles in Florida DOT's Highway System (Taylor, Pavement Management Section Overivew, 2012)

The Florida DOT considers the average initial performance period and rehabilitation period for asphalt pavements to each be 18 years (Taylor, 2012).

The Missouri DOT examined their performance periods of their highways using PMS data in a 2004 study (Missouri Department of Transportation, 2004). These results are summarized in Table 3.3.4.

Table 3.4.5 Results of Missouri DOT's Analysis of Overlay Performance Periods (Missouri Department of Transportation, 2004)

Route Type	Avg. Life to 1st Overlay (years)	Miles in Sample	Avg. 1st Overlay Life (years)	Miles in Sample	Avg. 2nd Overlay Life (years)	Miles in Sample
Interstate	18.9	12	13.2	11	14.0	2
US Highway	19.3	653	11.5	481	11.2	338
MO State Route	20.7	3010	12.4	2521	10.1	1890

Missouri's results are similar to those found by ARA, although these results must be considered carefully. Missouri reported results as the time until an overlay occurred, while ARA analyzed the time until a distress threshold was reached.

These data show a trend that the initial performance periods of asphalt pavements has increased in recent years, and that the initial performance period seen in the field is typically about 19 years. Similarly, rehabilitation with an asphalt overlay can conservatively be expected to add 13.5 years to a pavement's life.

NCAT recommended an initial performance period for asphalt pavements of 19 years for high-trafficked roads (interstates and urban freeways) and an initial performance period of 21 years all other roads. The rehabilitation period recommended was 13.5 years for all roads.

NCAT did not make a recommendation for the performance periods of rigid pavements. However, it was noted in Section 3.1 that average age of concrete pavements at the time they were rubblized or removed and replaced in Alabama was found to be 32 years (Bell, 2012).

3.4 Salvage Value

In the context of LCCA, salvage value refers to the value of an investment the end of the analysis period. The salvage value is a negative vector in the calculation of the NPV. The salvage value of an alternative often has two components. A “residual value” refers to the value received from liquidated the investment (for example, selling the asset via recycling). The investment may also have still function, and thus should be credited with “serviceable life” value (Walls III, 1998). The salvage value would thus be the sum of these components. The NPV of salvage for pavements is often considered to be insignificant because it is discounted for several decades.

3.4.1 ALDOT Policy

ALDOT does not currently consider a salvage value for asphalt or concrete pavements.

3.4.2 FHWA Recommendation

The FHWA recommends that the remaining serviceable life value of an alternative be the prorated cost of the last rehabilitation. This assumes that the value of the last rehabilitation effort diminishes linearly (often referred to as “straight-line depreciation”) (Walls III, 1998).

3.4.2 Common Practice

A 2008 survey conducted by the South Carolina DOT found that 10 agencies out of 22 surveyed considered salvage values (Rangaraju, 2008). Of the ten agencies that considered salvage values, eight only attributed value to remaining serviceability (California, Colorado, Georgia, Indiana, Maryland, Montana, Washington, and Wisconsin). Nebraska attributed value to residual value and remaining servable life. Minnesota incorporated the reusing of any in-situ bituminous or concrete material which can be recycled into the new pavement back into the initial construction costs.

3.4.3 NCAT Recommendation

NCAT recommends that LCCA include remaining serviceable life using straight line depreciation (West, 2012). This practice produces similar results for both pavement type options regardless of the analysis period. Equation 3.4.1 shows how this value is calculated for an asphalt rehabilitation.

$$Remaining\ Serviable\ Value = CLR \times \frac{Remaining\ Life\ of\ Last\ Resurf.}{Service\ Life\ of\ Last\ Resurf.} \tag{3.4.1}$$

Where: CLR = the cost of the last resurfacing.

However, lower layers of an asphalt pavement structure commonly remain in service well beyond the LCCA analysis period so their value should also be recognized. NCAT proposed calculating the cost of reconstructing these in-place foundation layers at the end of the analysis period and then discounting this value. Figure 3.4.1 shows how this process would occur in an ideal asphalt pavement.

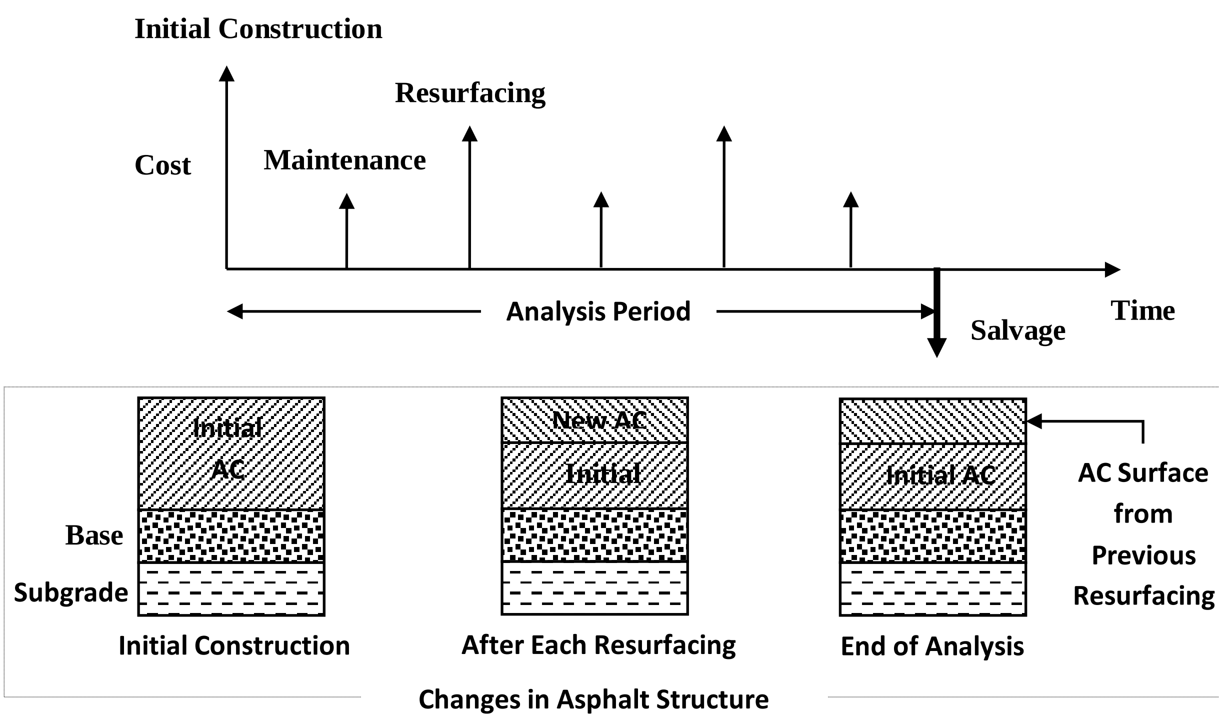

Figure 3.4.1 Stream of Expenditures and Salvage Value and Changes in Asphalt Structure for Asphalt Pavement (West, 2012)

Therefore, the salvage value of an alternative would be calculated by Equation 3.4.2.

$$Salvage\ Value = CLR \times \frac{Remaining\ Life\ of\ Last\ Resurf.}{Service\ Life\ of\ Last\ Resurf.} + CLI \qquad (3.4.2)$$

Where:

CLR = cost of the last resurfacing, and

CRI = cost of the lower asphalt layers remaining from the initial construction.

NCAT also recommended including costs that an alternative must incur at the end of its serviceable life. Concrete pavements are commonly rubblized or removed depending on geometric or subgrade conditions. Removal occurs more frequently in urban areas where bridge clearances and curb and gutter placement prevent pavement buildup. Asphalt pavements may require additional milling to meet grade or structural requirements.

4. User Costs

User costs are the extra costs incurred by the vehicle operators traversing a highway under construction or rehabilitation. These are normally split into three categories. “User delay costs” represent the opportunity cost incurred by a user due to loss of time. “Vehicle operating costs” (VOC) represent the cost incurred to users by operating vehicles, be it the expenses of additional fuel or vehicle maintenance. The third category is “crash costs”, which represent expenses incurred by users involved increases in crash rates in construction zones and detours. “Crash costs” account for all mayhem that result from vehicular crashes, including medical and disability costs.

4.1 ALDOT Policy

ALDOT does not currently calculate or consider user costs in LCCA.

4.1 FHWA Guidance

The FHWA has provided extensive guidance on calculating user costs (Walls III, 1998). However, the complex nature of their calculation requires predictions of future traffic, assumptions regarding work zones, and estimates of the three types of user costs based on limited studies. Before user costs can be calculated, a work zone must be defined. The work zone is the area where traffic is being directly affected by construction. Defining a work zone requires:

- Year of rehabilitation activity
- Number of lanes closed
- Specific hours of lane closure

- Work zone length (miles)
- Work zone posted speed (mph)
- Work zone duration (hours)

There are 12 steps involved in calculating user costs—beneath each step is the information required to compute the step (Walls III, 1998):

1. *Project Future Year Traffic Demand*
    - Base year AADT
    - Percent passenger vehicles
    - Percent single-unit trucks
    - Percent combination trucks
    - Traffic growth rate
2. *Calculate Work Zone Directional Hourly Demand*

    Directional hourly traffic demands should be calculated using agency traffic from the project under consideration or from traffic data from similar facilities. If this data is not available, default hourly distributions for rural and urban settings have been released by the NCHRP. This data is accessible through the FHWA's *RealCost* software and the Asphalt Pavement Alliance's *LCCA* software (Federal Highway Administration, 2008) (Asphalt Pavement Alliance, 2008).
3. *Determine Roadway Capacity*
    - Free-flow capacity (maximum traffic flow during hours when the work zone is not in place)
    - Capacity when work zone is in place
    - Capacity of work zone to dissipate traffic from a standing queue

The default ideal free-flow capacity is 2,200 passenger cars per hour per lane (pcphpl) for a 2-lane directional freeway and 2,300 pcphpl for a 3-lane directional freeway (Walls III, 1998). Work zone capacity can be estimated from past experience, or values from the *Highway Capacity Manual* can be used (Table 4.1). Queue dissipation rates average 1,818 pcphpl with a standard deviation of 144 pcphpl.

Table 4.1 Work Zone Capacities from the *Highway Capacity Manual* (Walls III, 1998)

Directional Lanes		**Average Capacity**
Free Flow Operations	**Work Zone Operations**	**Vehicles per Lane per Hour**
2	1	1,340
3	1	1,170
3	2	1,490
4	2	1,480
4	3	1,520
5	2	1,370

4. *Identify Queue Rate and Queue Length*

The queue rate (vehicles/ hour) and queue length (vehicles or miles) is calculated by demand (calculated in Steps 1 and 2) minus capacity (calculated in Step 3).

5. *Quantify Traffic Affected by Each Component*

- Vehicles traversing work zone
- Vehicles traversing queue
- Vehicles that stop
- Vehicles that slow down

A vehicle will stop when it encounters a queue and will slow down when it traverses a work zone (even if free-flow conditions exist, the posted speed will be lower). This information can be obtained from Step 5 and the work zone lane closure hours.

6. *Compute Reduced Speed Delay*

- Time delay per vehicle forced to slow down
- Time delay per vehicle forced to queue

The time delay for reduced speed is simple to calculate—a simple solution to consider the difference in the amount of time required to traverse the work zone under the reduced speed less the time required to traverse the same distance at the normal posted speed. The time delay for vehicles forced to queue is computed in a similar manner. A "queue speed" based on the queue length and queue duration is calculated and used a reduced speed. The queue length and queue durations are estimations based upon how long a vehicle will reasonably remain in queue before using a different route.

7. *Select and Assign Vehicle Operating Cost Rates*

Vehicle operating costs refer specifically to costs incurred while running the vehicle (generally, the amount extra fuel consumed while slowing down or stopped). The FHWA has data associated with stopping 1,000 vehicles from a particular speed and returning them to that speed. This value can be used to calculate the vehicle operating costs for queue delays. In order to calculate the vehicle operating costs for reduced-speed delays, the practice is to calculate the difference in costs from the high speed and the low speed. The FHWA's vehicle operating costs are reported in August 1996 dollars, and should be converted to present dollar amount by referencing the Consumer Price Index "transportation services" subcategory.

8. *Select and Assign Delay Cost Rates*

User delay costs refer specifically to opportunity costs the user incurs while delayed. The FHWA recommends values based on data from NCHRP Report 133 (1970) and NCHRP Project 7-12 *Microcomputer Evaluation of Highway User Benefits* (1993). The FHWA adjusts both of these delay costs to a present value (then August 1996) and averages them to arrive at their recommendation. Table 4.16 shows the FHWA's recommended user delay rates in August 1996 and their present (April 2013) values. The CPI used in LCCA is the Transportation-All Items index (Walls III, 1998) (Statistics, 2013).

Table 4.2 FHWA User Delay Rates (Walls III, 1998)

Vehicle Type	**Value of Time ($/hr)**	
	Aug-96	**May-13**
Passenger Cars	11.58	21.20
Single-Unit Truck	18.54	33.95
Combination Trucks	22.31	40.85

9. *Assign Traffic to Vehicle Classes*

In order to assign proper user cost rates, the number of passenger vehicles, single-unit and combination trucks experiencing each delay type must be calculated. This is done simply by multiplying the results from Step 1 and Step 5.

10. *Compute Individual User Costs Components by Vehicle Class*

This step is completed by assigning the affected vehicles the vehicle operating costs and the user delay costs.

11. *Sum Total Work Zone User Costs*

The total user costs from all three vehicle types is summed.

12. *Address Circuitry and Crash Costs*

Circuitry refers to the added cost of vehicles taking an alternate route due to the work zone. This re-route can be due to an agency mandate or it can be self-imposed. Vehicle operating costs of $0.57 per mile (April, 2013 cost) (Walls III, 1998) times the excess distance the detour imposes should be considered for passenger cars. If the detour is agency mandated, the numbers of vehicles affected should be set to the AADT from the facility under construction. A consumer-surplus approach should be employed if the detour is self-imposed. Appropriate $/hour user delay rates should also be applied.

Crash cost rates are currently $4.7 million for fatalities, $42,000 for injuries and $5,420 for property damage (all April-13$) (Walls III, 1998). These values can be used with estimated work zone crash rates provided by the FHWA to compute the crash cost to users, although it should be noted the FHWA does not stand by their accuracy (Walls III, 1998). All costs given in April 2013$ are inflated using the Consumer Price Index from September 1998$ provided by the FHWA.

4.2 Common Practice

A 2005 study commissioned by the South Carolina DOT found that 41% of states responding to their survey used user costs to some extent when calculating the life-cycle costs of alternatives. Some states reported only considering user costs in certain situations, for example, when one alternative creates large traffic queues or the two alternatives' NPVs are within 10% of each other.

4.3 NCAT Recommendation

NCAT recommended only considering user costs when the two alternatives' NPVs were within 10% or each other, or if it was suspected that one or more of the alternatives could cause excessively long queues. This recommendation recognizes the importance of user incurred costs, but also how speculative their prediction can be. Traffic projections are the most influential factor in a user delay cost sensitivity analysis. Traffic projections made by ALDOT between 1986 and 2011 were off by as much as 40% within 20 years (see Section 3.1.3). Since this error could be made in either direction, this alone is not a reason to discredit user delay costs, but it is a reason to analyze projected costs with skepticism.

For example, an LCCA was performed for State Project IM-NHF-I065 (393), the reconstruction of I-65 in Hoover, AL from I-459 to SR-3. An LCCA conducted by ALDOT in 2011 found that the NPV of the two pavement alternatives was close (asphalt $12.23 million, concrete $12.74 million). An agency decision was then made to bid the project as concrete pavement. Construction began on 11 March 2011 and completed on 1 January 2012 (297 construction days).

At certain times during this reconstruction, acceleration lanes from ramps to merge traffic onto the highway were not available. This resulted in approximately 500 accidents (Burnett & Andrew, 2012). The majority of these accidents were minor and resulted in only property damage or minor injury. The crash costs resulting from these accidents would have a significant effect on the LCCA, especially if the acceleration lanes were required to be closed for a longer period of time. ALDOT's current LCCA procedure did not account for these costs, and neither would have the FHWA method. Traffic on I-65 in this area regularly forms long queues (greater than 2 miles) during rush hours. This user-expected queue would not deter most commuters from taking the alternate route (in this case US-31), so they were more likely to sit in a queue than detour. This also cannot be foreseen during an LCCA. These small details that affected this particular project likely occur on most large urban projects and are potentially unpredictable during the pavement type selection phase. Indeed, it does not take much to render a user cost prediction inaccurate.

5 Deterministic v. Probabilistic Approach

It has been established that LCCA is a sum of estimations and predictions, many which span decades into the future. The inherent uncertainty involved in these predictions is easily overlooked if each alternative is assigned a single NPV (known as a "deterministic approach"). It is possible to produce a probability distribution for the NPV of each alternative using a "probabilistic approach" where the uncertainty of inputs is taken into account.

5.1 ALDOT Policy

ALDOT currently uses a deterministic approach. At the time ALDOT last updated their LCCA policies, common practice was to use a deterministic approach, and furthermore ALDOT did not possess a pavement management system capable of developing uncertainty models required for a probabilistic approach.

5.2 Uncertainty in LCCA

The FHWA determined several inputs to be of an uncertain nature (Walls III, 1998). These inputs are summarized in Table 5.1. Each uncertain input is described as either an estimate, assumption, or a projection.

Table 5.1 LCCA Input Variability (Walls III, 1998)

LCCA Component	Input Variable	Source
Initial and Future Agency Costs	Preliminary Engineering	Estimate
	Construction Management	Estimate
	Construction	Estimate
	Maintenance	Assumption
	Rehabilitation	Assumption
	Salvage Value	Estimate
Timing of Costs	Pavement Performance	Projections
User Costs	Current Traffic	Estimate
	Future Traffic	Projection
	Hourly Demand	Estimate
	Vehicle Distributions	Estimate
	Dollar Value of Delay Time	Assumption
	Work Zone Configuration	Assumption
	Work Zone Hours of Operation	Assumption
	Work Zone Duration	Assumption
	Work Zone Activity Years	Projection
	Crash Rates	Estimate
	Crash Cost Rates	Assumption
NPV	Discount Rate	Assumption

5.3 Deterministic Approach

A deterministic solution means there is a single, unique outcome for a given set of inputs. The NPV equation (see Equation 2.1) used for LCCA is an example of a deterministic solution. Using a deterministic approach to LCCA ignores uncertainty associated with the inputs. The NPV is calculated using “good practice” estimations, assumptions and projections. This approach may exclude valuable information that could affect the design decisions. ALDOT and most DOTs currently use a deterministic approach in LCCA (Rangaraju, 2008).

5.4 Probabilistic Approach

While the variability of some inputs may not significantly affect the NPV calculation, and others may be common to both design alternatives and therefore “wash out”, slight changes in some of these inputs can have drastic effects on the results. LCCA is particularly sensitive to changes in the cost estimates, discount rate, performance periods, and traffic forecasts when user costs are included.

A probabilistic approach computes the NPV of a design alternative by executing a Monte Carlo simulation to develop a probability distribution of possible outcomes. Each input is assigned a probability distribution. For a given Monte Carlo simulation, the input for each parameter is generated randomly based upon the distribution of the parameter. The NPV of the simulation is then summed using Equation 2.1. This process is carried out many times (usually between 500 and 5000) and a cumulative distribution function or a histogram is generated (Walls III, 1998).

The benefit of a probabilistic approach is that analysis of uncertainty of inputs is possible. Even though one alternative might have a lower NPV for the majority of simulations, the instances when it does not could influence a selection decision. This determination, however, would be open to interpretation and would require experienced engineering judgment.

Detailed pavement management data are necessary to successfully employ a probabilistic approach since some knowledge is required of both the central tendencies and the range or distribution for the inputs listed in Table 5.1. This, alas, is the short-coming of the probabilistic approach. Gathering accurate, appropriate historical data is already difficult to determine the average values used with a deterministic approach. The probabilistic approach requires an understanding of the shape of the data's distribution as well. Even if these distributions are can be determined from historical data, there is no assurance that they will remain so.

5.4.1 Distributions

The FHWA recommends using one of six different probability distributions (Walls III, 1998). They are described below.

- Triangular: this distribution is triangularly shaped with vertices at the minimum and maximum possible values on the x-axis, and a third vertex with an ordinate at the "most-likely" value and an abscissa such that the area under the curve achieves unity.
- Trigen: the trigen distribution eliminates the possibility of selections from the tails. The result is a truncated triangular pentagon. Often the distribution is truncated at the upper and lower 10% of the distribution.
- Uniform: a uniform distribution allocates all an equal chance of selection to all possible values. A minimum and maximum value must be known.
- Normal: the normal distribution can be shaped by backcalculation. The Empirical Rule requires that 95% of the distribution fall within two standard deviations of the mean. The standard deviation can be estimated as one-fourth the difference between the maximum and minimum values (Walls III, 1998).
- Discrete: this distribution is determined by weighing expert opinions or by modeling known probabilities.
- General: the general distribution is flexible in that it allows the user to tailor the shape of the distribution to values acquired by sampling.

5.4.2 Example Probabilistic Output

A sample probabilistic LCCA was performed for illustration purposes. The data used for this project was provided by ALDOT for the complete reconstruction of I-20 in Birmingham, Alabama. Alternative 1 was an asphalt pavement, and Alternative 2 was a concrete pavement. The analysis period used in the example follows the recommendation put forth by NCAT. Table 5.4.1 shows the basic inputs used in this example. Complete inputs are shown in the appendix.

Table 5.4.1 Example Inputs

Input Name	Input Value	Input Variability
Analysis Period	35 years	
Project Length	1.71 miles	
Number of Lanes	3 (each direction)	
Posted Speed Limit	55 mph	
Alternative 1	Asphalt	
Alternative 2	Concrete	
Discount Rate	2.83%	+-2.0% (triangular)
Project Type	Urban	
Terrain	Level	
Base AADT	65900 vpd	
Max AADT	88000 vpd	
Trucks	16%	+-2.0% (triangular)
Truck Growth	1.88%	+-2.0% (triangular)

The rehabilitation activities and their timings were also consistent with NCAT recommendations. Triangular distributions were used to model variability in the discount rate, agency costs, traffic growth, and construction activity timing. This example was conducted using the Asphalt Pavement Alliance's *LCCA* software. The results are shown in Figures 5.1-3. It can be seen that for this example project, the asphalt option is cheaper for all simulations. However, there is considerable variability in both pavement options. The minimum probable NPV of a

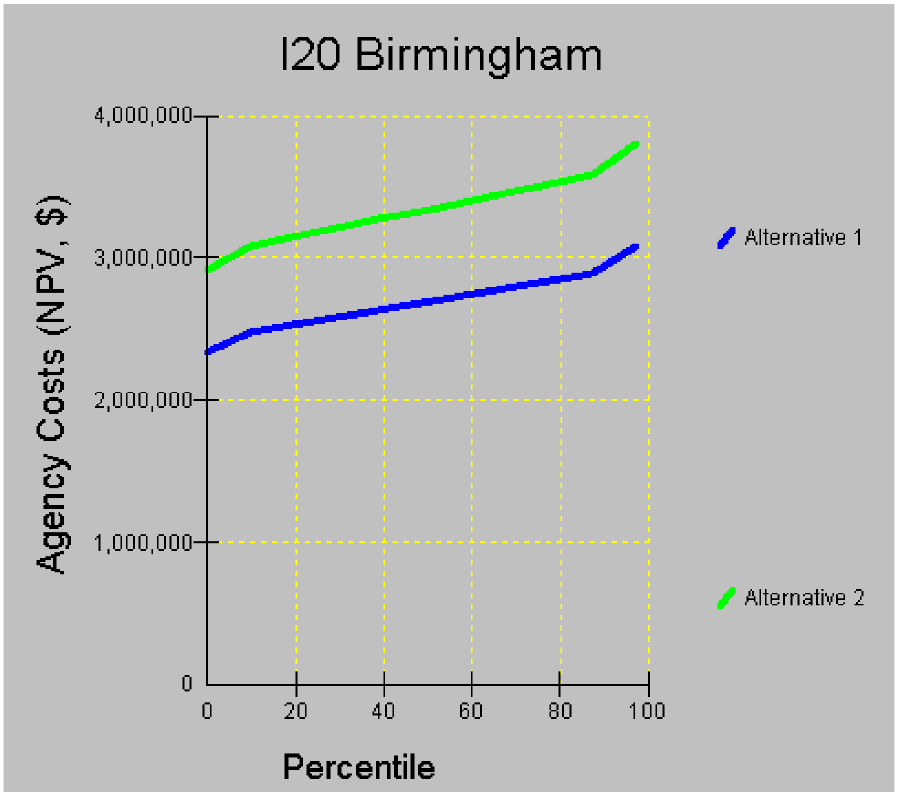

Figure 5.1 Cumulative Distribution of Agency Costs

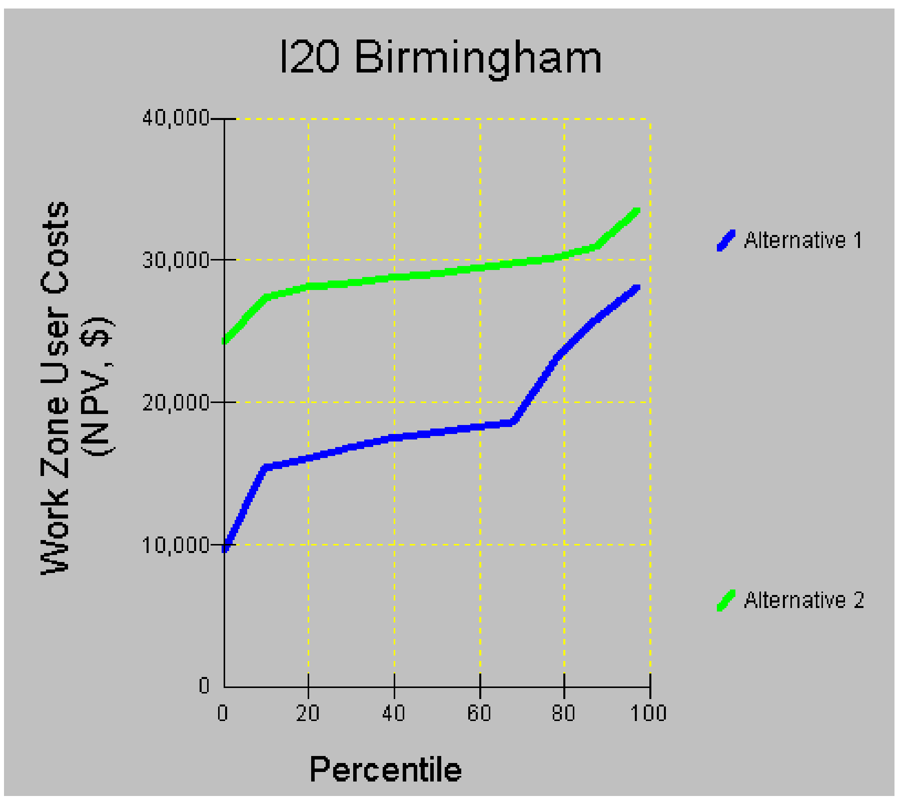

Figure 5.2 Cumulative Distribution of User Costs

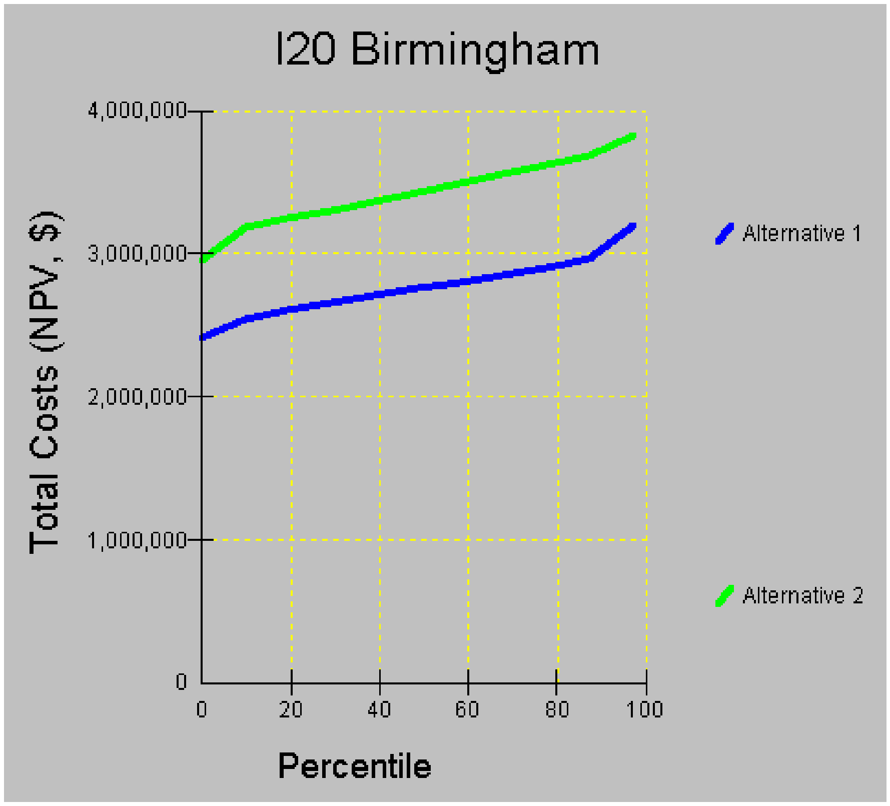

Figure 5.1 Cumulative Distribution of Total Costs

concrete surface in this example is $2,959,473, while the maximum probable NPV of an asphalt surface is $3,199,599. Asphalt would be selected in this scenario.

If the two cumulative distribution curves intersected, there would be a real probability that concrete would be the cheaper option. A decision using engineering judgment would be required to determine which surface should be used. This analysis would include the probability that Alternative 2 was cheaper than Alternative 1, and how extreme the differences at the tails were.

6. Software Platforms

There are several software platforms that can be used to conduct an LCCA. Several states have developed their own Excel spreadsheets and have them available online or by request. If user costs are not considered and a deterministic approach is used, Excel is an excellent tool for LCCA. If user costs are considered and/or a probabilistic approach is employed, Excel can still be used but a few add-ins would be required. Because available software contains FHWA traffic distributions by default, and allows for their manipulation to fit local conditions, it is not necessary to develop workbooks for LCCA.

6.1 RealCost 2.5

In 2005, the FHWA released *RealCost 2.5* that is a formal probabilistic-type spreadsheet program run in Excel. It is free for download on the FHWA website (Federal Highway Administration, 2008). *RealCost* has a simple user interface, shown here in Figure 6.1.

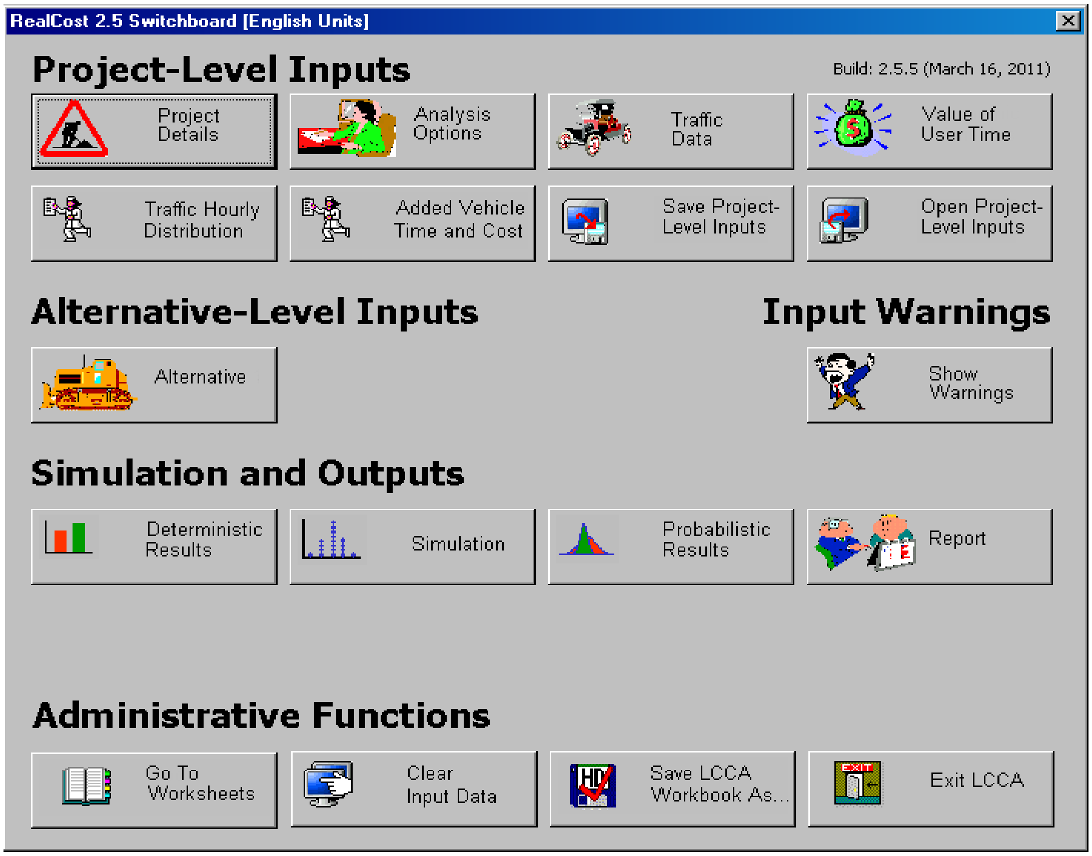

Figure 6.1 *RealCost* Graphical User Interface (Federal Highway Administration, 2008)

RealCost allows for both deterministic and probabilistic approaches within the same LCCA. Distributions that *RealCost* models are normal, truncated normal, lognormal, truncated lognormal, triangular, geometric, beta and uniform. *RealCost* allows for the simultaneous calculation only two alternatives.

RealCost outputs into an Excel file. If the probabilistic approach is taken, tornado graphs and extreme tail analysis are provided.

6.2 LCCA

The Asphalt Pavement Alliance released a software platform simply called *LCCA* that can also compute user costs and utilize a probabilistic approach. *LCCA* has an extensive help file that facilitates navigation through complicated user cost procedures. *LCCA* is also free for download (Asphalt Pavement Alliance, 2008). Figure 6.2 is the user interface found in *LCCA*.

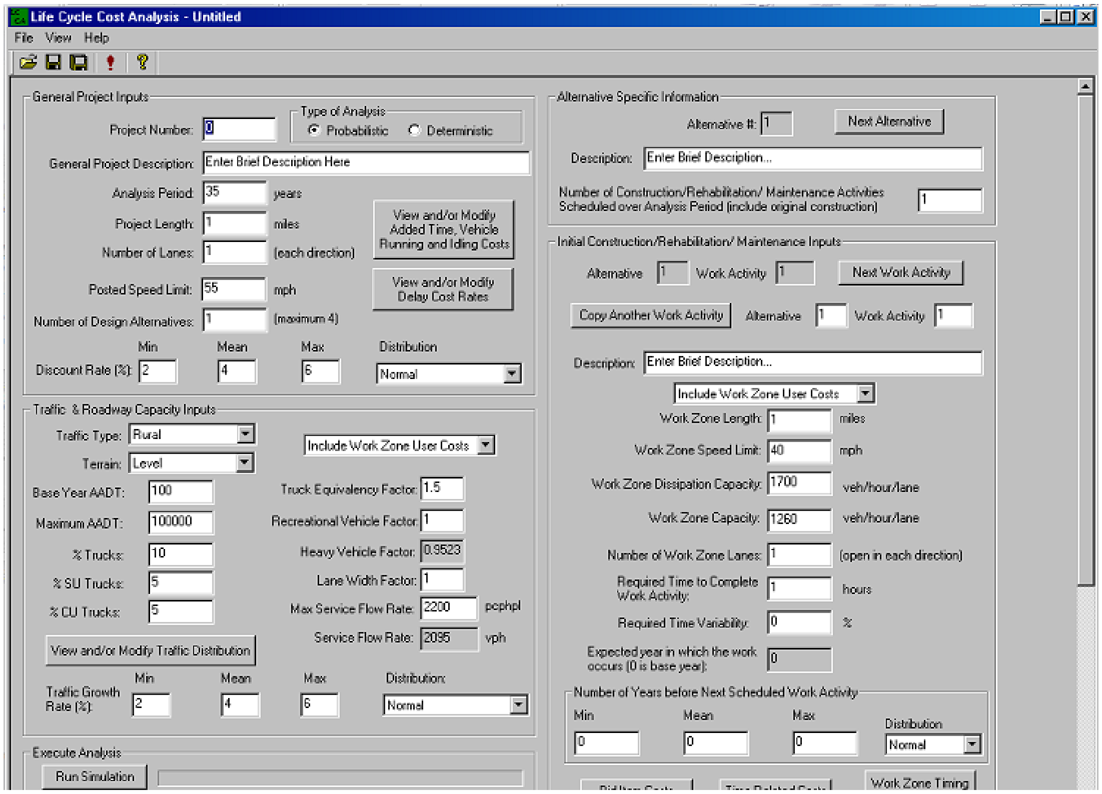

Figure 6.2 *LCCA* Graphical User Interface (Asphalt Pavement Alliance, 2008)

LCCA allows for up to four alternatives for a single LCCA. An advantage of *LCCA* is its ability to account for impossible queue dissipation. It is possible for queues to form that are too long to ever dissipate. This result could not occur in actuality, therefore *LCCA* will warn the user of this situation, and the user can adjust parameters accordingly.

7. Sensitivity Analysis

Sensitivity analyses can be used to examine the independent effect of the variability of one of the inputs on the outcome. The two inputs most commonly subject to sensitivity analyses in LCCA are the discount rate and the analysis period. Other parameters, such as performance periods and material costs, should be determined objectively from historical data. This section examines the effect of manipulating the discount rate and analysis period while leaving all other inputs as set by current ALDOT policy.

The data used for this analysis was from a complete reconstruction of a concrete pavement in Birmingham, Alabama. The cost and material information were provided by ALDOT. All calculations were done with Excel. Table 7.1 summarizes the cost data below. The nature of each construction activity is described in Section 8.

Table 7.1 Sensitivity Analysis Cost Data

	Asphalt (2010$)	Concrete (2010$)
Initial Construction ($):	4,379,688.34	5,514,632.77
1st Rehabilitation ($):	492,700.85	502,105.03
Subsequent Rehabilitations ($):	1,151,990.50	502,105.03

The construction timing was also set to ALDOT defaults. Table 7.2 summarizes these inputs.

Table 7.2 ALDOT Construction Timing Inputs

LCCA Parameter	Asphalt	Concrete
Initial Performance Period (yrs)	12	20
Rehabilitation Performance Period (yrs)	8	8

This example illustrates why an LCCA is necessary. The asphalt option is initially cheaper, yet is expected to have higher future expenditures throughout the remainder of the analysis period. The discount rate and analysis period will determine which option has a lower NPV. ALDOT currently assumes a discount rate of 4.0%. In this scenario, asphalt is the cheaper option regardless of the analysis period chosen, although the two options' NPVs are within 1.0% of each other if the analysis period chosen is between 45 and 50 years. Figure 7.1 shows these results.

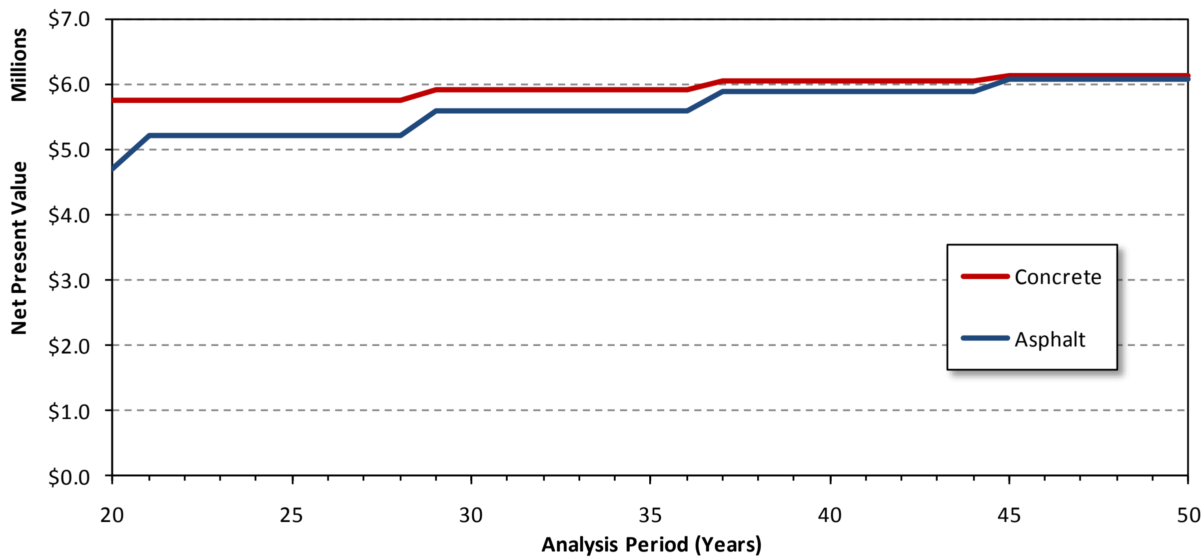

Figure 7.1 NPV of Asphalt and Concrete at a 4.0% Discount Rate

Higher discount rates reduce the effect of expenditures further into the time horizon, and therefore the concrete option will favor a longer analysis period (and thus more asphalt expenditures) in order to achieve a lower NPV. This example also illustrates another important aspect of an LCCA—the NPV of both options continues to rise as the analysis period is increased. Therefore, LCCA cannot be used as a tool to report the "true" life-cycle cost of an alternative, rather it can only be used as a tool in pavement type selection.

Currently, the OMB 30-year discount rate is set at 1.1%. If ALDOT were to adopt this policy, and leave all other policies the same, then concrete would become the cheaper option for any analysis period greater than 28 years. Figure 7.2 shows these results.

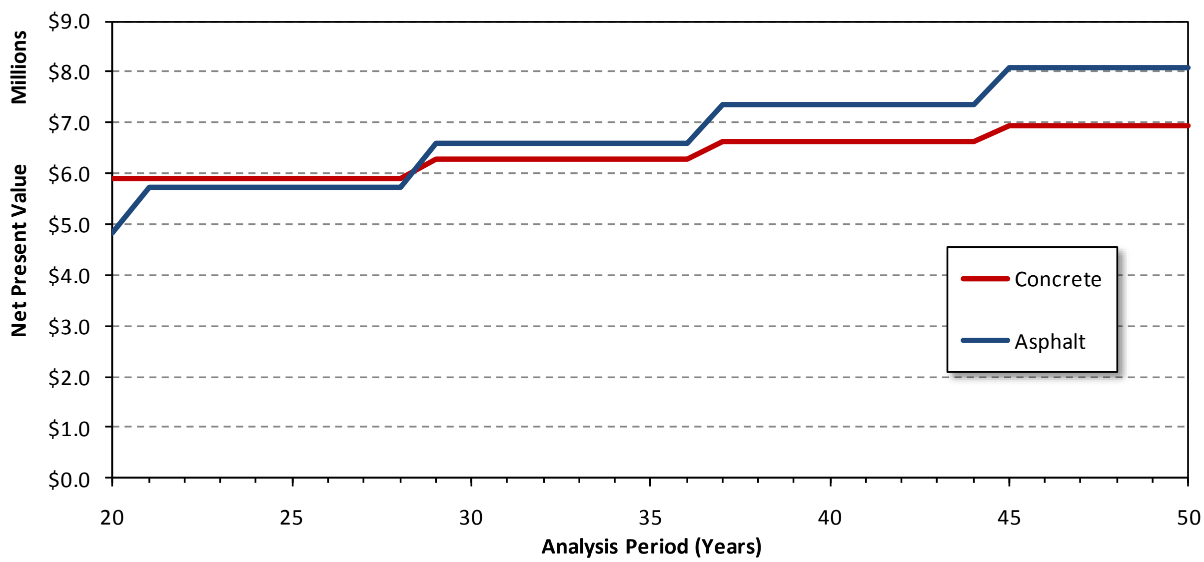

Figure 7.2 NPV of Asphalt and Concrete at a 1.1% Discount Rate

NCAT recommends using a 10-year rolling average of the OMB 30-year rate. This value is currently 2.62%. If ALDOT were to adopt this value, the asphalt pavement would be the cheaper option for this project for any analysis period less than 37 years. Figure 7.3 shows these results.

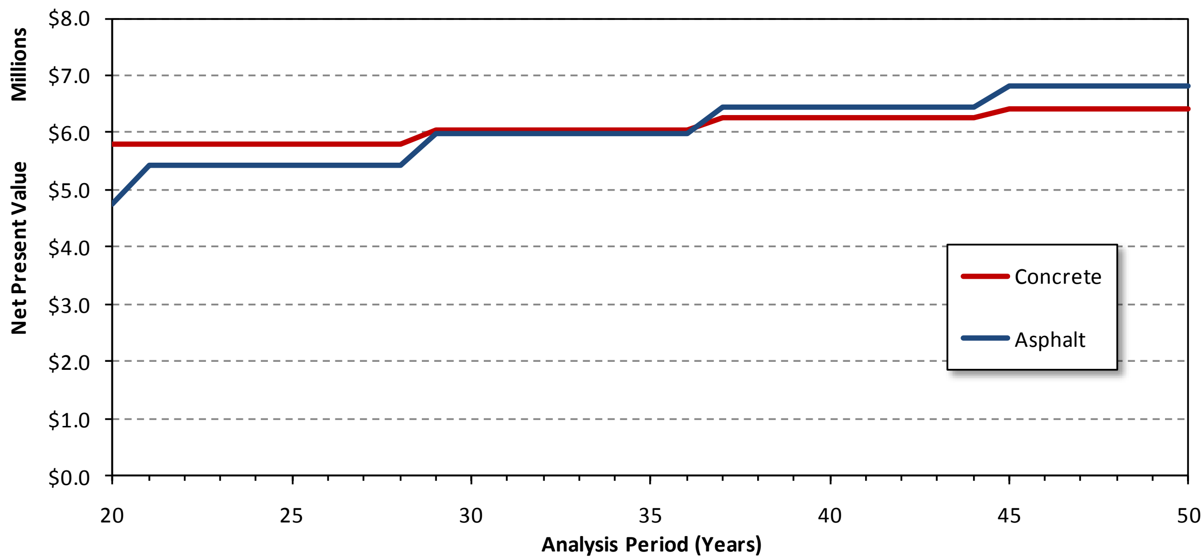

Figure 7.3 NPV of Asphalt and Concrete at a 2.62% Discount Rate

Interestingly, the UA team also recommended the use of this 10-year rolling average. But whereas NCAT recommended using an analysis period of 35 years, the UA team recommended using an analysis period of 50 years. For this example project above, the NCAT recommendations would result in asphalt as the cheaper option, while the UA recommendation would result in concrete as the cheaper option.

These results only represent the sensitivity analysis of a single project to discount rates and analysis period, but should not be interpreted to be typical for other projects. The results of the analysis do underline an important principle of LCCA, however, investment alternatives that are initially cheaper but more expensive throughout the analysis benefit from high discount rates and short analysis periods. It is up to the agency to determine its future needs and economic expectations before deciding these important parameters.

8. Sample Projects

The chapter examines how LCCA results would be affected by the proposed changes by NCAT and UA as compared to ALDOT's current policy. Several recent ALDOT projects from rural and urban settings were examined with each group's proposed inputs.

The inputs used for each group are from the position papers and comments during meetings. Where one group made no recommendation for an input, a reasonable assumption was made. User costs are also considered using NCAT's recommendations.

It should be noted that costs used these LCCA calculations are for one direction of traffic only. This one-direction approach has been used by ALDOT in previous LCCAs. Also, the UA approach results in significantly larger NPVs than the NCAT recommendations or current ALDOT policies due largely to the longer analysis period recommended by UA. Comparisons should be made between the NPVs of alternatives in LCCA, not the magnitude of individual NPVs. However, it is possible to compare methods with different analysis periods and discount rates using by comparing Equivalent Annual Costs (EAC) for each method (Walls III, 1998). The EAC is determined by using Equation 8.1.

$$EAC = \frac{NPV}{\left(\frac{1 - 1/(1+r)^n}{r}\right)} \qquad \text{Equation 8.1}$$

Where EAC= Equivalent Annual Cost,

NPV=Net Present Value,

r = Discount Rate, and

n =Analysis Period.

The following five projects were examined:

- I-20 (Irondale) Reconstruction between I-59 and Kilgore Memorial Drive
- I-65 (Hoover) from I-459 to US-31
- I-59 (Etowah County) Pavement Rehabilitation
- I-20 (Talladega) Pavement Rubblization, Additional Lane Added
- I-59 (Bessemer) Pavement Reconstruction from Alabama Adventure Parkway to North CSXT RR Overpass

8.1 Examination Criteria

Each project was examined using LCCA inputs suggested by ALDOT, NCAT, and UA. These inputs are summarized in Table 8.1 below.

Table 8.1 Sample Project LCCA Inputs

	ALDOT	NCAT	UA
Analysis Period	28 years	35 years	50 years
Discount Rate	4.00%	2.62%	2.62%
Salvage Value	Not Considered	Material Value and Remaining Service Life Considered	Remaining Service Life Considered
Asphalt Initial Performance Period	12 years	19 years (high volume), 21 years (low volume)	12 years
Asphalt Rehabilitation Performance Period	8 years	13.5 years	8 years
Concrete Initial Performance Period	20 years	20 years	35 years
Concrete Rehabilitation Performance Period	8 years	15 years	10 years
User Costs	Not Considered	Considered Separately	Not Considered
Deterministic or Probabilistic	Deterministic	Deterministic	Deterministic
Material Specific Inflation Rate	Not Considered	Not Considered	1.15% for Asphalt, -0.049% for Concrete
Asphalt Adjustment Multiplier	Not Considered	Not Considered	1.02%/yr for Asphalt

The asphalt adjustment multiplier (AAM) assumes construction occurs 6 months after the LCCA is performed. The AAM only escalates the prices of asphalt layers (essentially increasing the costs by 0.56%) to account for an expected increase in asphalt binder between the letting date and the time of construction. The material specific inflation rate (MSIR) supposes that the prices of asphalt mixes rise faster than general inflation, while the prices of concrete mix increases slower than general inflation (Mack, 2012). These are applied to future rehabilitations involving asphalt and concrete materials. The validity of the AAM and the MSIR are disputed by the asphalt paving industry and not used in practice by any state highway agency. They are included in the analysis of these projects as recommended by UA.

8.2 I-20 (Irondale) Reconstruction between I-59 and Kilgore Memorial Drive

An LCCA was performed by ALDOT for the complete reconstruction of I-20 in Irondale between I-59 and Kilgore Memorial Drive (ALDOT Project No. IM-I020(325)). The NPVs of the asphalt surface and the concrete surface were close, with asphalt being valued at $5,213,181 versus $5,743,786 for concrete (a difference of 9.2%). The project was directed by ALDOT senior management to be built as concrete.

During construction, this section was shut down for 90 days, and traffic was detoured along I-459 and I-59. Construction began on September 11th, 2012 and was not complete at the time this thesis was finalized. Figure 8.1 shows the general area of construction.

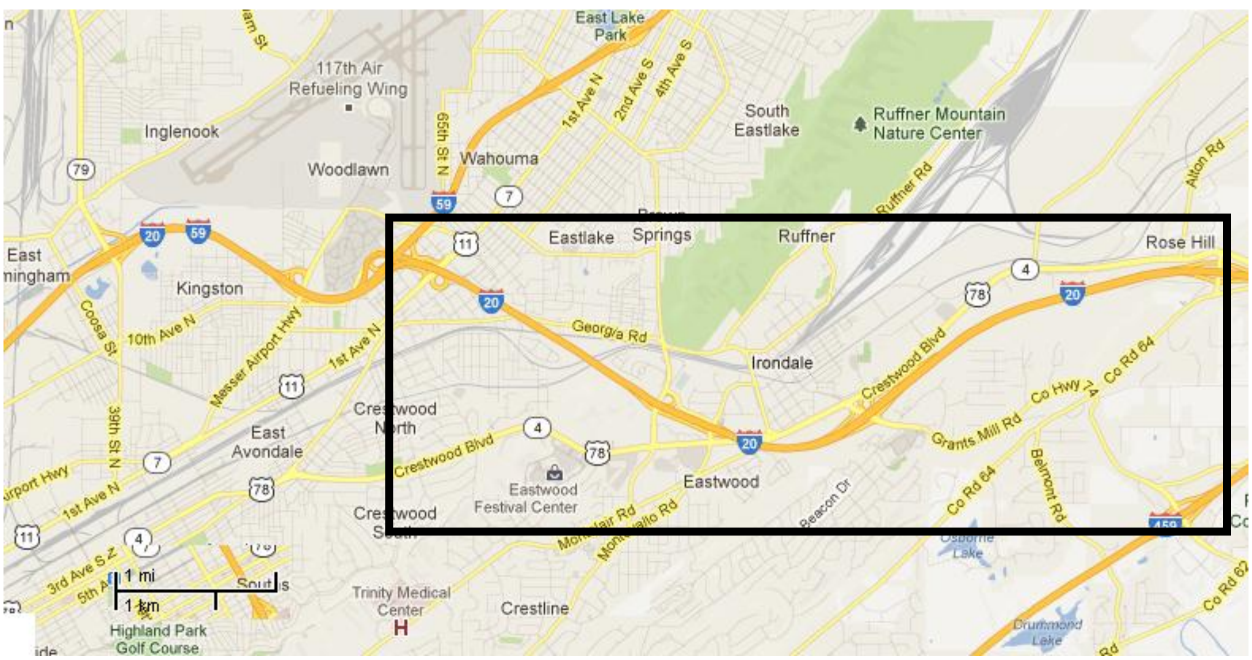

Figure 8.1 I-20 (Irondale) Reconstruction between I-59 and Kilgore Memorial Drive

This project was first examined using current ALDOT LCCA inputs. These results are shown in Figure 8.2. Detailed tabulated LCCA results for this project are provided in Appendix A.

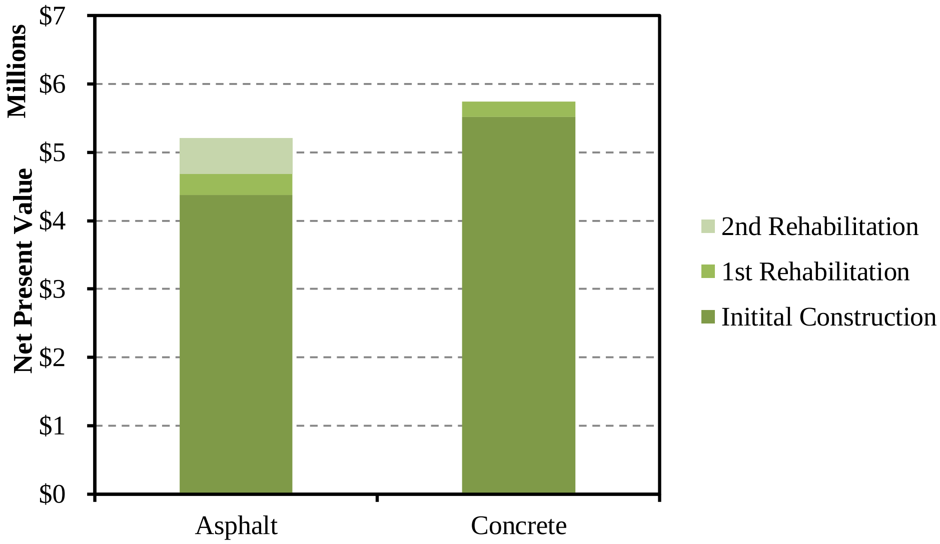

Figure 8.2 I-20 from I-59 to CR-64 in Birmingham, AL ALDOT Policy

Using ALDOT's current polices, the asphalt option NPV was about 9% lower than the concrete option. For both asphalt and concrete, the cost of initial construction dwarfs rehabilitation costs—this trend is consistent throughout all of the sample projects.

This project was also examined using the inputs recommended by NCAT. Because this project was located in an urban setting, it is assumed that the concrete pavement will be removed at the end of its lifespan. ALDOT's LCCA committee concluded that concrete pavements would be removed in urban environments to avoid raising bridges, signs, drainage structures, and safety features. Results based on NCAT's recommendations are shown in Figure 8.3. Using the NCAT recommended LCCA inputs, the asphalt option NPV was about 45% less than the concrete option.

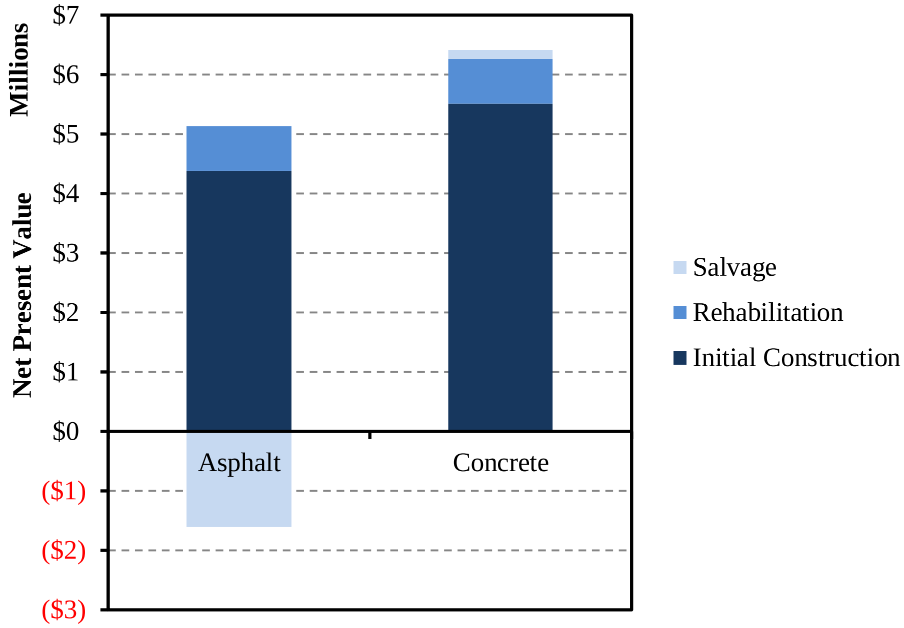

Figure 8.3 I-20 from I-59 to CR-64 in Birmingham, AL NCAT Recommendations

Note that compared to the current ALDOT policy, the LCCA using NCAT's recommendations results in reduction of the NPV for the asphalt option by about $1.69 million. This difference is due primarily to the salvage values for the asphalt pavement ($1.61 million) and to a much less degree, the longer service lives ($79,407). For the concrete option, the NCAT recommendations increased the NPV by $678,111due to including a 3% slab removal and replacement and diamond grinding at year 20 ($469,385) and removal of the concrete pavement at year 35 ($150,706).

Using the recommendations put forth by the UA team, concrete comes out as the cheaper option. These results are shown in Figure 8.4.

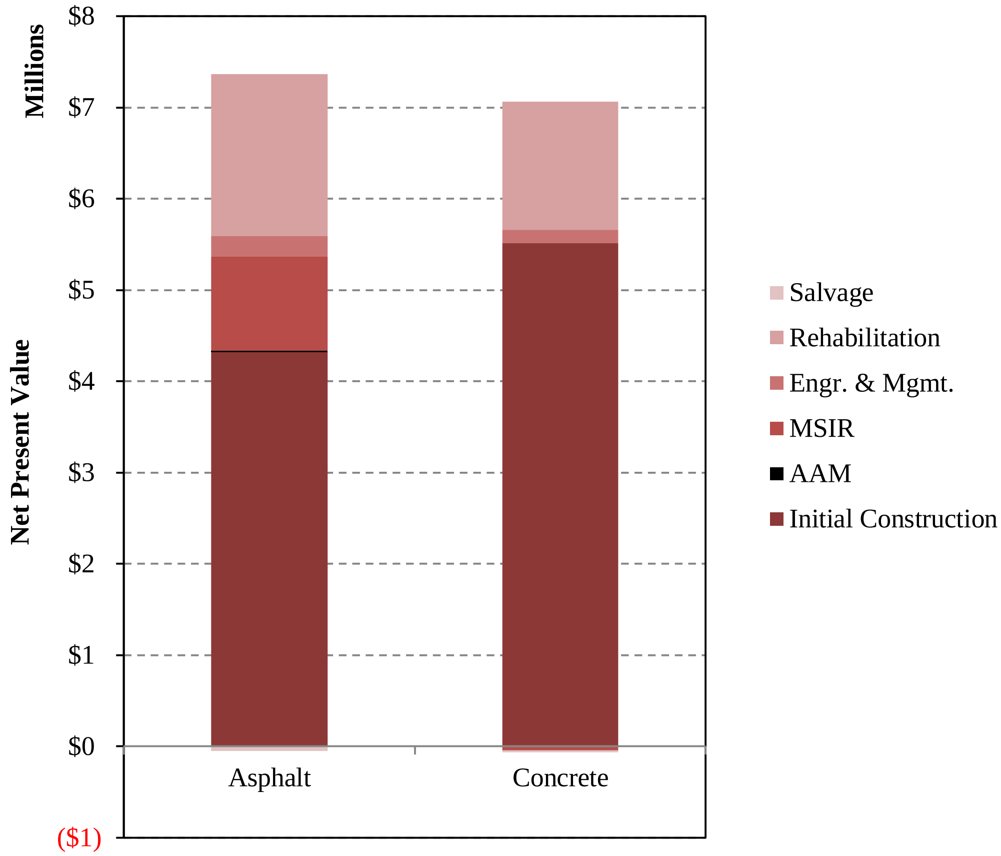

Figure 8.4 I-20 from I-59 to CR-64 in Birmingham, AL UA Recommendations

The UA team recommendations increase the NPV of the asphalt option by about $2.1 million over that of ALDOT’s current policies due to three changes. First, there are three additional rehabilitation activities needed to extend the analysis period to 50 years which adds a little more than $1 million. Second, the addition of the 10% to the asphalt rehabilitation activities for engineering and construction management increases the NPV by $223,111. Third, including the UA recommended materials-specific inflation rate increases the asphalt NPV by over $500,000. The inclusion of the AAM increases the NPV of the asphalt option by $16,000, which is essentially negligible.

User costs were also examined using the construction schedule recommended by NCAT (West, 2012) and the procedure detailed by the FWHA (Walls III, 1998). Traffic data was gathered through publically available traffic counts from the Alabama Department of Transportation (Alabama Department of Transportation, 2013). The duration of each activity was extrapolated on a per mile basis from ALDOT experience (Bell, 2012) Using these guidelines required the following inputs:

- Base year AADT: 56,830 vpd
- % Trucks: 16%
- % Single Unit Trucks: 11.2%
- % Combination Trucks: 4.8%
- Traffic Growth Rate: 0.75%
- October 2012 CPI: 232.85
- Maximum AADT: 100,000 vpd

Running this simulation through *LCCA* yielded the following results:

Table 8.2 User Costs for Asphalt Option, I-20 Irondale

Year	Activity	Hours	User Costs	NPV User Costs
19	Remove and Replace 2-Layers	206	$137,538.15	$ 80,892.00
32.5	Remove and Replace 3-Layers	309	$321,828.59	$ 129,813.00
			Total	**$ 210,705.00**

Table 8.3 User Costs for Concrete Option, I-20 Irondale

Year	Roadway Activity	Hours	User Costs	NPV User Cost
19	Rehabilitation	309	$404,643.60	$ 237,988.00
35	Pavement Removal	540	$4,588,441.10	$ 1,725,947.00
			Total	**$ 1,963,395.00**

The user costs from the concrete option dwarf the asphalt option's by $1.7MM. This is due to the dramatic increase in queue length at year 35 when it is assumed that the concrete pavement will have to be removed and replaced.

The EUAC of each option is shown in Table 8.2. For this project, the EUAC of the asphalt option using NCAT recommended inputs is the lowest relative cost. This is primarily due to the lower discount rate used (versus that used by ALDOT) and the favorable material salvage value for the asphalt option as recommended by NCAT.

Table 8.5 I-20 from I-59 to CR-64 in Birmingham, AL EUAC

Option	EUAC
ALDOT Asphalt	$312,858.52
ALDOT Concrete	$344,701.74
NCAT Asphalt	$159,982.66
NCAT Concrete	$291,499.65
UA Asphalt	$275,334.46
UA Concrete	$224,363.26

8.3 I-65 (Hoover) Reconstruction from I-459 to US 431

This sample project consisted of reconstruction of an existing concrete pavement in Hoover, AL (ALDOT Project No. IM-I065(393)). The interstate highway project contained 3-lane and 4-lane sections as well as six ramps. The location of the project is shown in Figure 8.3.1.

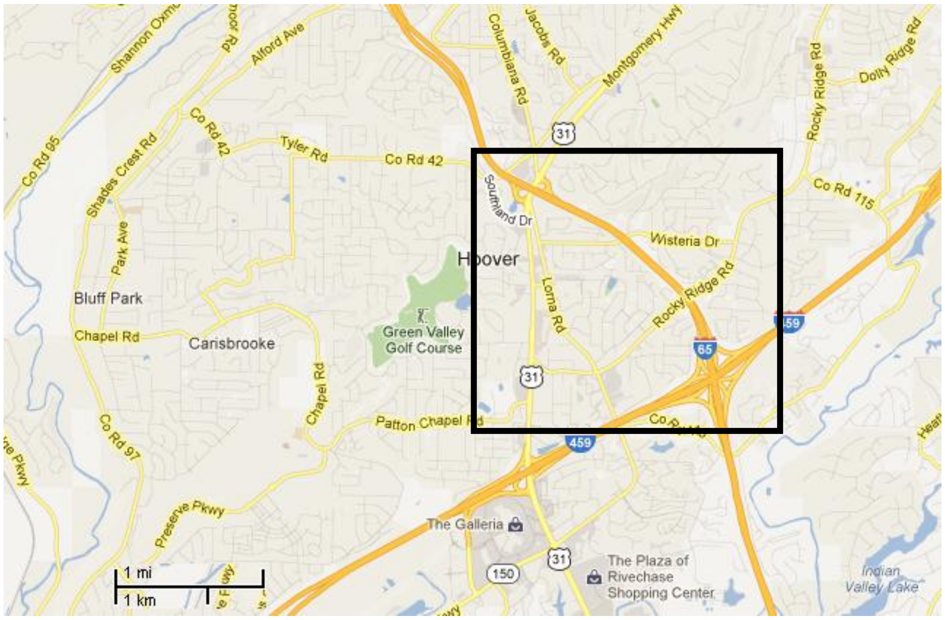

Figure 8.3.1 I-65 in Hoover, AL

ALDOT computed LCCAs for 10 project segments (4-lane north and south, 3-lane north and south, and six ramps). The following were costs assumed to incur to both pavement types and were excluded from the LCCA:

- Rubblization of existing concrete pavement and preliminary earthwork to prepare for new construction
- Construction of temporary lanes for traffic control during construction
- Unclassified excavation and topsoil required for outside shoulders
- Construction of concrete median safety barrier

Based on 2010 traffic data and a soil resilient modulus of 6,600 psi, and using the 1993 AASHTO Pavement Design Guide (ALDOT's current method), the design thicknesses were 16.25 in. for an asphalt pavement, and 16 in. for a concrete pavement. The results of the ALDOT LCCA calculations were very close: the NPV of the asphalt option was $12,220,092.25 and the NPV for a concrete surface was $12,464,473.42 (a difference of 2%). These results are shown in

Figure 8.3.1. Detailed tabulated LCCA results for the I-65 Hoover project are provided in Appendix B. This project was also directed to be rebuilt using a concrete paving option.

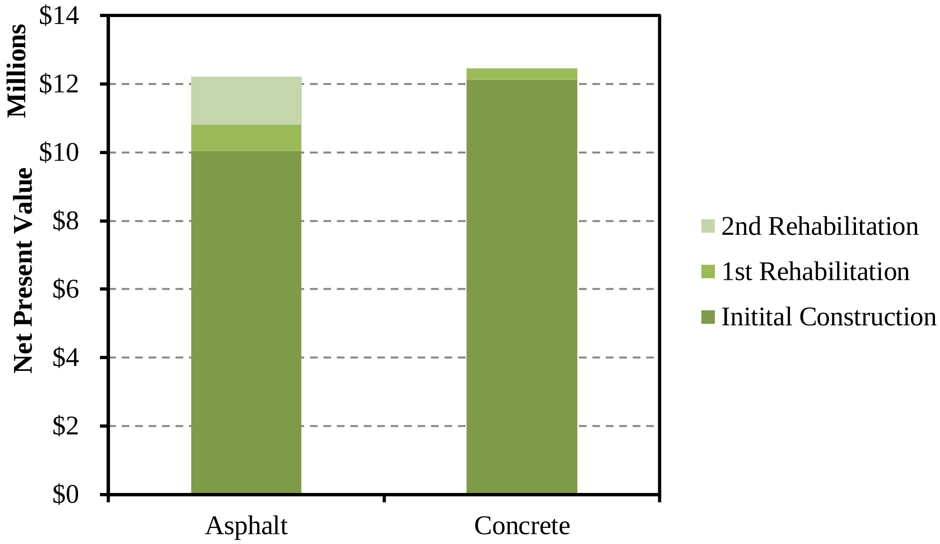

Figure 8.3.2 I-65 (Hoover) Reconstruction from I-459 to US 431ALDOT Results

For the analysis based on NCAT recommendations, it was assumed that the concrete pavement be removed at the end of its lifespan to avoid extensive adjustments to bridges, overpasses, drainage structures, barrier walls, etc. These are reflected in NCAT's results illustrated in Figure 8.3.3. The LCCA based on the NCAT recommended inputs for this project resulted in an NPV for the asphalt option that was 38% less than the concrete option.

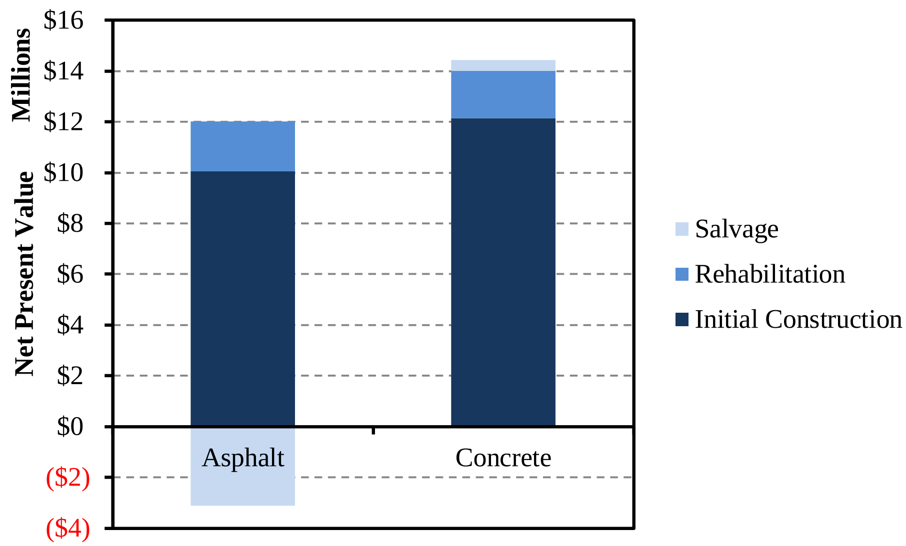

Figure 8.3.3 I-65 (Hoover) Reconstruction from I-459 to US 431 NCAT Results

Compared to the NPV from ALDOT's current policies, NCAT's recommendations reduced the NPV for the asphalt option for this project by $3,318,001. As with the first example, the difference is largely due to the salvage value for the asphalt pavement ($3,109,985) at the end of the analysis period. The longer service lives for the asphalt option reduced the NPV only by $208,015. For the concrete option, the NCAT recommendations increased the NPV by $1,978,874. That increase resulted from including 3% slab removal & replacement and diamond grinding at year 20 ($1,455,156) and removal of the concrete pavement at year 35 ($439,056).

The UA team's recommendations show concrete to be the cheaper option. Their results are shown in Figure 8.4.4. The LCCA based on the UA recommended inputs for this project resulted in an NPV for the concrete option that was 23% less than the asphalt option.

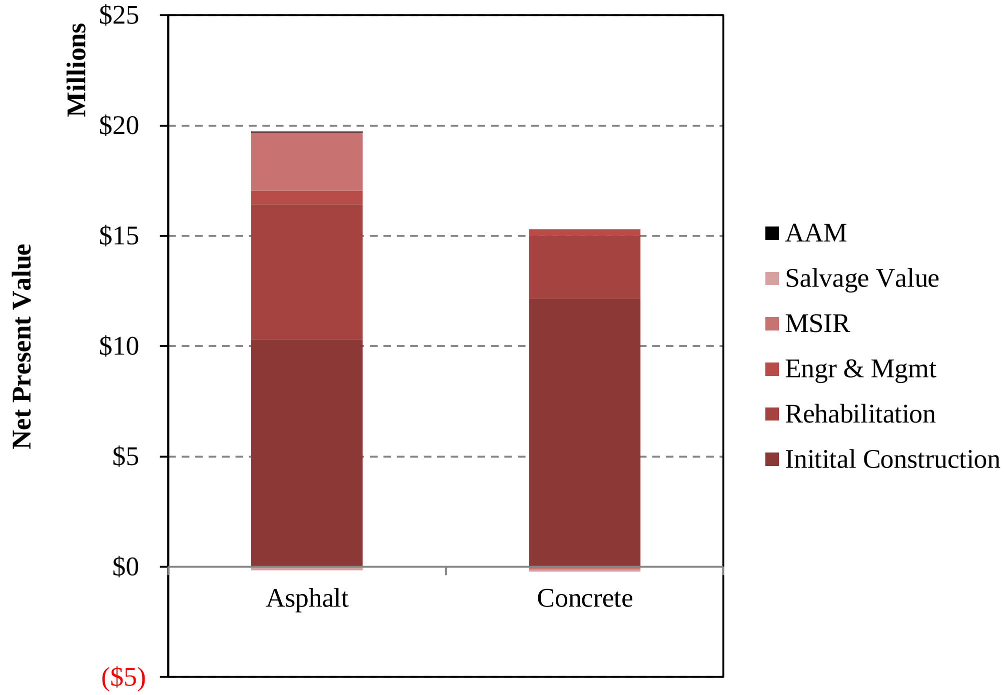

Figure 8.3.4 I-65 (Hoover) Reconstruction from I-459 to US 431 UA Results

The UA Team recommendations increased the NPV of the asphalt option by over $7 million compared to an increase of about $2.65 million for the concrete option, most of which ($2 million) was from the added 3% slab removal & replacement and diamond grinding rehabilitations. For both options, three additional rehabilitation activities were needed to extend the analysis period to 50 years. The addition of the engineering and construction management costs increased the asphalt option NPV by $610,789 and the concrete option by $289,565. The asphalt index adjustment factor and materials-specific inflation rate increased the asphalt NPV by over $1.3 million.

User costs were again calculated using the NCAT method with FWHA guidelines. The asphalt option again generated lower user costs due to excessive queue lengths formed by lengthy construction activities are required to remove concrete pavements in this urban location several years into the future. The inputs and results are shown below.

- Base year AADT: 46,667 vpd
- % Trucks: 11%
- Traffic Growth Rate: 2.59%
- October 2012 CPI: 232.85
- Length: 1.72
- Lanes: 3 for 0.66 miles, 4 for 1.06 miles
- Maximum AADT: 88,000 vpd

Table 8.5 I-65 Reconstruction Asphalt User Cost Summary

Year	Roadway Activity	Hours	User Costs	NPV
19	Remove and Replace 2-Layers	150.774	$110,868.00	$65,206.16
32.5	Remove and Replace 3-Layers	226.162	$162,814.00	$65,672.77
			Total	**$130,878.92**

Table 8.6 I-65 Reconstruction Concrete User Cost Summary

Year	Roadway Activity	Hours	User Costs	NPV
19	Rehabilitation	226.162	$68,823.00	$40,477.71
35	Pavement Removal	395.234	$1,875,410.00	$705,437.47
			Total	**$745,915.18**

A comparison of EUACs by analysis method is shown in Table 8.3.1. The NCAT asphalt option comes out the cheapest again. NCAT results tend to show lower EUAC because they do not consider administrative costs and use a lower discount rate than current ALDOT policy. There is a considerable difference between the recommendations set forth by UA and NCAT. NCAT's EUAC have asphalt being the cheaper option by $251,526 each year, while the UA guidelines show concrete being the cheaper option by $238,211.

Table 8.7.1 I-65 (Hoover) Reconstruction from I-459 to US 431 EUAC Results

	EUAC
ALDOT Asphalt	$637,786.13
ALDOT Concrete	$650,540.78
NCAT Asphalt	$404,079.32
NCAT Concrete	$655,605.30
UA Asphalt	$734,461.25
UA Concrete	$496,250.71

8.4 I-59 (Etowah County) Reconstruction of Concrete Pavement

The third example project was a concrete section of I-59 in Etowah County that required complete reconstruction in the spring of 2008 (ALDOT Project No. IM-I059(342)). The project length was 10.7 miles and has two lanes in each direction. The location of the project is shown in Figure 8.4.1.

Figure 8.4.1 Area of I-59 Reconstruction

Three options were considered by ALDOT during the LCCA. ALDOT’s calculated NPVs for each option are in shown in parentheses:

- Unbonded PCC overlay with slab repair ($11,972,896)

- Rubblize existing PCC and replace with asphalt pavement ($17,826,240)
- Asphalt pavement ($9,364,209)

Although the asphalt alternative had the lowest NPV by $2.6 million (21.8%), the project was directed to be built as an unbonded PCC overlay. These ALDOT LCCA results are shown in Figure 8.4.2. Detailed tabulated LCCA results for the I-59 Etowah Co. project are provided in Appendix C.

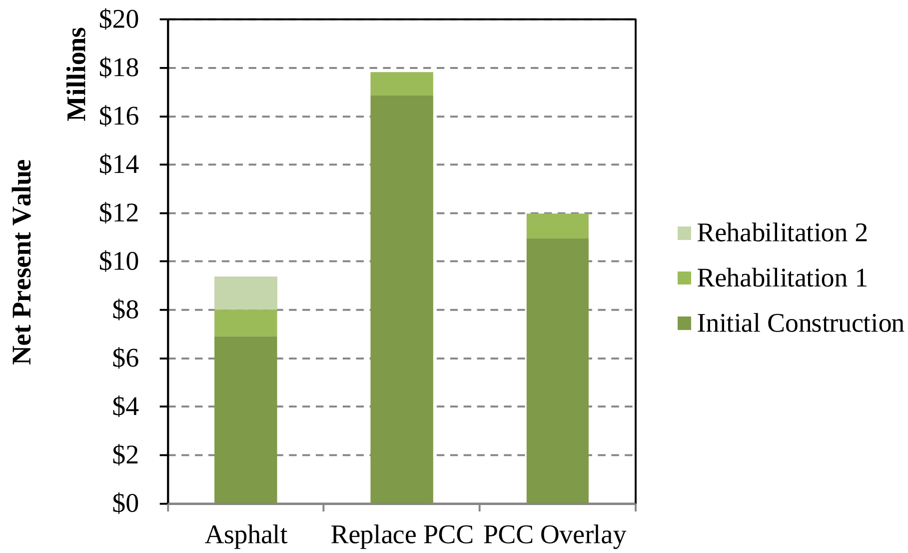

Figure 8.4.2 I-59 (Etowah County) Reconstruction of Concrete Pavement ALDOT Results

The results of the LCCA using NCAT recommendations are summarized in Figure 8.4.3. The results show that the asphalt option has a 40% lower NPV than the concrete option. As with the previous examples, NCAT's recommended changes to the LCCA results in a decrease in the NPV of the asphalt option due mostly to the the salvage value credit applied for the remaining asphalt structure and the remaining service life of the last resurfacing. For this project, the salvage value decreased the asphalt NPV by about 19%.

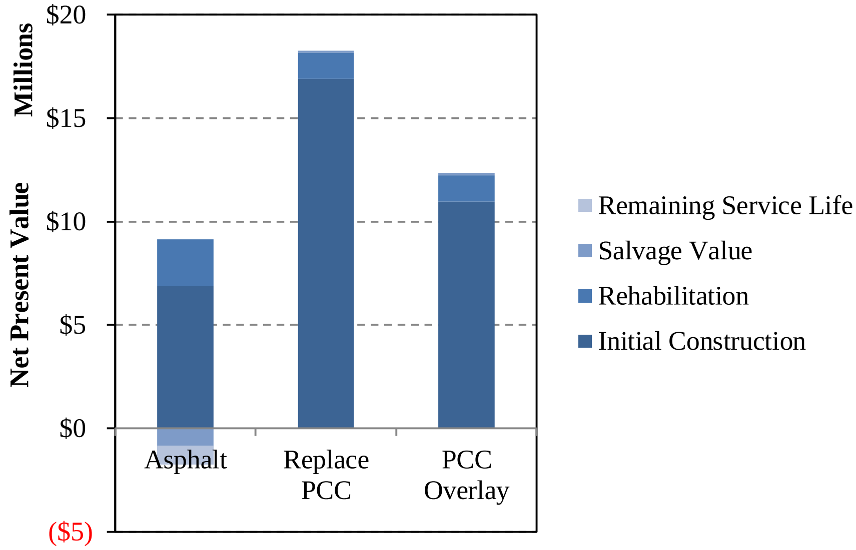

Figure 8.4.3 I-59 (Etowah County) Reconstruction of Concrete Pavement NCAT Results

Comparing the concrete option NPVs from the NCAT recommendations to those based on current ALDOT policies reveals that the total costs are slightly greater for the NCAT approach due to additional rehabilitation activities for the longer analysis period, the cost for rubblization of the concrete pavement at the end of the analysis period, and a difference in discount rates.

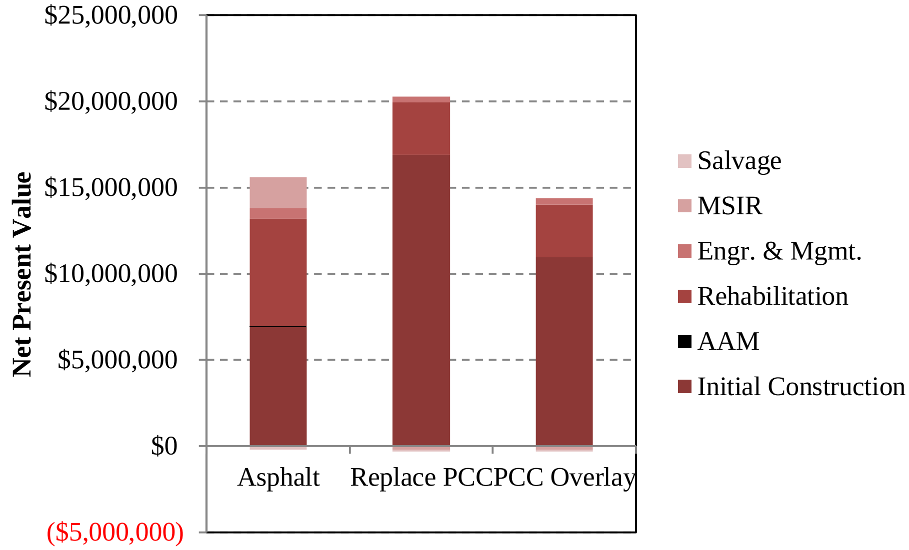

Figure 8.4.4 I-59 (Etowah County) Reconstruction of Concrete Pavement UA Results

For the UA recommended changes to LCCA, the unbonded PCC overlay has a 31% NPV less than the asphalt option.

Examining user costs using the recommendations used by NCAT and the FHWA yielded the following inputs and results.

- Base year AADT: 16,874 vpd
- % Trucks: 35%
- Traffic Growth Rate: 4.37%
- October 2012 CPI: 232.85
- Length: 10.7 miles
- Lanes: 2
- Maximum AADT:88,000

Table 8.8 I-59 Reconstruction Asphalt User Cost Summary

Year	Roadway Activity	Hours	User Costs	NPV
19	Remove and Replace 2-Layers	940	$164,359.00	$96,666.47
32.5	Remove and Replace 3-Layers	1410	$897,518.00	$362,023.47
			Total	**$458,689.94**

Table 8.9 I-59 Reconstruction Concrete User Cost Summary

Year	Roadway Activity	Hours	User Costs	NPV
19	Rehabilitation	1410	$251,999.00	$148,211.26
35	Rubblization	2463	$7,365,548.00	$2,770,558.71
			Total	**$2,918,769.98**

The asphalt option has a much lower user cost estimate because of the excessive queues formed after 35 years of traffic growth and long construction activities that generate significantly more costs to users when the concrete option is selected.

A comparison of EUAC shows similar results as the other sample projects. The NCAT asphalt option in the cheapest at $335,600/year, while the ALDOT concrete option is the most expensive at $718,529/year. The results from the UA method stand out again by showing concrete as the cheapest option.

Table 8.10 I-59 (Etowah County) Reconstruction of Concrete Pavement EUAC

	EUAC
ALDOT Asphalt	$561,974.07
ALDOT Concrete	$718,529.56
NCAT Asphalt	$335,600.44
NCAT Concrete	$560,229.71
UA Asphalt	$579,387.71
UA Concrete	$446,725.33

8.5 I-20 (Talladega) Rubblization & Reconstruction with a Lane Added

The fourth example project was the reconstruction of a jointed plain concrete pavement and addition of lanes on I-20 in Talladega County (ALDOT Project No. IM-NHF-I020(332)). The project location is shown in Figure 8.5.1.

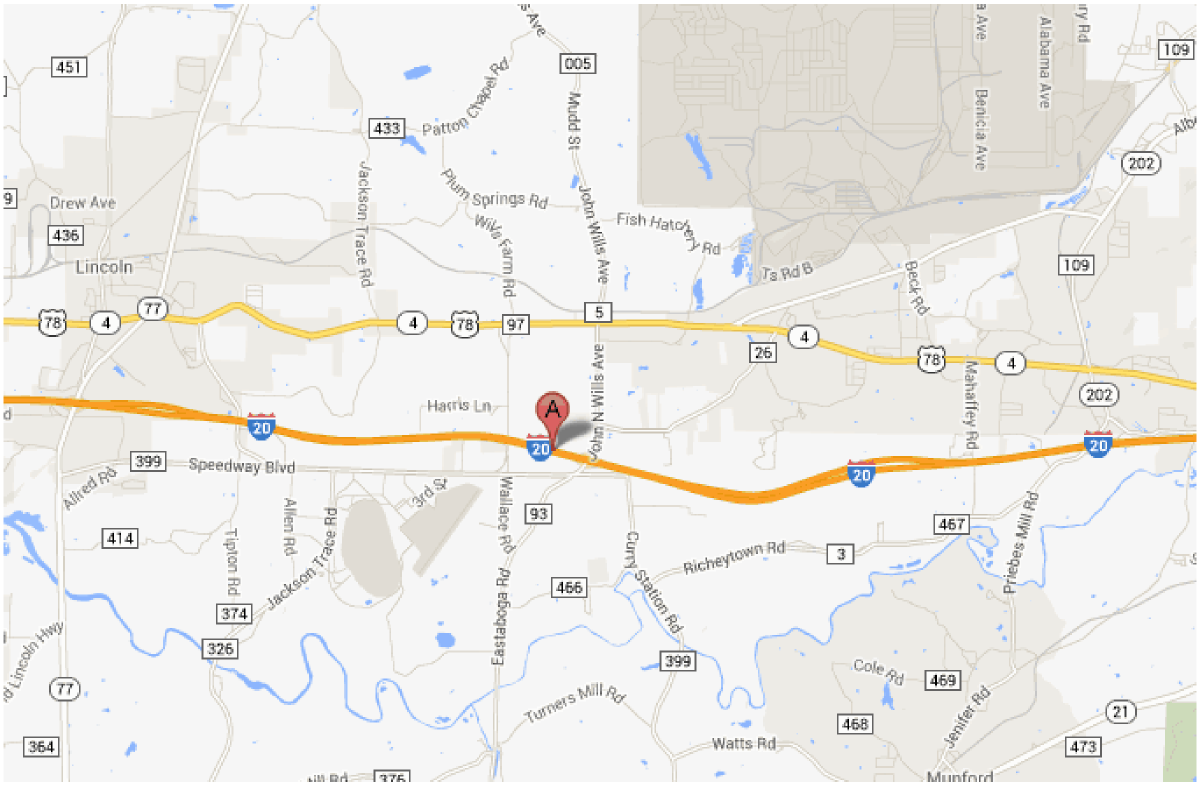

Figure 8.5.1 Area of I-20 Reconstruction

An LCCA was conducted by ALDOT in April of 2001. For the concrete option, an unbonded overlay was evaluated. The NPV of the asphalt option was found to be 24% lower. The ALDOT LCCA results are shown in Figure 8.5.2. Detailed tabulated LCCA results for the I-20 Talladega Co. project are provided in Appendix D. The project was eventually built as a new asphalt pavement over the rubblized concrete and was the runner up to NAPA's prestigious Sheldon G. Hayes award for the best project in the country in 2008.

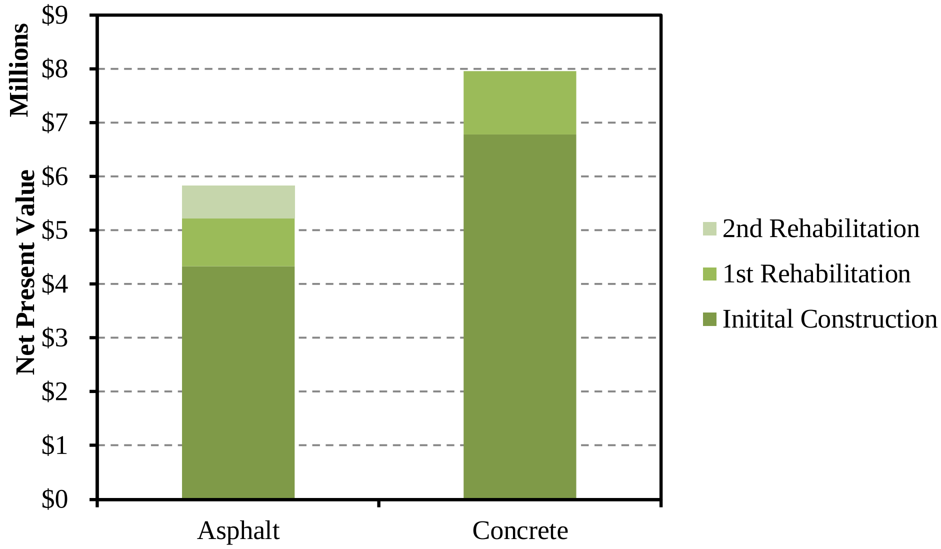

Figure 8.5.2 I -20 (Talladega) Rubblization & Reconstruction ALDOT Results

Comparison of the LCCA results using NCAT recommendations are shown in Figure 8.5.3. For this project, the NCAT recommendations yielded a 44% lower NPV for the asphalt option compared to the concrete option. The salvage value used in the NCAT approach reduced the NPV of the asphalt option by $1,162,387, a decrease of about 20%. The rubblization costs added to the concrete option at the end of the analysis period had a very minor impact (1.6%) on its total NPV for this project.

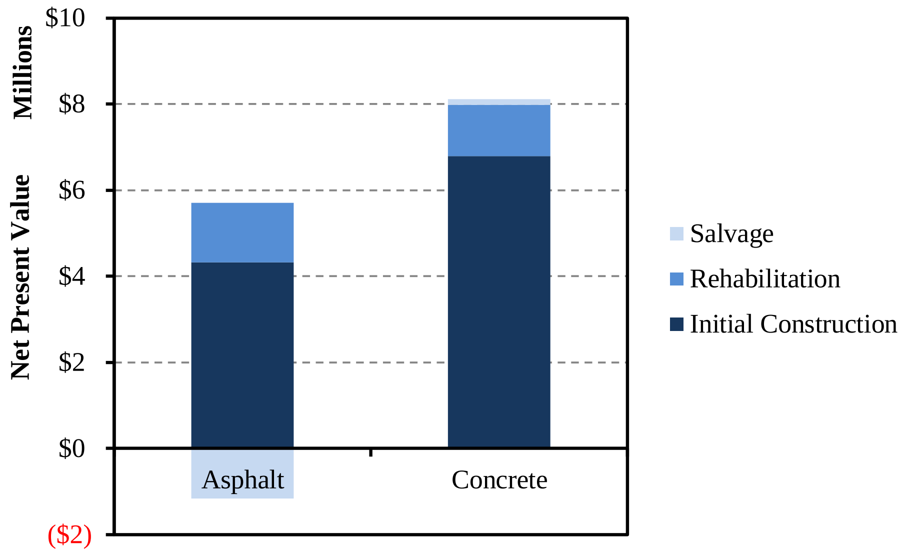

Figure 8.5.2 I -20 (Talladega) Rubblization & Reconstruction NCAT Results

The UA recommended LCCA inputs resulted in the concrete option winning by 5%. The materials specific inflation factor made about a million-dollar difference in the pavement options. For this project, the impact of the salvage values was even less than the previous project. This is due to the fact that the remaining service lives are applied only to the last rehabilitation activities and also due to having the amounts discounted over 50 years. As with the other projects, the impact of the UA proposed asphalt adjustment multiplier is negligible.

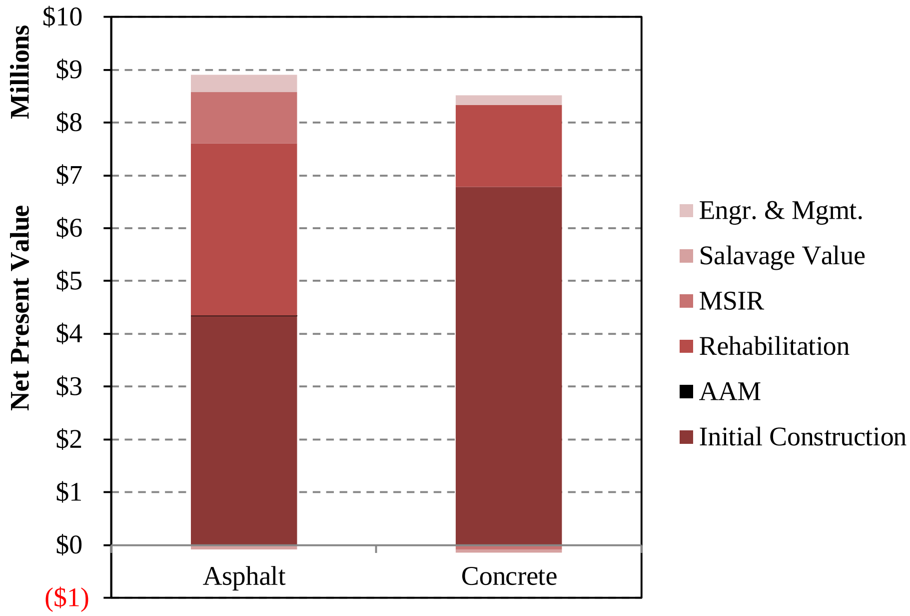

Figure 8.5.2 I -20 (Talladega) Rubblization & Reconstruction UA Results

User costs were unable to be determined for this project as reliable traffic data was not captured and retained during the construction of this project.

A comparison of EUAC's for each option shows the effects of a lower discount rate and longer performance period used by both NCAT and UA. The costs are significantly cheaper compared to those found by ALDOT. The method prescribed by UA again differs from that of ALDOT and NCAT by showing concrete to be a cheaper pavement option than asphalt.

Table 8.11 I -20 (Talladega) Rubblization & Reconstruction EUAC Comparison

	EUAC
ALDOT Asphalt	$349,754.73
ALDOT Concrete	$478,164.39
NCAT Asphalt	$206,220.76
NCAT Concrete	$368,037.72
UA Asphalt	$331,585.73
UA Concrete	$275,114.47

8.6 I-20/I-59 (Bessemer) Pavement Reconstruction from Alabama Adventure Parkway to North CSXT RR Overpass

The fifth example project was the reconstruction of a concrete pavement on I-59 in Bessemer (ALDOT Project No. IM-I059(351)). The location of the project is shown in Figure 8.6.1.

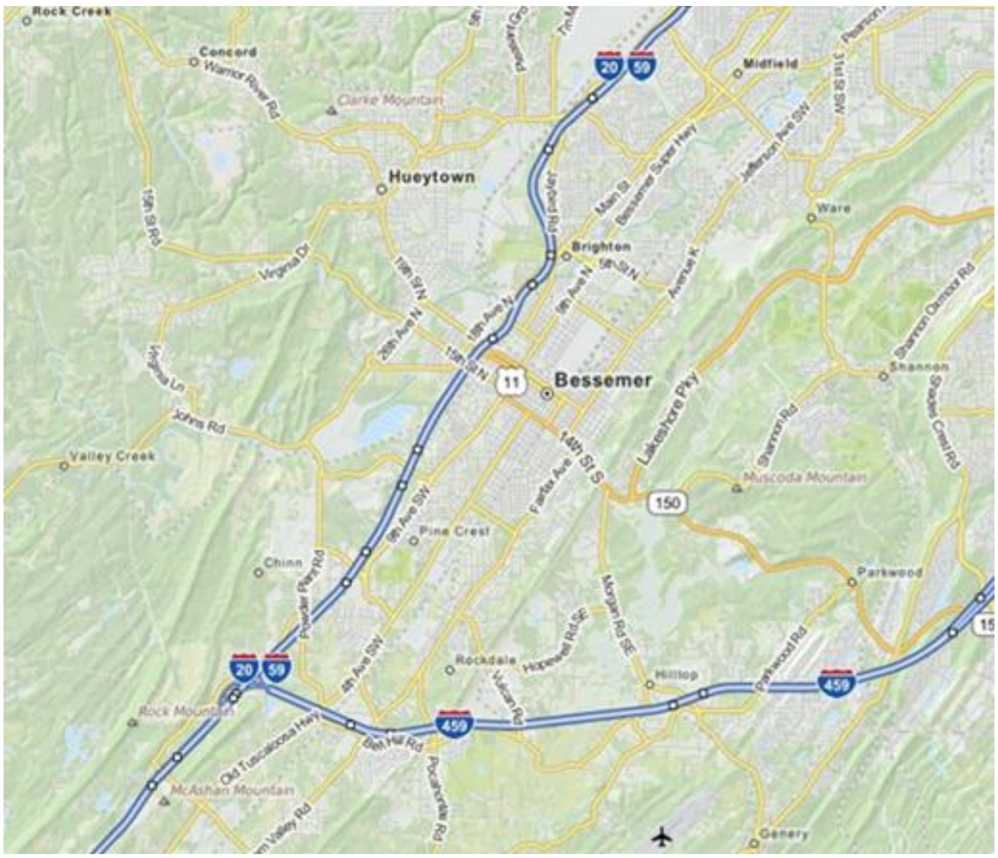

Figure 8.6.1 Area of I-59/I-20 Pavement Reconstruction

ALDOT performed an LCCA on this project in August of 2010. The asphalt option was valued at $5,060,817, and the concrete pavement option was valued at $7,575,696 (a difference of 49.6%). The project was let as an asphalt pavement. The existing pavement was a continuously reinforced concrete. The existing pavement was rubblized as part of the reconstruction. This pavement design therefore required bridges on the project to be raised 16 inches. These costs were not included in the LCCA as they applied to both pavement types. ALDOT's LCCA results are shown in Figure 8.6.2. For this project, the asphalt option had a 25% lower NPV than the concrete option. Tabulated LCCA results for the I-20/59 project in Bessemer are provided in Appendix E.

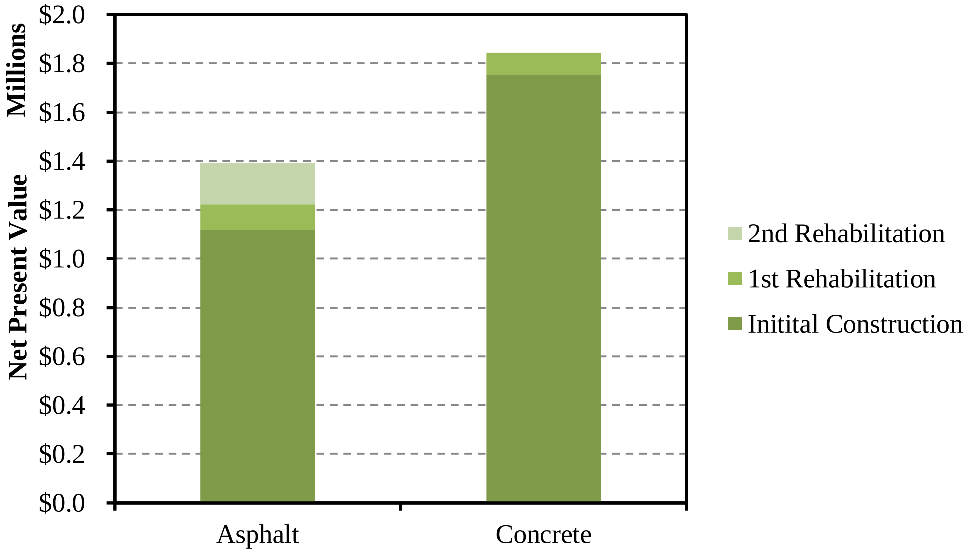

Figure 8.6.2 I-59/I-20 Pavement Reconstruction ALDOT Results

Results with the NCAT recommendations are shown in Figure 8.6.3. Using the NCAT recommended LCCA inputs, the NPV of the asphalt option is 50% less than the concrete option.

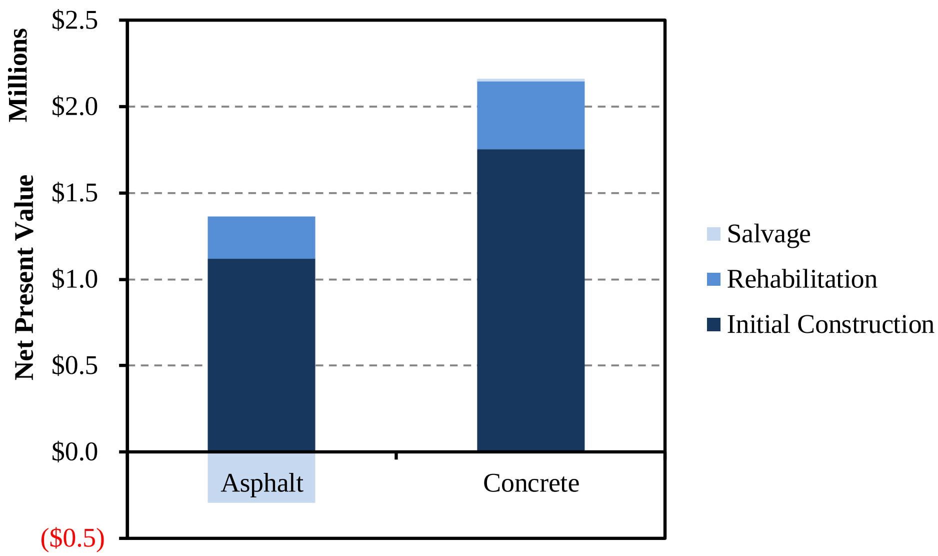

Figure 8.6.3 I-59/I-20 Pavement Reconstruction NCAT Results

Using UA inputs the NPV of asphalt remains the cheaper option in this example, although the difference is only $320,000.

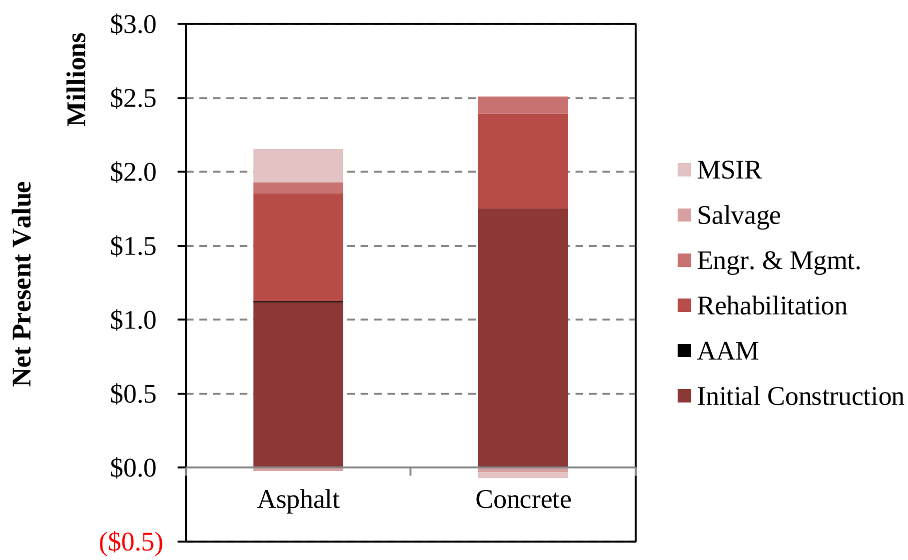

Figure 8.6.4 I-59/I-20 Pavement Reconstruction UA Results

Examining user costs for this project again show that the lengthy duration of construction activities associated with future removal of the concrete pavement will accrue more costs to the public. For this project, using NCAT recommendations and FHWA guidelines, asphalt incurred $82,108 in user costs and concrete $245,241. The inputs are results are shown below.

- Base year AADT: 50,239 vpd
- % Trucks: 17%
- Traffic Growth Rate: 2.50%
- October 2012 CPI: 232.85
- Length: 1.20
- Lanes: 3
- Maximum AADT: 110,000 vpd

Table 8.12 I-59/I-20 Reconstruction Asphalt User Cost Summary

Year	Roadway Activity	Hours	User Costs	NPV
19	Remove and Replace 2-Layers	151	$80,892.00	$47,576.00
32.5	Remove and Replace 3-Layers	226	$85,611.00	$34,532.11
			Total	**$82,108.11**

Table 8.13 I-59/I-20 Reconstruction Concrete User Cost Summary

Year	Roadway Activity	Hours	User Costs	NPV
19	Rehabilitation	226	$42,491.00	$24,990.75
35	Slab Removal	395	$585,538.00	$220,250.74
			Total	**$245,241.49**

An analysis of EUACs shows that asphalt is the cheapest option for all three methods. The largest difference is calculated using the NCAT method ($48,538 for asphalt vs. $98,071 for concrete).

Table 8.4.1 I-59/I-20 Pavement Reconstruction EUAC Results

	EUAC
ALDOT Asphalt	$72,517.81
ALDOT Concrete	$96,181.32
NCAT Asphalt	$48,538.89
NCAT Concrete	$98,070.97
UA Asphalt	$80,105.44
UA Concrete	$91,773.64

In each of these sample projects asphalt was the cheaper pavement option when using both the current ALDOT policy and the recommendations made by NCAT. Including the use of a residual salvage value made a significant difference in the NPVs of the two surface types that favored asphalt by up to 50%. Longer Analysis Periods, including Engineering and Management costs, and applying Material Specific Inflations Rates all favored the concrete option. The latter would change the NPV calculations by up to 14%. The impact of accounting for potential cost increases resulting from the asphalt index was negligible for all projects. Incorporating user costs consistently added more to the NPV of concrete options over the asphalt options due to lane closures to remove or rubblize the concrete pavements at the end of the pavements life.

9. Conclusions and Recommendations

Life-cycle cost analysis is a useful tool for making engineering judgment decisions. However, the term "life-cycle cost" is a misnomer. The calculation of the NPV is not the total cost incurred to the agency. Furthermore, the process of conducting an LCCA involves predicting conditions well into the future, and therefore contains significant uncertainties. However, the notion that LCCA is not a perfect method for economic decisions does not render it useless. In fact, at this point it is considered the best method for making a decision regarding long-term investments by public institutions.

NCAT's evaluation of ALDOT's LCCA policy yielded the following results.

Table 9.1 Summary of NCAT Findings

Parameter	Current ALDOT Policy	NCAT Recommendation	Justification
Analysis Period	28 years	35 years	35 years is the minimum time period that falls within the FHWA guidelines of a best practice and captures one major rehabilitation for each alternative
Discount Rate	4.00%	2.62%	2.62% is the 10-year rolling average of OMB's published discount rates. This rate is based off of real world data and using the 10-year average will protect against sudden swings
Asphalt Performance Period	12 years	19 years	19 years is based off of more current data than the current policy
Asphalt Rehabilitation Period	8 years	13.5 years	13.5 years is based off of more current data than the current policy
Concrete Performance Period	20 years	35 years	35 years is based off of more current data than the current policy
Concrete Rehabilitation Period	8 years	N/A	
Deterministic vs. Probabilistic	Deterministic	Deterministic	The deterministic method should be used until there is a better understanding of what the variability in each parameter is
Salvage Value	None	Residual Salvage Value, Remaining Service Life should be credited	Any portion of the structure that does not need to be replaced at the end of the analysis should be credited long with any remaining service life. Replacements should count against the NPV at the end of the analysis period.

Some of ALDOT's current LCCA policies and inputs are not within the range of "good practice" set forth by the FHWA and they are often inconsistent with the current policies of peer transportation agencies. However, ALDOT's policies were developed prior to the FHWA recommendations. ALDOT should revise their LCCA current policy to conform with the FHWA guidelines. Specifically, the discount rate currently used (4.0%) should be lowered to 2.62%, the initial performance period for asphalt should be increased to 19 years, and the performance period for mill and fill rehabilitations should be increased to 13.5 years. These performance periods should be periodically reviewed using pavement management data. The analysis period for should be increased to 35 years so that a major rehabilitation of concrete pavements is expected to occur within the time period. ALDOT should consider the value of the pavement at the end of the analysis period and discount in-situ structure in the calculation of the NPV. Work should also be done to improve data from the ALDOT pavement management system to provide reliable inputs for LCCA. This is especially important should ALDOT choose to implement the probabilistic approach to LCCA.

The calculation of the NPV is easily done with several software platforms. ALDOT can use publicly available software or create an in-house program or worksheet. The results are the same.

Regardless of the outcome on an LCCA, engineering judgment should always be used in selecting pavement types.

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APPENDIX A I-20 (Irondale) Reconstruction between I-59 and Kilgore Memorial Drive

A.1 Current ALDOT Policy I-20 Irondale, Asphalt

Asphalt Cost Schedule for I-20, Irondale			
Year	Activity	Cost	NPV
0	Initial Construction	$ 4,379,688.34	$ 4,379,688.34
12	Remove/Replace 2 Layers	$ 492,700.85	$ 307,739.50
20	Remove/Replace 3 Layers	$ 1,151,990.50	$ 525,753.43
		Total	**$ 5,213,181.26**

A.2 Current ALDOT Policy I-20 Irondale, Concrete

Concrete Cost Schedule for I-20, Irondale			
Year	Activity	Cost	NPV
0	Initial Construction	$5,514,632.77	$ 5,514,632.77
20	Clean and Seal Joints	$ 502,105.03	$ 229,154.18
		Total	**$ 5,743,786.95**

A.3 NCAT Method I-20 Irondale, Asphalt

Asphalt Cost Schedule for I-20, Irondale			
Year	Activity	Cost	NPV
0	Initial Construction	$ 4,379,688.34	$ 4,379,688.34
19	Remove/Replace 2 Layers	$ 492,700.85	$ 289,778.19
32.5	Remove/Replace 3 Layers	$ 1,151,990.50	$ 464,667.67
35	Remaining Service Life of Last Rehab	$ (938,658.93)	$ (353,077.55)
35	Residual Pavement Salvage Value	$ (3,340,546.72)	$ (1,256,550.20)
		Total	**$ 3,524,506.45**

A.4 NCAT Method I-20 Irondale, Asphalt

Concrete Cost Schedule for I-20, Irondale			
Year	Activity	Cost	NPV
0	Initial Construction	$ 5,514,632.77	$ 5,514,632.77
20	Diamond Grinding	$ 127,353.93	$ 72,881.22
20	3% Slab Removal	$ 369,751.23	$ 211,475.23
20	3% Slab Replacement	$ 323,512.59	$ 185,029.54
20	Clean and Seal Joints	$ 502,105.03	$ 287,173.56
35	Pavement Removal	$ 400,653.30	$ 150,706.16
		Total	**$ 6,421,898.49**

User Costs

The user costs were computed based on the NCAT recommended LCCA. Traffic information was taken from traffic counting stations 128, 128A, and 900.

Additional Inputs

- Base year AADT: 56,830 vpd
- % Trucks: 16%
- % Single Unit Trucks: 11.2%
- % Combination Trucks: 4.8%
- Traffic Growth Rate: 0.75%
- October 2012 CPI: 232.85
- Maximum AADT: 100,000 vpd

A.5 NCAT Method I-20 Irondale, Asphalt

Asphalt Option for I-20, Irondale				
Year	Roadway Activity	Hours	User Costs	NPV User Costs
19	Remove and Replace 2-Layers	206	$137,538.15	$ 80,892.00
32.5	Remove and Replace 3-Layers	309	$321,828.59	$ 129,813.00
			Total	**$ 210,705.00**

A.6 NCAT Method I-20 Irondale, Asphalt

Concrete Option for I-20, Irondale				
Year	Roadway Activity	Hours	User Costs	NPV User Cost
19	Rehabilitation	309	$404,643.60	$ 237,988.00
35	Pavement Removal	540	$4,588,441.10	$ 1,725,947.00
			Total	**$ 1,963,395.00**

A.7 UA Recommendations

Asphalt Cost Schedule for I-20, Irondale				
Year	Activity	Cost	MSIR	NPV
0.5	Initial Construction	$4,379,688.34	$4,396,681.90	$4,335,695.69
12	Milling 2 Layers	$73,875.02	$73,875.02	$52,833.28
12	Replacing 2 Layers	$384,903.18	$441,511.63	$315,756.34
12	Engr. & Mgmt. Cost	$45,877.82	$45,877.82	$32,810.49
20	Milling 3 Layers	$358,857.10	$358,857.10	$205,244.45
20	Replacing 3 Layers	$768,749.59	$966,279.22	$552,652.99
20	Engr. & Mgmt. Cost	$112,760.67	$112,760.67	$64,492.25
28	Milling 3 Layers	$358,857.10	$358,857.10	$164,138.85
28	Replacing 3 Layers	$768,749.59	$1,058,838.53	$484,305.69
28	Engr. & Mgmt. Cost	$112,760.67	$112,760.67	$51,575.98
36	Milling 3 Layers	$358,857.10	$358,857.10	$131,265.72
36	Replacing 3 Layers	$768,749.59	$1,160,264.04	$424,410.99
36	Engr. & Mgmt. Cost	$112,760.67	$112,760.67	$41,246.53
44	Milling 3 Layers	$358,857.10	$358,857.10	$104,976.31
44	Replacing 3 Layers	$768,749.59	$1,271,405.04	$371,923.54
44	Engr. & Mgmt. Cost	$112,760.67	$112,760.67	$32,985.83
50	Remaining Service Life	$(192,187.40)	$(192,187.40)	$(47,544.43)
			Total	**$7,318,770.49**

A.8 UA Recommendations

I-20 Concrete Cost Schedule				
Year	Activity	Cost	MSIR	NPV
0	Initial Construction	$5,514,632.77	$5,514,632.77	$5,514,632.77
20	3% Slab Replacement	$369,751.23	$335,153.80	$191,687.61
20	Clean and Seal Joints	$502,105.03	$502,105.03	$337,902.29
20	3% Slab Removal	$127,353.93	$127,353.93	$85,705.54
20	Engr. & Mgmt. Cost	$99,921.02	$99,921.02	$67,243.98
28	Diamond Grinding	$323,512.59	$323,512.59	$185,817.40
28	Engr. & Mgmt. Cost	$32,351.26	$32,351.26	$18,581.74
36	3% Slab Replacement	$369,751.23	$309,821.66	$113,329.13
36	Clean and Seal Joints	$502,105.03	$502,105.03	$246,143.51
36	3% Slab Removal	$127,353.93	$127,353.93	$62,431.84
36	Engr. & Mgmt. Cost	$99,921.02	$99,921.02	$48,983.60
44	Diamond Grinding	$323,512.59	$323,512.59	$135,357.91
44	Engr. & Mgmt. Cost	$32,351.26	$32,351.26	$13,535.79
50	Remaining Service Life	($63,676.97)	($63,676.97)	($23,657.77)
			Total	**$6,997,695.34**

APPENDIX B I-65 (Hoover) from I-459 to US-31

B.1 Current ALDOT Policy

Asphalt Cost Schedule for I-65, Hoover			
Year	Activity	Cost	NPV
0	Initial Construction	$ 10,049,297.90	$10,049,297.90
12	Remove/Replace 2 Layers	$ 1,223,935.49	$ 764,466.50
20	Remove/Replace 3 Layers	$ 3,081,437.50	$ 1,406,327.85
		Total	**$ 12,220,092.25**

B.2 Current ALDOT Policy

Concrete Cost Schedule for I-65, Hoover			
Year	Activity	Cost	NPV
0	Initial Construction	$12,130,211.76	$ 12,130,211.76
20	Clean and Seal Joints	$ 732,408.45	$ 334,261.66
		Total	**$ 12,464,473.42**

B.3 NCAT Recommendations

Asphalt Cost Schedule for I-65, Hoover			
Year	Activity	Cost	NPV
0	Initial Construction	$ 10,049,297.90	$ 10,049,297.90
19	Remove and Replace 2 Layers	$ 1,223,935.49	$ 719,848.19
32.5	Remove and Replace 3 Layers	$ 3,081,437.50	$ 1,242,930.72
35	Remaining Service Life	$ (2,510,800.93)	$ (944,440.44)
35	Residual Salvage Value	$ (5,757,116.00)	$ (2,165,545.31)
			$ 8,902,091.06

B.4 NCAT Recommendations

Concrete Cost Schedule for I-65, Hoover			
Year	Activity	Cost	NPV
0	Initial Construction	$ 12,130,211.76	$ 12,130,211.76
20	Diamond Grinding	$ 942,497.74	$ 539,051.43
20	3% Slab Removal	$ 371,023.56	$ 212,202.92
20	3% Slab Replacement	$ 1,230,781.27	$ 703,932.08
20	Clean and Seal Joints	$ 732,408.45	$ 418,893.12
35	Pavement Removal	$ 1,167,233.80	$ 439,056.24
			$ 14,443,347.55

User Costs

The user costs were computed based on NCAT's recommended LCCA inputs. Traffic information was obtained from the LCCA performed by ALDOT.

Additional Inputs

- Base year AADT: 46,667 vpd
- % Trucks: 11%
- Traffic Growth Rate: 2.59%
- October 2012 CPI: 232.85
- Length: 1.72
- Lanes: 3 for 0.66 miles, 4 for 1.06 miles
- Maximum AADT: 88,000 vpd

B.5 NCAT Recommendations

Asphalt Option for I-65, Hoover				
Year	Roadway Activity	Hours	User Costs	NPV
19	Remove and Replace 2-Layers	150.774	$110,868.00	$65,206.16
32.5	Remove and Replace 3-Layers	226.162	$162,814.00	$65,672.77
			Total	**$130,878.92**

B.6 NCAT Recommendations

Concrete Option for I-65, Hoover				
Year	Roadway Activity	Hours	User Costs	NPV
19	Rehabilitation	226.162	$68,823.00	$40,477.71
35	Pavement Removal	395.234	$1,875,410.00	$705,437.47
			Total	**$745,915.18**

B.7 UA Recommendations

Asphalt Cost Schedule for I-65, Hoover				
Year	Activity	Cost	MSIR	NPV
0	Initial Construction	$10,326,222.89	$10,330,934.20	$10,330,934.20
12	Milling 2 Layers	$193,993.78	$193,993.78	$138,738.74
12	Replacing 2 Layers	$1,016,185.86	$1,214,970.28	$868,911.58
12	Engr. & Mgmt. Cost	$121,017.96	$121,017.96	$86,548.55
20	Milling 3 Layers	$525,256.70	$525,256.70	$300,414.91
20	Replacing 3 Layers	$2,581,082.03	$3,476,343.25	$1,988,257.07
20	Engr. & Mgmt. Cost	$310,633.87	$310,633.87	$177,663.70
28	Milling 3 Layers	$525,256.70	$525,256.70	$240,248.92
28	Replacing 3 Layers	$2,581,082.03	$3,916,074.90	$1,791,186.57
28	Engr. & Mgmt. Cost	$310,633.87	$310,633.87	$142,081.86
36	Milling 3 Layers	$525,256.70	$525,256.70	$192,132.75
36	Replacing 3 Layers	$2,581,082.03	$4,411,429.35	$1,613,649.16
36	Engr. & Mgmt. Cost	$310,633.87	$310,633.87	$113,626.23
44	Milling 3 Layers	$525,256.70	$525,256.70	$153,653.11
44	Replacing 3 Layers	$2,581,082.03	$4,969,442.46	$1,453,708.76
44	Engr. & Mgmt. Cost	$310,633.87	$310,633.87	$90,869.59
50	Remaining Service Life	$(645,270.51)	$(645,270.51)	$(159,630.74)
			Total	**$19,522,994.94**

B.8 UA Recommendations

Concrete Cost Schedule for I-65, Hoover				
Year	Activity	Cost	MSIR	NPV
0	Initial Construction	$12,130,211.76	$12,130,211.76	$12,130,211.76
20	3% Slab Replacement	$1,230,781.27	$1,115,617.72	$638,065.53
20	Clean and Seal Joints	$732,408.45	$732,408.45	$418,893.12
20	3 % Slab Removal	$371,023.56	$371,023.56	$212,202.92
20	Engr. & Mgmt. Cost	$233,421.33	$233,421.33	$133,502.81
28	Diamond Grinding	$942,497.74	$942,497.74	$431,092.19
28	Engr. & Mgmt. Cost	$94,249.77	$94,249.77	$43,109.22
36	3% Slab Replacement	$1,230,781.27	$1,031,295.26	$377,235.72
36	Clean and Seal Joints	$732,408.45	$732,408.45	$267,906.43
36	3% Slab Removal	$371,023.56	$371,023.56	$135,716.07
36	Engr. & Mgmt. Cost	$233,421.33	$233,421.33	$85,382.79
44	Diamond Grinding	$942,497.74	$942,497.74	$275,708.44
44	Engr. & Mgmt. Cost	$94,249.77	$94,249.77	$27,570.84
50	Remaining Service Life	$(259,186.88)	$(259,186.88)	$(64,119.14)
			Total	**$15,112,478.70**

C.1 Current ALDOT Policy

Remove and Replace PCC with PCC Cost Schedule, I-59 (Gadsden)			
Year	Activity	Cost	NPV
0	Initial Construction	$16,874,264.28	$16,874,264.28
20	Rehabilitation	$2,085,896.72	$951,976.03
		Total	**$17,826,240.31**

C.2 Current ALDOT Policy

Unbonded PCC Overlay, I-59 (Gadsden)			
Year	Activity	Cost	NPV
0	Initial Construction	10,957,048.00	$10,957,048.00
20	Rehabilitation	$2,225,847.85	$1,015,847.90
		Total	**$11,972,895.90**

C.3 Current ALDOT Policy

Asphalt Cost Schedule, I-59 (Gadsden)			
Year	Activity	Cost	NPV
0	Initial Construction	$6,893,772.00	$6,893,772.00
12	1st Rehabilitation	$1,809,371.40	$1,130,128.04
20	2nd Rehabilitation	$2,936,784.00	$1,340,309.88
		Total	**$9,364,209.92**

C.4 NCAT Recommendations

Remove and Replace PCC with PCC Cost Schedule, I-59 (Gadsden)			
Year	Activity	Cost	NPV
0	Initial Construction	$16,888,375.11	$16,888,375.11
20	Rehabilitation	$2,219,630.72	$1,269,493.87
35	Rubblization	$307,338.24	$115,605.61
		Total	**$18,196,994.93**

C.5 NCAT Recommendations

Unbonded PCC Overlay, I-59 (Gadsden)			
Year	Activity	Cost	NPV
0	Initial Construction	$10,957,071.03	$10,957,071.03
20	Rehabilitation	$2,219,630.72	$1,269,493.87
35	Rubblization	$307,338.24	$115,605.61
		Total	**$12,342,170.51**

C.6 NCAT Recommendations

Asphalt Cost Schedule, I-59 (Gadsden)			
Year	Activity	Cost	NPV
0	Initial Construction	$6,894,008.78	$6,894,008.78
19	Remove and Replace 2 Layers	$1,809,355.72	$1,064,158.57
32.5	Remove and Replace 3 Layers	$2,936,761.24	$1,184,574.01
35	Remaining Service Life	($2,392,916.57)	($900,098.11)
35	Residual Salvage Value	($2,257,550.00)	($849,179.83)
		Total	**$7,393,463.41**

User Costs

The user costs were computed using NCAT recommendations. Traffic information was taken from the LCCA performed by ALDOT.

Additional Inputs

- Base year AADT: 16,874 vpd
- % Trucks: 35%
- Traffic Growth Rate: 4.37%
- October 2012 CPI: 232.85
- Length: 10.7 miles
- Lanes: 2
- Maximum AADT:88,000

C.7 NCAT Recommendations

Asphalt Option for I-59, Gadsden				
Year	Roadway Activity	Hours	User Costs	NPV
19	Remove and Replace 2-Layers	940	$164,359.00	$96,666.47
32.5	Remove and Replace 3-Layers	1410	$897,518.00	$362,023.47
			Total	**$458,689.94**

C.8 NCAT Recommendations

Concrete Option for I-59, Gadsden				
Year	Roadway Activity	Hours	User Costs	NPV
19	Rehabilitation	1410	$251,999.00	$148,211.26
35	Rubblization	2463	$7,365,548.00	$2,770,558.71
			Total	**$2,918,769.98**

C. 9 UA Recommendations

Remove and Replace PCC with PCC Cost Schedule, I-59 (Gadsden)				
Year	Activity	Cost	MSIR	NPV
0	Initial Construction	$16,888,375.11	$16,888,375.11	$16,888,375.11
20	Rehab Activities	$1,243,130.82	$1,243,130.82	$710,995.28
20	Replace 3% Slabs	$842,780.00	$763,921.52	$436,916.68
20	Engr. & Mgmt. Cost	$208,591.08	$208,591.08	$119,301.42
28	Rehab Activities	$1,243,130.82	$1,243,130.82	$568,599.76
28	Replace 3% Slabs	$842,780.00	$734,484.37	$335,948.26
28	Engr. & Mgmt. Cost	$208,591.08	$208,591.08	$95,408.17
36	Rehab Activities	$1,243,130.82	$1,243,130.82	$454,722.69
36	Replace 3% Slabs	$842,780.00	$706,181.55	$258,312.93
36	Engr. & Mgmt. Cost	$208,591.08	$208,591.08	$76,300.17
44	Rehab Activities	$1,243,130.82	$1,243,130.82	$363,652.50
44	Replace 3% Slabs	$842,780.00	$678,969.36	$198,618.60
44	Engr. & Mgmt. Cost	$208,591.08	$208,591.08	$61,019.06
50	Remaining Service Life	($573,625.48)	($532,672.82)	($131,775.67)
			Total	**$19,974,562.06**

C. 10 UA Recommendations

Unbonded PCC Overlay, I-59 (Gadsden)				
Year	Activity	Cost	MSIR	NPV
0	Initial Construction	$10,957,071.03	$10,957,071.03	$10,957,071.03
20	Rehab Activities	$969,476.46	$969,476.46	$554,481.61
20	Replace 3% Slabs	$842,780.00	$763,921.52	$436,916.68
20	Engr. & Mgmt. Cost	$181,225.65	$181,225.65	$103,650.06
28	Rehab Activities	$969,476.46	$969,476.46	$443,432.07
28	Replace 3% Slabs	$842,780.00	$734,484.37	$335,948.26
28	Engr. & Mgmt. Cost	$181,225.65	$181,225.65	$82,891.40
36	Rehab Activities	$969,476.46	$969,476.46	$354,623.13
36	Replace 3% Slabs	$842,780.00	$706,181.55	$258,312.93
36	Engr. & Mgmt. Cost	$181,225.65	$181,225.65	$66,290.22
44	Rehab Activities	$969,476.46	$969,476.46	$283,600.51
44	Replace 3% Slabs	$842,780.00	$678,969.36	$198,618.60
44	Engr. & Mgmt. Cost	$181,225.65	$181,225.65	$53,013.86
50	Remaining Service Life	($498,370.53)	($457,417.87)	($113,158.67)
			Total	**$14,061,874.98**

C.11 UA Recommendations

Asphalt Cost Schedule, I-59 (Gadsden)				
Year	Activity	Cost	MSIR	NPV
0	Initial Construction	$6,924,782.65	$6,940,782.65	$6,940,782.65
12	Replace Asphalt Layers	$1,275,590.72	$1,463,194.29	$1,046,434.20
12	Rehab Activities	$533,765.00	$533,765.00	$381,733.28
12	Engr. & Mgmt. Cost	$180,935.57	$180,935.57	$129,399.88
20	Replace Asphalt Layers	$2,390,567.12	$3,004,821.54	$1,718,575.30
20	Rehab Activities	$546,194.12	$546,194.12	$312,389.84
20	Engr. & Mgmt. Cost	$293,676.12	$293,676.12	$167,964.89
28	Replace Asphalt Layers	$2,390,567.12	$3,292,651.61	$1,506,036.91
28	Rehab Activities	$546,194.12	$546,194.12	$249,825.55
28	Engr. & Mgmt. Cost	$293,676.12	$293,676.12	$134,325.50
36	Replace Asphalt Layers	$2,390,567.12	$3,608,052.75	$1,319,783.41
36	Rehab Activities	$546,194.12	$546,194.12	$199,791.41
36	Engr. & Mgmt. Cost	$293,676.12	$293,676.12	$107,423.28
44	Replace Asphalt Layers	$2,390,567.12	$3,953,665.97	$1,156,564.12
44	Rehab Activities	$546,194.12	$546,194.12	$159,777.92
44	Engr. & Mgmt. Cost	$293,676.12	$293,676.12	$85,908.94
50	Remaining Service Life	($807,609.34)	($807,609.34)	($199,791.05)
			Total	**$15,616,717.10**

APPENDIX DI-20 (Talladega) Pavement Rubblization, Additional Lane Added

D.1 Current ALDOT Policy

Asphalt Cost Schedule, I-20 (Talladega)			
Year	Activity	Cost	NPV
0	Initial Construction	$4,327,160.70	$4,327,160.70
12	1st Rehab	$1,438,052.20	$898,203.16
20	2nd Rehab	$1,320,417.70	$602,621.40
		Total	**$5,827,985.26**

D.2 Current ALDOT Policy

Concrete Cost Schedule, I-20 (Talladega)			
Year	Activity	Cost	NPV
0	Initial Construction	$6,786,538.62	$6,786,538.62
20	Rehab	$2,063,953.20	$1,181,144.76
		Total	**$7,967,683.38**

D.3 NCAT Recommendations

Asphalt Cost Schedule, I-20 (Talladega)			
Year	Activity	Cost	NPV
0	Initial Construction	$4,327,160.70	$4,327,160.70
19	Remove/Replace 2 Layers	$1,438,052.20	$845,779.28
32.5	Remove/Replace 3 Layers	$1,320,417.70	$532,604.58
35	Remaining Service Life of Last Rehab	$(2,014,317.50)	$(757,687.67)
35	Residual Pavement Salvage Value	$(1,075,895.90)	$(404,699.39)
		Total	**$4,543,157.50**

D.4 NCAT Recommendations

Concrete Cost Schedule, I-20 (Talladega)			
Year	Activity	Cost	NPV
0	Initial Construction	$6,786,538.62	$6,786,538.62
20	Rehab	$2,083,056.89	$1,192,077.29
35	Rubblization	$343,815.48	$129,458.68
		Total	**$8,108,074.59**

D.5 UA Recommendations

Asphalt Cost Schedule, I-20 (Talladega)				
Year	Activity	Cost	MSIR	NPV
0	Initial Construction	$4,327,160.70	$4,347,415.65	$4,347,415.65
12	Milling 3 Layers	$224,200.20	$224,200.20	$160,341.49
12	Replacing 2 Layers	$1,213,852.00	$1,392,375.53	$995,786.68
12	Engr. & Mgmt. Cost	$143,805.22	$143,805.22	$102,845.33
20	Milling 3 Layers	$106,565.70	$106,565.70	$60,949.10
20	Replacing 3 Layers	$1,213,852.00	$1,525,750.36	$872,636.48
20	Engr. & Mgmt. Cost	$132,041.77	$132,041.77	$75,519.87
28	Milling 3 Layers	$106,565.70	$106,565.70	$48,742.44
28	Replacing 3 Layers	$1,213,852.00	$1,671,901.08	$764,716.41
28	Engr. & Mgmt. Cost	$132,041.77	$132,041.77	$60,395.03
36	Milling 3 Layers	$106,565.70	$106,565.70	$38,980.48
36	Replacing 3 Layers	$1,213,852.00	$1,832,051.48	$670,142.96
36	Engr. & Mgmt. Cost	$132,041.77	$132,041.77	$48,299.33
44	Milling 3 Layers	$106,565.70	$106,565.70	$31,173.62
44	Replacing 3 Layers	$1,213,852.00	$2,007,542.61	$587,265.53
44	Engr. & Mgmt. Cost	$132,041.77	$132,041.77	$38,626.12
50	Remaining Service Life	$(363,114.87)	$(363,114.87)	$(89,829.45)
			Total	**$8,814,007.08**

D.6 UA Recommendations

Concrete Cost Schedule, I-20 (Talladega)				
Year	Activity	Cost	MSIR	NPV
0	Initial Construction	$6,786,538.62	$6,786,538.62	$6,786,538.62
20	Rehab Activities	$395,228.49	$395,228.49	$226,046.68
20	Replace Concrete	$776,043.23	$703,767.15	$402,512.04
20	Engr. & Mgmt. Cost	$117,127.17	$117,127.17	$66,989.62
28	Rehab Activities	$911,785.17	$911,785.17	$417,044.46
28	Engr. & Mgmt. Cost	$91,178.52	$91,178.52	$41,704.45
36	Rehab Activities	$395,228.49	$395,228.49	$144,569.95
36	Replace Concrete	$776,043.23	$650,823.84	$238,063.73
36	Engr. & Mgmt. Cost	$208,591.08	$208,591.08	$76,300.17
44	Rehab Activities	$98,463.43	$98,463.43	$28,803.46
44	Engr. & Mgmt. Cost	$9,846.34	$9,846.34	$2,880.35
50	Remaining Service Life	($240,176.46)	($240,176.46)	($59,416.24)
			Total	**$8,372,037.30**

APPENDIX E I-59 (Bessemer) Pavement Reconstruction from Alabama Adventure Parkway to North CSXT RR Overpass

E.1 Current ALDOT Policy

Asphalt Cost Schedule, I-59 (Birmingham)			
Year	Activity	Cost	NPV
0	Initial Construction	$1,117,195.32	$1,117,195.32
12	1st Rehab	$170,495.84	$106,491.20
20	2nd Rehab	$363,216.20	$165,767.13
		Total	**$1,389,453.65**

E.2 Current ALDOT Policy

Concrete Cost Schedule, I-59 (Birmingham)			
Year	Activity	Cost	NPV
0	Initial Construction	$1,753,002.96	$1,753,002.96
20	Rehabilitation	$196,867.44	$89,847.73
		Total	**$1,842,850.69**

E.3 NCAT Recommendations

Asphalt Cost Schedule, I-59 (Birmingham)			
Year	Activity	Cost	NPV
0	Initial Construction	$1,117,195.32	$1,117,195.32
19	Remove/Replace 2 Layers	$170,495.84	$100,275.81
32.5	Remove/Replace 3 Layers	$363,216.20	$146,507.13
35	Remaining Service Life of Last Rehab	$(295,953.94)	$(111,323.39)
35	Residual Pavement Salvage Value	$(487,347.52)	$(183,316.29)
		Total	**$1,069,338.58**

E.4 NCAT Recommendations

Concrete Cost Schedule, I-59 (Birmingham)			
Year	Activity	Cost	NPV
0	Initial Construction	$1,753,002.96	$1,753,002.96
20	Rehab	$687,728.58	$393,568.52
35	Pavement Removal	$37,144.80	$13,986.33
		Total	**$2,160,557.81**

User Costs

The user costs were computed using NCAT recommendations. Traffic information was taken from the LCCA performed by ALDOT.

Additional Inputs

- Base year AADT: 50,239 vpd
- % Trucks: 17%
- Traffic Growth Rate: 2.50%
- October 2012 CPI: 232.85
- Length: 1.20
- Lanes: 3
- Maximum AADT: 110,000 vpd

E.5 NCAT Recommendations

Asphalt Option for I-59, Birmingham				
Year	Roadway Activity	Hours	User Costs	NPV
19	Remove and Replace 2-Layers	151	$80,892.00	$47,576.00
32.5	Remove and Replace 3-Layers	226	$85,611.00	$34,532.11
			Total	**$82,108.11**

E.6 NCAT Recommendations

Concrete Option for I-59, Birmingham				
Year	Roadway Activity	Hours	User Costs	NPV
19	Rehabilitation	226	$42,491.00	$24,990.75
35	Slab Removal	395	$585,538.00	$220,250.74
			Total	**$245,241.49**

E. 7 UA Recommendations

Asphalt Cost Schedule, I-59 (Birmingham)				
Year	Activity	Cost	MSIR	NPV
0	Initial Construction	$1,117,195.32	$1,122,390.15	$1,122,390.15
12	Milling 3 Layers	$66,742.76	$66,742.76	$47,732.49
12	Replacing 2 Layers	$103,753.08	$119,012.24	$85,114.11
12	Engr. & Mgmt. Cost	$17,049.58	$17,049.58	$12,193.37
20	Milling 3 Layers	$60,429.60	$60,429.60	$34,562.06
20	Replacing 3 Layers	$302,786.60	$380,587.39	$217,672.86
20	Engr. & Mgmt. Cost	$36,321.62	$36,321.62	$20,773.76
28	Milling 3 Layers	$60,429.60	$60,429.60	$27,640.10
28	Replacing 3 Layers	$302,786.60	$417,043.63	$190,752.98
28	Engr. & Mgmt. Cost	$36,321.62	$36,321.62	$16,613.27
36	Milling 3 Layers	$60,429.60	$60,429.60	$22,104.44
36	Replacing 3 Layers	$302,786.60	$456,991.99	$167,162.31
36	Engr. & Mgmt. Cost	$36,321.62	$36,321.62	$13,286.02
44	Milling 3 Layers	$60,429.60	$60,429.60	$17,677.44
44	Replacing 3 Layers	$302,786.60	$500,766.98	$146,489.14
44	Engr. & Mgmt. Cost	$36,321.62	$36,321.62	$10,625.15
50	Remaining Service Life	$(99,884.46)	$(99,884.46)	$(24,709.99)
			Total	**$2,128,079.65**

E.8 UA Recommendations

Concrete Cost Schedule, I-59 (Birmingham)				
Year	Activity	Cost	MSIR	NPV
0	Initial Construction	$1,753,002.96	$1,753,002.96	$1,753,002.96
20	Rehab Activities	$314,938.01	$314,938.01	$180,125.40
20	Replace Concrete	$342,797.53	$310,871.39	$177,799.54
20	Engr. & Mgmt. Cost	$65,773.55	$65,773.55	$37,618.48
28	Rehab Activities	$29,993.04	$29,993.04	$13,718.62
28	Engr. & Mgmt. Cost	$2,999.30	$2,999.30	$1,371.86
36	Rehab Activities	$314,938.01	$314,938.01	$115,200.63
36	Replace Concrete	$342,797.53	$287,485.02	$105,158.65
36	Engr. & Mgmt. Cost	$208,591.08	$208,591.08	$76,300.17
44	Rehab Activities	$29,993.04	$29,993.04	$8,773.85
44	Engr. & Mgmt. Cost	$2,999.30	$2,999.30	$877.39
50	Remaining Service Life	($128,911.04)	($128,911.04)	($31,890.76)
			Total	**$2,438,056.79**